Modelling land-use decisions in production systems involving multiple crops and varieties

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Abstract

This paper argues and provides empirical evidence that trade-offs and/or complementarities are inherent in technological options that shape the adoption of and land-use decisions in production systems involving multiple crops in Ethiopia. By applying a fractional response model to a nationally representative sample of 1 469 households, this paper found that, while there are trade-offs in the land-use decisions regarding barley and potatoes, there are complementarities in the land-use decisions of their improved varieties. A striking result from this analysis is that the frequency of extension visits does not affect land allocation among crops and their improved varieties, which, in the light of the very high density of extension personnel in Ethiopia, shows the poor performance of the extension service delivery system. These results imply that the analysis of smallholder adoption decisions and agricultural technology targeting needs to consider all major crops in the farmers' portfolio, and Ethiopia should consider overhauling its extension service delivery systems.

Key words: adoption; land use; multiple technologies; endogeneity; fractional response model

1. Introduction

1.1 Background

Previous technology-adoption studies have made important contributions in identifying the factors that affect smallholder farmers' decisions and in suggesting ways to design policies and strategies that enhance the adoption of improved technologies and desirable land-use practices. The studies, however, were not free from limitations, with most of them having poor explanatory power (Besley & Case 1993; Abadi Ghadim & Pannell 1999; Doss 2003). One of the important areas of improvements over the years has been the treatment of adoption decisions as sequential, and hence the use of sequential decision models (Byerlee & Hesse de Polanco 1986; Leathers & Smale 1991).

Subsequent studies that recognise the argument for multi-stage decisions that may be independent (or sequential) have suggested the use of a double-hurdle model (Gebremedhin & Swinton 2003).

The arguments for sequential and dynamic models of technology-adoption decisions are valid in terms of capturing the evolution and progress within the adopter households. However, we argue that the adoption and land-use decisions on related crops and varieties that have to be made simultaneously would carry much weight. Moreover, there is a compelling reason for advances in cross-sectional analysis, as most analysts do not have the luxury of panel data but are still expected to provide useful information for institutional and policy decisions. Perhaps it is with this understanding that the vast majority of the most recent work has been directed towards addressing the problems of endogeneity, including those arising from simultaneity, omitted variables and selection bias. These problems were not the concern of early research, which mainly employed descriptive analysis, but have received considerable attention in the adoption literature (Hassan 1996; Doss 2003; Diagne & Demont 2007).

An issue that has serious implications in terms of choice of models is that farmers are faced with technology and land-use options that may involve complementarity or trade-offs in dealing with their multiple constraints or in exploiting current and potential opportunities (Dorfman 1996; Khanna 2001; Moyo & Veeman 2004). Adoption and impact analysis of technologies that ignore these inter-relationships may underestimate or overestimate the effects of various factors on the adoption decision and on the impacts of adoption (Wu & Babcock 1998). The modelling of technology adoption and impact analysis in a multiple technology-choice framework is therefore important to capture useful economic information contained in related and joint adoption decisions (Dorfman 1996; Teklewold *et al*. 2013).

Acknowledging the potential problem of endogeneity due to the use of single equation models, more recent papers have modelled the adoption of various technologies as a system of interrelated decisions (Hassan 1996; Yirga & Hassan 2008; Kassie *et al*. 2013; Teklewold *et al*. 2013). With significant correlations among the decisions for the adoption of different technologies, their results reveal that adoption decisions about multiple technologies are interrelated.

While the more recent studies have generally benefited and built on the advances made by earlier studies, specification-related problems still prevail. One clearly visible shortcoming of the existing literature is that, while only a few address the issue of interrelation among the decisions, none explicitly model the complementarity or trade-offs among multiple crops and technologies that exhibit bi-directional effects. This paper attempts to fill this gap by using the fractional response model, which is estimated as a single system of equations in which each dependent variable (area share of crop and variety combinations) in the system is included as a covariate in all other equations. By so doing, advances made in this paper are expected to close an important gap in the existing literature.

1.2 Objectives of the paper

This paper agrees with Teklewold *et al*. (2013) and Yirga and Hassan (2008) that there is simultaneity in the plot-level adoption of multiple technologies. However, we argue that there is also simultaneity between the decisions on crop choices and the adoption of improved technologies. This argument can be justified on at least two grounds: 1) the relative importance of each crop in the farmers' crop portfolio influences the decision on whether to adopt an improved technology of the crop, where farmers are likely to invest more in the crops of higher importance; 2) even though past adoption studies assumed area under each crop to be constant, we argue that land-use decisions for each one of the crop types are influenced by the presence or absence of highly rated improved technologies (such as varieties) of each crop. In a situation where a new variety that is very much liked by the farmer becomes available, the farmer may consider increasing the relative share of that particular crop in total crop area, while reducing that of the other crops. This means the new variety may not only replace old varieties of the same crop, but also replace other crops. The introduction of the rust-resistant lentil variety called *Alemaya* in the Gimbichu district of central Ethiopia is a good example (Ayele & Alemu 2004; Fikre & Bejiga 2004). The variety exhibited phenomenal expansion at the expense of both old varieties of lentil and other crops. As a result, it transformed the district into being the main hub for lentil production and processing in the country, leading also to the establishment of many cottage industries.

We also hypothesise that there is simultaneity in the land-use decisions on multiple crops and varieties. This is so because the positive/negative experiences of the adoption of one variety are more likely to have positive/negative effects on the adoption of the other. For example, farm households who have tried and benefited from one technology are more likely to be open (and in some cases eager) to adopt other technologies as well. One can also argue that, in the case of technologies requiring high investment, there could be competition for limited resources among smallholders, and this may negatively affect the adoption of the other. Likewise, the increase in the area share of one crop may come at the expense of other crop(s) under consideration.

This paper is based on data from a sample of 1 469 barley- and potato-growing households in the Ethiopian highlands, which are analysed using the fractional response model (Papke & Wooldridge 1996) applied to systems of equations. By doing so, the paper provides empirical evidence that there is simultaneity in the decisions not only between the area shares of individual crops in total farm size, but also in the area shares of their improved varieties. The main contribution of this paper is in terms of modelling the complementarities and/or trade-offs between area allocations between different crops and their varieties.

2. Data

A project called Diffusion and Impacts of Improved Varieties in Africa (DIIVA), funded by the Bill & Melinda Gates Foundation, aimed, among other things, to gain deeper understanding of the adoption and diffusion of new varieties of barley and potato in Ethiopia. Taking advantage of the 65% geographical overlap of these two crops within the targeted regions of Ethiopia, it was decided to conduct a joint national survey for both crops to generate reliable estimates of the adoption of the improved varieties at the level of different administrative units, namely Kebele or peasant association (PA), wereda (district), zone, regional and national.

Given that Ethiopia is a big country and that only three regional states, namely Amhara, Oromiya and the Southern Nation Nationalities and Peoples (SNNP), constitute more than 94% and 97% of the total national barley and potato areas respectively, conducting a national survey was not justifiable – both on cost and technical grounds. Hence, a decision was made by the research team to focus only on the three regional states. Our sample frame targeted a total of 3 509 007 barley growers and 1 869 236 potato growers. It also corresponded to the production of 965 677 ha of barley and 164 146 ha of potatoes (CSA 2010).

This study employed a multi-stage sampling procedure to select sample zones, districts and Kebeles or peasant associations (PAs) from among the three target regions. The PAs are the primary sampling units (PSUs) or clusters. Households, which are the units of observation within each PSU, were selected randomly. Using power analysis, the minimum sample size required for observing up to 70% adoption levels of each of the crops of interest at confidence and precision levels of 95% and 3% respectively was determined to be 1 100. However, as two crops are involved, the sample size was increased to 1 469. For proportional distribution of the sample size across the different administrative units, an index using area under the two crops and the number of barley and potato growers at the wereda level was used for weighting. Accordingly, the sample of farm households was distributed among 122 PAs, 41 weredas (districts), 24 zones and three regions. After the survey was conducted, 191 farmers were found to have grown neither barley nor potato in the 2009/2010 cropping season, and they thus were dropped. Therefore, only the remaining 1 278 households were used in this analysis.

The average household head in the survey was about 42 years old with only 3.5 years of education. The average household size was about seven members, with an average total land holding of only 1.94 ha, out of which 0.62 ha was dedicated to barley and 0.26 ha to potatoes. The area dedicated to improved varieties of barley accounted for about 32% of total barley area, while the share of improved varieties of potatoes in total potato area was 70%. Table 1 provides summary statistics on the important variables for the sample.

Table 1: Descriptive statistics for important variables

	Description of variable	Unit	N	Min.	Mean	Max.	Std. dev.
Age	Age of household head (hhh)	years	1 278	12	42.47	90	13.22
educ	Education level of hhh	years	1 278	0	3.43	13	3.36
famlysize	Family size	No.	1 278	1	6.99	25	2.77
Tot_house_unit	Number of separate housing units owned	No.	1 278	0	2.25	11	1.26
farmsize	Farm size	ha	1 278	0.065	1.94	16.28	1.43
offincome	Off-farm income per year	Birr	1 278	0	1,522	67 400	4002
t_brly_area	Total barley area	ha	1 278	0.012	0.623	5.45	0.61
t_impbrly_area	Total area under improved barley varieties	ha	547	0.015	0.57	5.45	0.56
lclbrly_area	Area under local barley varieties	ha	993	0.012	0.29	2.25	0.28
t_pota_ara	Total potato area in ha	ha	876	0.02	0.258	2	0.27
t_imppota_area	Total area under improved potato varieties	ha	280	0.01	0.20	1.25	0.20
t_lpota_area	Area under local potato varieties	ha	741	0.002	0.23	2	0.24
extvist_no	Number of extension visits in the year	No.	1 278	0	19.90	200	24.6
plotdist	Plot distance measured in minutes of walk	Min.	1 278	0.05	10.84	120	16.12
potshr	Share of potatoes in total crop area	%			16		
barshr	Share of barley in total crop area	%			34		
impbrly	Share in total barley area of improved barley	%			32		
imppot	Share in total potato area of improved potatoes	%			71		
Sex	Household head is male (0 = No, 1 = Yes)	% of Yes			92		
usedap	Farmer applies DAP fertilisers (0 = No, 1 = Yes)	% of Yes			58		
useurea	Farmer applies urea fertilisers (0 = No, 1 = Yes)	% of Yes			22		
usefert	Farmer applies fertilisers (0 = No, 1 = Yes)	% of Yes			59		
vertshare	Soil on the plot is vertisol (0 = No, 1 = Yes)	% of Yes			28		
redsoilsh	Soil on the plot is reddish (0 = No, 1 = Yes)	% of Yes			35		
Othercolor	Soil on the plot is black or grey (0 = No, 1 = Yes)	% of Yes			37		
Goodfertshr	Soil on plot has good fertility (0 = No, 1 = Yes)	% of Yes			38		
Medfertshr	Soil on plot has medium fertility (0 = No, 1 = es)	% of Yes			46		
swc	Plot has soil and water conservation structures	% of Yes			29		
legumerot	Legumes are rotated on the plot (0 = No, Yes)	% of Yes			21		
deep	Soil on plot is deep (0 = No, Yes)	% of Yes			47		
medium_slp	Plot has medium slope (0 = No, Yes)	% of Yes			52		
steep_slp	Plot has steep slope (0 = No, Yes)	% of Yes			39		

3. Methodology

This paper argues that smallholder households' decision to adopt improved agricultural technologies is much more complex than the way the existing literature attempts to model. At the household level, there could be exceptional cases where an extremely successful crop variety replaces all other local varieties of the same crop as well as all or some varieties of other crops. This can happen only if the variety has much higher yield and/or very low costs relative to all other available crop–variety combinations, and hence becomes more profitable for the market-oriented farmer. Under subsistence farming systems such as in the Ethiopian highlands, however, due to their desire to minimise biotic, abiotic and market risks and other factors, such as social taboos of buying food from the market, smallholder farmers insist on producing (even at higher opportunity costs) a large enough amount of each of the crops they use for their own consumption on their own farms (Yigezu & Sanders 2012).

While farmers, especially those very close to the major urban centres, have recently started becoming more integrated into the market, production in rural Ethiopia was predominantly for subsistence purposes when data for this study was collected in 2010. Moreover, even those well integrated into the market usually base their crop choice on historical output and input prices for all crops, with more weight given to the immediate past prices. Hence, contrary to most previous adoption studies, we argue that farmers' planting and area allocation decisions are interdependent across multiple crops and varieties.

Suppose the share in the total farm size of barley, potatoes, improved varieties of barley and improved varieties of potatoes is denoted by *barshr*, *potshr*, *impbarshr* and *imppotshr* respectively. Then, the area allocation decisions by crop (barley and potatoes) and variety (improved barley and improved potatoes) can be formulated as:

$$barshr_i = \boldsymbol{X_i \beta} + \varepsilon_i \quad (1)$$

$$potshr_i = \boldsymbol{X_i \alpha} + \vartheta_i \quad (2)$$

$$impbarshr_i = \boldsymbol{X_i \gamma} + \mu_i \quad (3)$$

$$imppotshr_i = \boldsymbol{X_i \theta} + \omega_i \quad (4)$$

where $\boldsymbol{\beta}, \boldsymbol{\alpha}, \boldsymbol{\gamma}$ and $\boldsymbol{\theta}$ are parameters to be estimated, and $\varepsilon_i, \vartheta_i, \gamma_i, \omega_i$ are error terms. $\boldsymbol{X}$ is a vector of exogenous household-level farm and farmer characteristics that are included as explanatory variables in the land-use decision on different crops and their varieties. These include household head's sex, age and education, family size, regional dummies, whether or not farmer practices legume rotation, and shares of land area under different crop types and varieties and shares of land with different soil fertility levels (see Table 1 for complete list). Among the major variables that determine the land use and extent of adoption of new agricultural technologies are access to information and existing extension delivery system, and frequency of contacts with extension agents.

Despite a long history of and sizeable national and international investment in barley research, the low adoption levels (39%) of improved varieties of barley (Yigezu *et al*. 2015) call for further inquiry in terms of what could possibly be the reason. Given that knowledge is cumulative, the number of extension visits in the previous year (extvist_no) is expected to affect the farmer's adoption decisions and management in the current year. Therefore, the extvist_no is included as an explanatory variable. Assuming homogeneity in the quality of extension service per visit, we hypothesise that more extension visits will have positive and significant effects on crop and variety choices.

Theoretically, land-use decisions across crops and varieties have to be well informed from the farmer's previous experience with the crop–variety combinations, and their relative performance under different weather and farmland characteristics. If this is true (and we argue it is), it will involve full consideration of all plots, crops and varieties simultaneously where the farmer allocates area for all crop–variety combinations at the same time. The area allocation is done bearing in mind the specific characteristics of each of the farmer's plots, which he/she then aggregates to the level of the whole farm. We therefore hypothesise that area allocation decisions are made by farmers jointly for each crop and variety combination. This means the error terms in all four equations – (1) to (4) – are correlated. Mathematically,

$$corr(\varepsilon_i, \vartheta_i, \gamma_i, \omega_i) \neq 0$$

Validating this hypothesis will require the estimation of equations (1) to (4) simultaneously.

Behaviourally, farmers' past positive/negative experience of the use of improved varieties of a crop are expected to motivate/discourage them to also try to reap the benefits of improved varieties of other crops. Therefore, we hypothesise that, for given proportions of land allocated to specific crops, the decision on the area devoted to an improved variety of one crop has a positive effect on the decision on the area devoted to improved varieties of the other crops cultivated by the farmer, and vice versa. Likewise, we hypothesise that the area allocation decision for a given crop has an effect on (and is affected by) the area allocation decisions on the another crops in the farmers' portfolio, and vice versa. Moreover, we hypothesise that there is endogeneity in these decisions because: 1) the land-use decisions across crops and varieties are interrelated where those decisions are made simultaneously, as the farmer makes a decision on one bearing the other in mind, making simultaneous adjustments as needed; and 2) although at varying levels, omitted variables such as weather, skill and food habits are likely to have effects on the area allocation decisions for each crop and variety combination.

To test for the above set of two hypotheses, there is a need to modify equations (1) to (4) by including the dependent variables of each equation as explanatory variables in the other equations, as follows:

$$barshr_i = potshr + impbarshr + \boldsymbol{X_i\beta} + \varepsilon_i \tag{5}$$

$$potshr_i = barshr + imppotshr + \boldsymbol{X_i\alpha} + \vartheta_i \tag{6}$$

$$impbarshr_i = barshr + imppotshr + \boldsymbol{X_i\gamma} + \mu_i \tag{7}$$

$$imppotshr_i = potshr + impbarshr + \boldsymbol{X_i\theta} + \omega_i \tag{8}$$

The above specifications state that the shares of each crop and variety are influenced by the shares of each of the other crops and varieties. The dependent variables in equations (5) to (8) above are censored from below at zero. To this effect, the tobit model (Tobin 1958) would be appropriate to estimate each equation individually. Given the problem of endogeneity described above, all four equations would need to be solved simultaneously using the multivariate tobit model for extended dimensions (Kamakura & Wedel 2001). However, in addition to being censored from below, each of the four dependent variables are fractions that take values between 0 and 1, making the fractional response models (Papke & Wooldridge 1996) more appropriate. To correct for the potential endogeneity problem that may be introduced by omitted variables and the simultaneity of decisions on land use and technology adoption for all the crop–variety combinations, the conditional mixed process (CMP) estimator is used here for estimating all four fractional response models (i.e. equations (5) to (8)) simultaneously. In estimating the fractional response model for land use and extent of adoption, the zero area allocations by non-adopters are also included – thereby omitting the first hurdle in the technology adoption decision and hence averting the need for correcting for possible selection bias in adoption decisions. Version 15 of the Stata software (StataCorp 2017) was used for all econometric estimations in this paper.

4. Results and discussion

4.1 Results related to specification of the model

Table 2 presents the results of the four fractional response models estimated using the conditional mixed-process (cmp) estimator. The Wald chi squared statistic is significant at 1% – showing that the model exhibits good explanatory power. With the exception of equations (6) and (7), the significant correlation between all six possible pairwise combinations of the error terms in equations (5) to (8) show that there indeed is simultaneity within and across land-use and extent of variety adoption decisions. Therefore, specifying land-use decisions for multiple crops and varieties in a way that allows the simultaneous estimation of all equations as a system is necessary. Ignoring this important aspect and undertaking the estimation of land-use and adoption decisions using single equation systems could lead to erroneous conclusions.

The positive and significant coefficient estimates on the variables *imppotshr* and *impbarshr* in equations (7) and (8) respectively show that there is a bi-directional effect between the decisions on the land allocation decisions on different varieties across the two crops. This result substantiates our argument that an analysis of the land-use decisions for a given variety of a certain crop should not be seen in isolation from the land-use decisions on varieties of the other crops in the farmer's crop portfolio. Likewise, there is a bi-directional relationship between land-use decisions across crops, showing the need to model land-use decisions in a simultaneous equation system setting.

4.2 Determinants of land-use decisions

Generally, most farm and farmer characteristics traditionally included in most adoption studies (such as soil fertility, sex, age and education) are found to be less important in influencing the decisions on the land-use decisions on improved technologies. Instead, other factors, such as history of land use, rotation requirements and relative importance of the crop in the farmer's crop portfolio are found to be more important. If a farmer allocated a larger share of his/her farm to barley or potato in the previous year, our results show that he/she would still allocate a larger share of land to the same crops this year, showing that familiarity with the crops and history of land use are important.

Our results show that the rotation requirement is important for potato, but not for barley. Barley is the main staple food in the highlands and hence it is no wonder that the subsistence farmers in the highlands of Ethiopia practise barley mono-cropping. Theoretically, one would expect male-headed households to have better access to resources and hence to have a higher tendency to adopt all improved technologies. Likewise, young and more educated household heads would be expected to allocate larger areas for improved agricultural technologies. However, the results of our model provide evidence that sex, age and education of the household head do not have consistent effects on the land-use decisions related to varieties. For example, while young and female-headed families cultivate potatoes on a larger scale, age and sex do not have a significant effect on the size of land allocated to improved barley varieties. These results indicate that, for main staples, the role of the education, age and sex of the household head in technology adoption decision may be undermined by other, more important factors. For example, larger families, and households headed by model farmers, would plant improved barley varieties on a relatively larger area, which, given the importance of barley in the daily diet in the Ethiopian highlands, and the special attention given to model farmers, make these results reasonable.

Table 2: Results of the simultaneous estimation of the four fractional response models

Variable	**Equation 5 - barshr**		**Equation 6 - potshr**		**Equation 7 - impbarshr**		**Equation 8 - imppotshr**	
	Coef.	**Std. err**	**Coef.**	**Std. err**	**Coef.**	**Std. err**	**Coef.**	**Std. err**
SEX	-0.079	0.063	0.117	0.064*	-0.107	0.091	-0.238	0.094***
AGE	0.001	0.001	-0.004	0.001***	-0.002	0.002	0.004	0.002**
educ	-0.004	0.005	0.001	0.006	0.020	0.008***	0.015	0.010
famlysize	-0.003	0.006	-0.001	0.008	0.045	0.008***	-0.013	0.011
extvist_no	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
model_farmer	-0.009	0.032	-0.025	0.035	0.159	0.051***	0.063	0.059
corrugated	-0.041	0.018**	-0.013	0.019	-0.074	0.025***	0.086	0.029***
AMHARA	-0.060	0.042	-0.183	0.045***	-0.232	0.079***	-0.369	0.087***
OROMIA	-0.059	0.047	-0.150	0.042***	0.520	0.057***	0.022	0.077
Vertshare	0.090	0.044**	0.113	0.045***	-0.017	0.064	0.117	0.071*
Fertileshr	-0.023	0.063	0.049	0.066	0.248	0.100***	-0.123	0.103
Fertuser	-0.251	0.049***	0.095	0.054*	0.486	0.111***	0.111	0.100
rot	-0.031	0.035	0.121	0.037***	0.075	0.061	-0.016	0.070
prevbarshr	0.836	0.080***	NI	NI	NI	NI	NI	NI
prevpotshr	NI	NI	1.919	0.122***	NI	NI	NI	NI
barshr	Dependent variable		-0.602	0.097	2.326	0.132***	NI	NI
potshr	-0.579	0.119***	Dependent variable		NI	NI	2.481	0.191***
impbarshr	1.902	0.088***	NI	NI	Dependent variable		0.463	0.171***
imppotshr	NI	NI	2.928	0.255***	0.899	0.363***	Dependent variable	
_cons	-0.615	0.122***	-1.495	0.128***	-3.244	0.207***	-2.425	0.196***
			Parameter	Coef.	Std. err			
			rho_56	0.028	0.008***			
			rho_57	-0.193	0.011***			
			rho_58	0.028	0.012**			
			rho_67	0.002	0.013			
			rho_68	-0.104	0.007***			
LR chi^2 (59)	-1532***		rho_78	-0.045	0.015***			

Notes: *, ** and *** represent significance at α levels of 0.1%, 0.05% and 0.01% respectively; NI = not included

Share of fertile lands in total crop land and whether the farmer is a fertiliser user are found to have no significant influence on the size of area devoted to improved potato varieties, while they have a positive and significant effect on that of improved barley varieties. Location factors, however, are found to be important, with farmers in Amhara allocating smaller proportions of their crop area to improved varieties of barley and potatoes, and those in Oromia allocating a larger proportion to barley relative to those in the SNNPR. Farm household's wealth proxied by possession of houses roofed with corrugated metal sheets is found to have a positive and significant effect on area allocated to improved potato varieties, while it has a negative and significant effect on that of improved barley varieties. This result is to be expected, as potato is a more recently introduced crop and is still considered a rich man's food.

Number of extension visits does not have a significant effect on the area allocations of varietals. In particular, as the main focus of the Ethiopian extension programme is on increasing the use of fertilisers and improved varieties of different crops, this result is counterintuitive. However, this result is consistent with the generally low level of adoption of improved varieties and other agricultural technologies in Ethiopia, which is a country with an estimated 21 extension agents per ten thousand farmers (one of the highest globally), showing that the current extension service delivery system is not working.

The results that came as a surprise in this analysis are that whether the household head is a model farmer and the number of extension visits do not have significant effects on land-use decisions in relation to improved varieties of both barley and potatoes. This will definitely raise the eyebrows of both government officials and other onlookers, because the country, with one of the densest extension systems globally, has a farmer training centre in nearly every village, besides the 21 extension agents per ten thousand farmers. These results are also consistent with the generally low levels of adoption of improved varieties and other agricultural technologies in Ethiopia. It is evident that these results are clearly indicative of the ineffectiveness and hence poor impact of the current extension service delivery system.

5. Conclusions

Considering the role of personal choices, preferences and farmers' behaviour in relation to risk, analysing the farmers' adoption decisions regarding agricultural technology adoption is very complex. It is even more so when the farming system involves many smallholder subsistence farmers, for whom agricultural production is a matter of survival. Unlike commercial farms, where profit maximisation could safely be assumed to be the objective function, multiple and often competing objectives characterise the adoption decision of smallholder subsistent farmers in the highlands of Ethiopia.

With few exceptions, the literature on technology adoption focuses predominantly on the analysis of the farmers' adoption behaviour towards single technologies. Moreover, adoption decisions are treated as either sequential or simultaneous. Using data from 1 469 barley- and potato-growing farm households in the Ethiopian highlands and a fractional response model, this paper argues and provides empirical evidence that endogeneity is inherent in the land-use and technology-adoption decisions of multiple crops and agricultural technologies. These results are in line with the theoretical expectation, as farmers have to optimise their land use and technology adoption given their limited crop area – signalling that one cannot view one crop–variety combination in isolation from another. Therefore, to generate reliable results, any analysis that aims to understand land-use and technology-adoption decisions needs to use a specification that allows for simultaneous estimation of the equations describing land-use decisions for all major crop–variety combinations in the farmer's portfolio.

Among the traditional explanatory variables in adoption studies, only family size, wealth and location are found to be important factors in varietal adoption. Others, including sex, age and education of the household head and soil fertility-related variables, are found to have no significant effect on land allocation across varieties. Instead, history of cultivation, relative importance of each crop in the farmer's portfolio (proxied by area share), and rotation requirements are found to be more important determinants of land-use decisions across both crops and varieties.

A rather striking result from our analysis is that the frequency of extension service delivery (proxied by the number of extension visits to the farmer) is found to have no significant effect on land-use decisions across different crops and their varieties. This result may seem to be counterintuitive, but despite the fact that Ethiopia is among the few developing countries with a very high density of extension agents, the adoption levels for most of the improved crop varieties are low. This fact, along with the model results, suggests that, despite the huge investments, the extension system in the country is not effective.

The implications of these results are: 1) Modelling efforts for agricultural technology adoption and technology targeting and promotion should consider all major crops in the farmers' portfolio. Analysing only a single crop and variety in a single equation setting could potentially lead to erroneous results. The low adoption levels for improved agricultural technologies in the country could possibly be a result of the failure to target farmers with improved varieties of multiple crops. This is especially important among subsistence farmers such as those in the study areas. 2) Ethiopia needs to thoroughly review and take the necessary corrective measures to increase the efficacy of its extension system to enhance the adoption of improved agricultural technologies, and thereby to ultimately speed up the development of the agriculture sector. Without such an effort, agricultural development in Ethiopia may remain a far-fetched dream.

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