Three hurdles towards commercialisation: integrating subsistence chickpea producers in the market economy

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Abstract
Enhancing agricultural productivity through the adoption of improved technologies presents a credible pathway to economic development and poverty reduction especially through increased commercialisation of production. We used a triple hurdle (TH) model to estimate the production and commercialisation of smallholder farmers in Ethiopia. In doing so, we account for the adoption of improved \textit{Cicer arietinum} (chickpea) varieties on commercialisation using a three-wave panel data set. We estimate a correlated random effect model with a control function and find the adoption of improved chickpea to have a significant positive effect on smallholder commercialisation. Our findings that are robust over different specifications and identification strategies also support the role of transaction cost in driving market participation (MP). Finally, we argue that the TH model is a better fit to the commonly used double hurdle model for MP, when not all households in a population produce a particular crop.

Keywords: adoption, improved technologies, transaction costs, correlated random effects, panel data

JEL classification: O12, Q13, Q16

1. Introduction
The transition of smallholder agriculture from subsistence to market orientation has been a core theme in the fields of development and agricultural economics over the last few decades (Barrett, 2008). The understanding of this transition, i.e. from low productivity and food self-sufficiency to high productivity and marketing surplus, is of utmost significance for most developing countries.
countries reliant on agriculture. In this regard, most of the policy environments in these countries have been geared towards promoting the production and commercialisation of high-value products for local and export markets. However, smallholder farmers are often unable to benefit from such policy developments because of the prevailing use of low-yielding varieties, high transaction costs (TC), lack of rural infrastructure and inadequate institutional services (Gebremedhin and Hoekstra, 2007; Verkaart et al., 2017).

Existing literature supports the premise that the adoption of improved varieties leads to improved welfare and poverty reduction (Walker and Alwang, 2015). Poverty among smallholder farmers can also be reduced through output market participation (MP) as this will increase their returns to farming. Moreover, increased adoption and the transition to intensified agriculture strongly depends on market opportunities (Asfaw et al., 2011) as well as the objectives and opportunities smallholder farming households consider (Mausch, Orr and Miller, 2017). Thus, the promotion of market orientation in smallholder agriculture requires food value chains that connect farmers to consumers. Successful MP allows farmers to sell surplus production for income generation, growth and improved livelihoods (Ochieng et al., 2019; Ogutu and Qaim, 2019). Furthermore, this has the potential to maximise growth through input supply channels. As a result, MP can be regarded as one avenue to achieve agricultural productivity and profitability.

*Cicer arietinum* (chickpeas) have recently been identified as a promising crop to achieve the transition of small producers to a more market-oriented and profitable farming system (Michler et al., 2019; Verkaart et al., 2017, 2019). Three closely related studies on the processes and effects of the introduction and adoption of improved chickpea varieties in Ethiopia have been published in the recent past. They have established that the adoption of improved chickpea varieties has indeed increased welfare levels of adopting households (Verkaart et al., 2017). This adoption process has been driven by significantly higher returns to these varieties, which made them attractive and helped their widespread adoption (Michler et al., 2019). Adoption has also been supported by good market access in the study regions and no major hurdles (Verkaart et al., 2019).

Adding to this body of work, here we analyse the linkage between the adoption of improved chickpea varieties and smallholder production and commercialisation. While previous work stressed that increased returns were also realised through increased sales, the decision on the degree of commercialisation has been treated as an explanatory variable rather than as a distinct decision taken by the farmer. Therefore, this paper specifically seeks to (i) determine if there exists a causal relationship between improved chickpea adoption and the household MP and (ii) estimate the extent to which the adoption of improved chickpea influences the quantity of chickpea sold in markets.

We used a triple hurdle (TH) model to elicit the production and commercialisation decisions of households. The TH is a flexible extension of the double hurdle (DH) model with an additional tier for the production decision.
The use of this model is motivated by the fact that not all households in our study region grow chickpea, despite being potential growers. It becomes relevant to explicitly model the production decision as any policy encouraging producers to participate in markets may also induce non-producers to produce and subsequently participate in markets (Burke, Myers and Jayne, 2015). Moreover, this framework avoids potentially problematic restrictions as it allows different structural processes to drive production and commercialisation. That notwithstanding, we also estimated a DH model for comparison purposes and show that the TH is a better fit than the DH, and highlight some insights gained from its use. Over different specifications and various robustness checks, we show that the adoption of improved chickpea leads to smallholder commercialisation.

Our contribution to the literature on smallholder commercialisation is thus twofold. First, we empirically test the hypothesis that the adoption of an improved seed variety drives output MP of farmers. Most empirical studies investigating MP either focus on the role of market failures (Alene et al., 2008; Holloway et al., 2005; Key, Sadoulet and Janvry, 2000; Ouma et al., 2010) or assets in explaining household’s MP (Boughton et al., 2007). However, as Camara (2017) demonstrates in his study on grain cereals in Guinea, MP is also influenced by production shifters such as the adoption of new technologies. Furthermore, Mausch, Orr and Miller (2017) explore the twin challenges of profitability and resilience in smallholder agriculture as they are being addressed through the use of different types of modern agricultural technologies, but caution about the limitations for some groups and contexts. Second, we improve causal identification compared with those of most previous observational studies on MP by controlling for (i) self-selection into chickpea production and (ii) unobserved heterogeneity by using panel data. The presence of omitted variables in the form of time-invariant unobserved household characteristics such as risk aversion, managerial ability and preferences may bias estimates if not well-controlled for. We addressed these challenges using a correlated random effect estimator on a three-wave, balanced panel dataset of 614 households in the Oromia and Amhara regions of Ethiopia.

The remainder of this paper is structured as follows: Section 2 situates the production of chickpea in the local context whereas Section 3 presents the theoretical framework and the farm household model. Section 4 describes the econometric framework, the identification strategy and the data used. Section 5 gives a full synopsis of both the descriptive and econometric results and discusses the findings before concluding and offering policy implications in Section 6.

2. Chickpea production in Ethiopia

In Ethiopia, the agricultural sector is widely in the hands of subsistence smallholder farmers. Recognizing that low-productivity subsistence agriculture will not ensure the much-needed food security and household welfare,
the Ethiopian government has liberalised its economy and set in place strategies to reduce poverty. These encompass market-oriented policies for the achievement of economic growth and agricultural development (Shiferaw and Teklewold, 2007) as well as the commercialisation of subsistence agriculture (Mekonnen, 2015).

For chickpea production, Ethiopia ranks first in Africa with a share of about 51 per cent in area and 70 per cent in production (FAOSTAT, 2019). Among the different legumes grown in the country, a lot of attention is being placed on chickpea as it has been identified as an emerging export crop (Shiferaw and Teklewold, 2007). Two types of chickpeas are produced in Ethiopia: the more recently introduced improved Kabuli varieties and the widely used traditional Desi varieties (which are not considered here). Kabuli chickpeas (garbanzo) are larger in size and creamy white in colour and command a higher market price, whereas the smaller Desi chickpeas are reddish-brown and relatively cheaper.

Improved chickpea is more attractive based on superior returns driven by market preferences and various desirable traits such as resistance to drought and diseases (e.g. Fusarium wilt and Ascochyta blight). Chickpea is a leguminous staple crop usually cultivated in rotation with cereals such as teff, barley and wheat. The crop provides an important source of protein to households that cannot afford expensive livestock products. Due to its relatively low water demand and early maturity, it can be cultivated in areas of land scarcity as a second crop using residual moisture.

Being a leguminous crop, it fixes atmospheric nitrogen in the soil, which can be used by other cereal crops such as teff and wheat. This increased soil fertility can reduce the use of chemical fertilisers, preventing potentially adverse effects on the environment. Therefore, improved chickpea has been described by Verkaart et al. (2017) as a pro-poor and environmentally friendly technology. This coupled with the increased profitability could spur economic and agricultural growth and development in Ethiopia. Hence, it is argued that policymakers should treat this sector with urgency and foster its development by enhancing product quality and consistently supplying seeds with market-preferred traits at competitive prices (Verkaart et al., 2017).

3. Theoretical framework

Households maximise utility by choosing their level of production \( (q_i) \), consumption \( (c_i) \), amount purchased in the market \( (b_i) \), and amount sold \( (s_i) \), with the application of inputs \( (x_k) \) in the following utility maximisation framework.

\[
\max_{c_i, q_i, b_i, s_i, x_k} U(c_i, z_u) \quad (1)
\]

subject to

\[
\sum_{i=1}^{N} p_i^{m} (s_i - b_i) - \sum_{k=1}^{M} p_k x_k + y \geq 0 \quad (2)
\]
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\[ q_i - x_i - c_i + b_i - s_i + E_i = 0 \]  \hspace{1cm} (3)

\[ F(q, x_k : z_q) \geq 0 \]  \hspace{1cm} (4)

\[ c_i, q_i, b_i, x_k, s_i \geq 0 \]  \hspace{1cm} (5)

\[
i = 1, \ldots, N \text{ and } k = 1, \ldots, M,\]

where \( p_i^m \) is the market price of product \( i \); \( E \) denotes endowments, \( z_u \) and \( z_q \) are vectors of household consumption and production characteristics, respectively; \( y \) is transfers and other incomes; whereas \( F(q, x_k : z_q) \) represents the production technology.

The above framework is only valid in the absence of TC. TC includes transportation costs and the consequences of imperfect and asymmetric information. Assume a household faces TC \( tc_i(a, g, z, y) \) for trading in the market for each good \( i \). TC can either be proportional \((tc_i^p)\) or fixed \((tc_i^f)\). These costs jointly depend on asset holding \( a \) (land, labour, improved seeds, livestock holding, etc.); vector \( g \) (extension service and farmer associations, road access); vector \( z \) (household characteristics such as age, gender, education, experience etc.); and \( y \) reflects income from other sources for the proportional transaction cost case \((Key, Sadoulet and Janvry, 2000)\). Recent empirical studies demonstrate the role of TC in explaining the autarkic behaviour of farmers \((Alene et al., 2008; Barrett, 2008; Burke, Myers and Jayne, 2015)\).

Producing an improved variety has the potential to lower TC (especially, \( tc_i^f \)) and improve commercialisation through three avenues. First, the improved variety is of higher quality/standard and offers better features that make it more sellable on the market. Second, it reduces the sorting efforts of producers as the output from the improved variety is more uniform. Finally, for farmers using the improved variety, there is probably little or no need for large pre-screening to make output acceptable on the market and thus improved chickpea adoption may also relax producers’ time constraints. Following this, we expect fixed and variable transaction cost per unit sold to be lower with the Kabuli variety. We proxied for fixed TC using information variables and measures of distance to represent proportional transaction cost which is variant to the sales quantity.

Following Key, Sadoulet and Janvry \((2000)\), TC can be incorporated into the income constraint of the agricultural household model framework as:

\[
\sum_i \left[ (s_i (p_i^m - tc_i^p \delta_i^s) - tc_i^f \delta_i^b) - (b_i (p_i^m + tc_i^p \delta_i^b) - tc_i^f \delta_i^b) \right] - \sum_{k=1}^{M} p_k x_k + Y = 0
\]  \hspace{1cm} (6)

1 Chickpea is one of the commodities that are traded at Ethiopian commodity exchange (ECX) and Kabuli is graded as top quality.
where $\delta^s_i$ equals 1 if the household sells and 0 for autarkic households, $\delta^b_i$ equals 1 for buyer households and 0 otherwise. From equation (6), the proportional TC lower the price effectively received by sellers, and increase the price effectively paid by buyers by an unobservable amount $tc^p_i$.

Based on equation (6), we can define the MP decision price, $p_i$ as

$$p_i = p^m_i - tc^p_i$$

for seller households ($s_i > 0$).

We can now establish the conditions that determine the MP of a household facing TC by comparing the utility obtained from selling its output or remaining autarkic. We represent this utility using the indirect utility function $V(p, y, z, u)$, where $p$ is the decision price of chickpea and $y$ is the income measured at the decision price as:

$$V^s = V(p^m_i - tc^p_i, y_0 (p^m_i - tc^p_i) - tc^f_i, z, u), \text{ if seller}$$

$$V^a = V(\tilde{p}_i, y_0(\tilde{p}_i), z, u), \text{if autarkic}$$

where $y_0$ is the household income before it incurs the fixed TC, $\tilde{p}_i$ is the unobservable internal shadow price when the household is autarkic. It is optimal for a household to sell when the market prices are above $p^m_i + tc^p_i$ and be autarkic when $p_i < p^m_i + tc^p_i$ as any increase in $tc^p_i$ lowers household income and utility. The corresponding supply function for households facing TC can thus be presented as:

$$q^s = q(p^m_i - tc^p_i, z, q)$$

for sellers.

$$q^a = q(\tilde{p}_i, z, q)$$

for autarkic households.

After manipulation of the first-order conditions of the utility maximisation problem and integrating the other variables from equation (6), the solution of the model for the supply side can be generally written as:

$$q^p_i = f\left(p^m_i, z, g, y, x_k, tc^f_i, t_i^p, a, z_q\right)$$

$$s^p_i = f\left(p^m_i, z, g, y, x_k, tc^f_i, t_i^p, a, z_q\right)$$

where $q^p_i$ and $s^p_i$ are binary variables ($p$ represents participation). They represent the household’s production and MP decision and conditional on this, the

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2 Demand side for optimal quantities consumed and input used are also part of the first-order equations. Here, we present only the supply side equations in which we are interested.
intensity of the MP \( (s_i) \) is expressed as:

\[
    s_i = f(p_i^m, g, y, x, a, t_c^p, z_q)
\]  

(14)

From the above, we see that the supply curve (quantity sold) is not affected by the fixed TC. When the household decides to participate in the market, only the marginal return to production affects supply decisions. In the face of fixed TC, households delay participating in output markets till the decision price is high enough to compensate and cover the fixed TC. In this case, farmers are assumed to be able to trade any volume after meeting all fixed TC.\(^3\)

4. Empirical approach

4.1. TH approach

Most studies on MP either used the Tobit model or one of the commonly used two-part models: Heckman’s or a DH model. However, as mentioned above, such models are only appropriate when all members of a population are producers of a particular crop, which is not the case in our study area. Using such models leads to less-representative analyses. Inspired by this major limitation of the DH which only models producing households, Burke, Myers and Jayne (2015) pioneered the TH approach to estimate the production and MP of milk farmers in Kenya.

The empirical model specification derives directly from equations (12–14) above. We use a TH model where the parameters in all the hurdles can be estimated simultaneously through the maximum likelihood estimation\(^4\) technique. The first hurdle, which is the decision to produce chickpeas, is estimated using a probit model. The second hurdle (MP decision) is again estimated with a probit model using only households that produce chickpeas. Finally, a truncated normal regression models the level of participation (quantity sold) conditional on producing chickpeas and participating in the market.

More formally, the three stages of the TH model are as follows:

(i) Decision to produce chickpeas by a given household \( j \) at time \( t \)

\[
    q_{jt}^p = w_{jt} \lambda + c_{jl} + \kappa_{jt}
\]  

(15)

\[
    q_{jt}^p = \begin{cases}  
    1 & \text{if } q_{jt}^p > 0 \\
    0 & \text{otherwise}
    \end{cases}
\]  

(16)

\(^3\) For more details about supply response under transaction costs, see Key, Sadoulet and Janvry (2000).

\(^4\) Due to the separability of the likelihood function, the three MLE of the parameter estimates are obtained in a probit–probit–truncated regression framework.
(ii) Decision to participate in chickpea market conditional on producing chickpeas

\[ s_{jt}^{p*} = x_{jt}'\alpha + \omega d_{jt} + c_{j2} + \varepsilon_{jt} \]  

\[ s_{jt}^p = \begin{cases} 
1 & \text{if } s_{jt}^{p*} > 0 \text{ and } q_{jt}^p = 1 \\
0 & \text{otherwise} 
\end{cases} \qquad (18) \]

(iii) Decision on the quantity to sell conditional on MP

\[ s_{jt} = v_{jt}'\beta + d_{jt} + c_{j3} + \mu_{jt} \]  

\[ j = 1,2,...,N \\
t = 1,2,...,T, \]

where \( q_{jt}^{p*} \) and \( s_{jt}^{p*} \) are latent variables representing utility differences between the two choices in the first two cases. The dummy variable \( d_{jt} \) in (17) and (19) is of key interest, taking on the value of one for a household cultivating the improved chickpea variety at time \( t \) and zero otherwise. Its coefficients \( \omega \) and \( \delta \) give the effect of improved chickpea adoption on MP and intensity of MP, respectively. The vectors of explanatory variables \( w_{jt}, x_{jt} \) and \( v_{jt} \) affect the likelihood of chickpea production, the probability of selling in the market and the marketed surplus of chickpea farmers, respectively, with \( \lambda, \alpha \) and \( \beta \) being the corresponding vectors of coefficients. As shown above, there are two types of errors exhibited in the models. We have unobserved time-invariant factors in the different hurdles above \( (c_{j1}, c_{j2}, c_{j3}) \) representing unobserved individual characteristics affecting the household’s decisions and the idiosyncratic, time-variant and uncorrelated errors, \( \kappa_{jt}, \varepsilon_{jt} \) and \( \mu_{jt} \).

4.2. Unobserved heterogeneity and error correlation across equations

The unobserved heterogeneity mentioned above is time-invariant and usually includes characteristics that are difficult to measure (or have not been measured due to other reasons) such as motivation and abilities that vary across individuals and households. To obtain unbiased and consistent estimates for the coefficients of nonlinear panel models, covariates must be independent of unobserved heterogeneity. The Correlated Random Effect model (CRE) as pioneered by Mundlak (1978) and generalised by Chamberlain (1984) is an approach to relax this strong assumption of no correlation (Ricker-Gilbert, Jayne and Chirwa, 2011; Woldeyohanes, Heckelei and Surry, 2017). It assumes that the correlation is a linear function of the average across time of all time-variant covariates in models (15), (17) and (19) above. The CRE, being a flexible extension of a random effect estimator, additionally provides fixed effect estimates for the time-invariant heterogeneity, while avoiding the incidental parameters problem for non-linear models.
If the error terms \((\kappa_{jt}, \varepsilon_{jt}, \mu_{jt})\) are assumed to be uncorrelated and follow the independent and identically distributed assumption conditional on the covariates, then the estimated standard errors will be non-biased. However, if the uncorrelated errors assumption does not hold, the standard errors will be biased, making it invalid for statistical inference. Testing for this assumption follows the same procedure as the Heckman’s method for sample selection bias (Wooldridge, 2010). In our case, we begin by estimating the first hurdle probit model and obtain the Heckman’s lambda, the inverse Mills ratio (IMR). The second hurdle probit model is now estimated with the generated IMR from the first hurdle added as an additional covariate. If the estimate of the IMR is significant, we reject the null hypothesis of no correlation between the two hurdles and correct the standard errors. If not significant, we drop the IMR and re-run the model. The same procedure is repeated for the second and third commercialisation hurdles, where we also get another IMR from the second hurdle estimation that is used to test if errors from hurdles 2 and 3 are correlated. If the coefficient on the IMR is significant, we let it control for the correlation in the two hurdle models, otherwise, we drop it. We impose two exclusion restrictions (ER) on the ownership of agricultural tools and access to market information in the second and third hurdles, respectively.

### 4.3. Identification strategy

Our key variable, the adoption of improved chickpea is likely endogenous. The heterogeneity of households regarding asset holdings, information access and other observed and unobserved factors may affect the MP decision and the quantity to sell as well as adopt. Furthermore, there exists potential reverse causality between the adoption of improved seeds and commercialisation. Whereas increased adoption could lead to MP through higher yields, commercialisation on the other hand may result in adoption through higher incomes, making it possible to easily obtain the improved seeds. In this case, adoption correlates with unobserved time-variant shocks.

There are two approaches to address this for the case of observational data: the widely used two-stage least squares and control function (CF). For non-linear models, the CF is more appropriate and offers some distinct advantages. First, it is easy to implement as it only entails adding a new variable to the regression, and second, it leads to a straightforward exogeneity test for such models (Wooldridge, 2015). Moreover, it can easily be combined with the CRE model for addressing time-invariant heterogeneity. The CF uses a two-step procedure, wherein a probit model is used to estimate the reduced form adoption equation with an appropriate instrumental variable (IV). To obtain consistent estimates, we used the same set of explanatory variables and the IV in the reduced form model. The residual obtained from the reduced form regression is now added as an additional covariate with the other variables in the second and third hurdles. Following Mason and Smale (2013) and Smale and Mason (2014), we used the average adoption rate at the ward level. This is constructed by counting the number of households that grow improved
chickpea in a ward (excluding the specific household) and dividing by the number of households in the ward. Using this instrument is based on a recent extant literature that highlights the role of social networks, social capital and learning in improving the use of improved varieties (Krishnan and Patnam, 2013; Magnan et al., 2015). Indeed, farmers learn by doing and also from others in their neighbourhood and networks (Jaleta et al., 2013). These networks ease and reduce the information constraints most farmers face in rural areas.

The ward adoption scale serves as a reasonable proxy to the flow of information about improved chickpea. It is correlated with the adoption of improved chickpea as shown in Table A1 in the appendix. As the instrument is measured at the ward level, which is a higher spatial level, we believe that it is uncorrelated with the household level, time-varying errors especially after controlling for the observed covariates, time fixed-effect and time-invariant unobserved heterogeneity. As we included the residuals from the reduced form equations, the standard errors may be biased. To overcome this, the standard errors are bootstrapped and clustered at the ward level.

4.4. Data

The panel data for this study have been collected by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) over three survey rounds, each of which has been conducted shortly after the harvesting period in January/February and has been used in previous works analysing the changes in the chickpea production in the regions (see Michler et al., 2019; Verkaart et al., 2017, 2019). The sample was drawn from chickpea-producing regions in the East Shewa zone of Amhara and the Oromia Regional States of Ethiopia. It is located in the northeast of Bishoftu (50 km south-east of the capital Addis Ababa).

The initial survey was carried out in two stages: first, a reconnaissance visit was undertaken, wherein production and marketing conditions of the area were understood through discussions with farmers, traders and extension officers in the area. The findings from the visit were then used to refine the survey instrument and the sampling design. Three districts (Minjar-Shenkora, Gimbichu and Lume-Ejere) were selected using a multistage sampling from accessible regions with a suitable agroecology and high intensity of chickpea cultivation. These districts represent early dissemination areas for the new Kabuli chickpea varieties. In each of the districts, 8–10 wards were selected randomly, and 150–300 households also randomly chosen from the districts. In total, 700 farm households were then surveyed using a standardised survey instrument. For this study, three rounds of panel data collected in the years 2007–08, 2009–10 and 2013–14 were used. Because of the random selection of households, both chickpea and non-chickpea farmers were interviewed. For the three panel years, 700, 661 and 631 households were surveyed, respectively, in the three rounds.

We used a balanced sample of 614 households giving an attrition rate of 12.2 per cent. This attrition rate is both relatively and reasonably low as compared with other integrated household surveys in developing countries, which
report attrition rates as high as 50 per cent between survey rounds (for a detailed discussion, cf Alderman et al., 2001). Attrition, a problematic feature in most longitudinal household surveys leads to biased estimates through the collection of selective samples. Our low attrition rate makes us confident about the data and the resulting estimates. Moreover, previous analyses using these data report no significant differences between attritors and non-attritors (Verkaart et al., 2017, 2019). However, as Baulch and Quisumbing (2011) highlight, attrition tests are usually model-specific and should be performed under different model conditions. We thus perform an attrition probit regression with some of the baseline explanatory variables that are believed to affect the outcomes (Table A2 in the appendix). None of the regression coefficients is statistically different from zero, implying attrition is not explained by any of the observed covariates. The pseudo R² of 0.03 further confirms that attrition is not systematic and not an issue in the analysis.

5. Results and discussion

5.1. Variable description

Table 1 presents the summary statistics of the dependent and explanatory variables used in the regression models. The explanatory variable of main interest, adoption, is a dummy with the value of 1 if the household cultivates the improved chickpea variety in the season surveyed. Disaggregating by adoption status, we observe that there are significant differences between households that adopt the improved varieties and those that do not. In terms of the commercialisation variable, adopters participate more in markets than non-adopters throughout the three-panel years both in terms of the binary decision and the quantity sold. It is remarkable to note that adopters sell twice as much chickpea or more than non-adopters. Again, while the participation and sales level of adopters is somewhat increasing over the panel years, these indicators are rather reducing for the non-adopters. Most of the socio-economic household characteristics are not consistently different between adopters and non-adopters over the panel years. Age is captured as the household head’s age measured in years with an average of 49.2 years. It is not significantly different between adopting and non-adopting households. Gender, which is also an important variable for adoption studies, shows about 93.1 per cent of the households are male headed. A gender perspective is quite interesting here as commercialisation has always been linked to changing gender roles in households. This is, even more, the case in the face of novel technologies such as improved seeds. Education of the head of the household is proxied as the number of years spent in school. It has an average of about 1.84 years implying most households are not educated, which is quite predominant among the non-adopters. As education increases access to information, this is expected as the adoption of any novel technology entails information diffusion.

All income measures are given in purchasing power parity (PPP) US dollars though originally measured in the local currency, Ethiopian Birr (ETB). To
| Variable                  | 2008          | 2010          | 2014          |
|---------------------------|---------------|---------------|---------------|
|                           | Adopter       | Non-adopter   | Adopter       | Non-adopter   | Adopter       | Non-adopter   |
|                           | 2008          | 2010          | 2014          |               |               |               |
| MP (%)                    | 0.811***      | 0.454         | 0.900***      | 0.327         | 0.900***      | 0.195         |
|                           | (0.023)       | (0.027)       | (0.015)       | (0.030)       | (0.015)       | (0.034)       |
| Quantity sold (kg)        | 840.686***    | 207.268       | 727.486***    | 104.525       | 649.985***    | 57.443        |
|                           | (76.952)      | (20.087)      | (35.004)      | (13.406)      | (35.911)      | (16.892)      |
| Head age (years)          | 47.111        | 46.829        | 48.065        | 49.659        | 52.041        | 50.736        |
|                           | (0.694)       | (0.694)       | (0.602)       | (0.814)       | (0.543)       | (1.029)       |
| Head is male (%)          | 0.951         | 0.924         | 0.945         | 0.939         | 0.915         | 0.909         |
|                           | (0.012)       | (0.014)       | (0.011)       | (0.015)       | (0.013)       | (0.024)       |
| Head education (years)    | 1.965**       | 1.485         | 2.002         | 1.853         | 1.804         | 2.067         |
|                           | (0.172)       | (0.130)       | (0.135)       | (0.166)       | (0.124)       | (0.229)       |
| Experience (years)        | 21.809***     | 18.963        | 23.695**      | 21.504        | 23.307        | 22.992        |
|                           | (0.723)       | (0.665)       | (0.609)       | (0.893)       | (0.654)       | (1.161)       |
| Total household asset (USD)| 440.402***    | 215.685       | 478.971*      | 386.496       | 1980.939***   | 1130.817      |
|                           | (86.461)      | (17.458)      | (39.637)      | (26.662)      | (147.232)     | (131.452)     |
| Off-farm income (USD)     | 198.3355      | 193.9535      | 195.795       | 274.195       | 661.1546      | 920.8481      |
|                           | (37.150)      | (27.952)      | (36.763)      | (51.707)      | (102.440)     | (208.751)     |
| Total production (kg)     | 2218.95***    | 614.3537      | 1460.97***    | 288.965       | 1439.55***    | 278.270       |
|                           | (118.864)     | (43.230)      | (65.318)      | (35.859)      | (59.360)      | (50.315)      |
| Area of cultivation (ha)  | 2.670***      | 2.010         | 2.415***      | 2.054         | 2.233***      | 1.989         |
|                           | (0.345)       | (0.298)       | (0.314)       | (0.256)       | (0.342)       | (0.123)       |
## Table 1. (Continued)

| Variable                  | 2008          | 2010          | 2014          |
|---------------------------|---------------|---------------|---------------|
|                           | Adopter       | Non-adopter   | Adopter       | Non-adopter   | Adopter       | Non-adopter   |
| Livestock owned (TLU)     | 4.646***      | 2.693         | 4.238***      | 2.919         | 5.039         | 4.593         |
|                           | (0.230)       | (0.162)       | (0.192)       | (0.167)       | (0.139)       | (0.275)       |
| Chickpea yield (kg/ha)    | 2210***       | 1882          | 2274***       | 1858          | 2432***       | 1862          |
|                           | (1177)        | (1002)        | (1124)        | (1086)        | (1098)        | (784.8)       |
| Distance to main market (km) | 9.670     | 9.009          | 8.340         | 8.134         | 9.292         | 9.030         |
|                           | (0.343)       | (0.301)       | (0.300)       | (0.339)       | (0.298)       | (0.466)       |
| District market price (USD/kg) | 1.961*** | 1.449          | 1.751***      | 0.972         | 0.955***      | 0.763         |
|                           | (0.671)       | (0.336)       | (0.432)       | (0.197)       | (0.140)       | (0.156)       |
| Access to market information (%) | 0.876*** | 0.589          | 0.734***      | 0.503         | 0.789***      | 0.481         |
|                           | (0.054)       | (0.022)       | (0.051)       | (0.030)       | (0.067)       | (0.043)       |
| Owns agricultural tools (%) | 0.832*** | 0.734          | 0.840         | 0.827         | 0.896         | 0.846         |
|                           | (0.022)       | (0.024)       | (0.018)       | (0.024)       | (0.020)       | (0.041)       |
| Ward adoption rate (%)    | 0.690***      | 0.560         | 0.671***      | 0.537         | 0.654***      | 0.500         |
|                           | (0.010)       | (0.008)       | (0.008)       | (0.009)       | (0.007)       | (0.013)       |
| Number of observations    | 190           | 424           | 382           | 232           | 481           | 133           |

**Notes:** Chickpea yield is represented here as the difference in yields between the improved variety and the local variety. For instance, in 2008, the average yield of the improved variety was 2210 kg/ha as opposed to 1882 kg/ha for the local variety. The same applies to district market price, which is just the difference in price between the improved and local varieties.
convert to the USD PPP values, we used conversion rates obtained from the 2011 International Comparison Program from the World Bank. Furthermore, to enable comparison across periods, we report real values adjusted using the national consumer price index with the base year being 2005.

The average households’ total value of assets is about 853.7 USD. The average off-farm income is 379.60 USD.\textsuperscript{5} The asset level is steadily increasing for both adopters and non-adopters over the panel years though higher for the adopters. Off-farm income however is higher for non-adopters though statistically insignificant. The amount of livestock owned is included using the tropical livestock unit (TLU). The TLU is calculated with the aid of FAO conversion factors for Ethiopia, wherein one sheep equals 0.10 TLU, one cattle 0.70 TLU, etc.

Transaction cost variables as well as the market price of chickpea are also captured. We proxy for TC using distance to market and access to market information, which reduces search costs and increases information access. Adopting households are more exposed to market information than their non-adopting counterparts. The mean walking distance to the main market is 8.94 km. District market prices for improved chickpea are higher than market prices for the local variety and this difference is significant in all panel years. In all 3 years, yields from the use of improved seeds are significantly higher than the yields from using the local seeds. Although these descriptive results point into expected directions, it is important to estimate an analytical model to verify whether these differences between adopters and non-adopters are unchanged after controlling for confounding factors.

5.2. Production and marketing trends

To characterise adoption and MP across time, the mean and standard deviation of the dependent variables and adoption are estimated for each survey wave. This is shown in Figure 1. The proportion of households who participated in the market increased from 65 per cent in 2008 through 68 per cent in 2010 to 71 per cent in 2014. However, the mean quantity of chickpea sold reduced from 502 Kg in 2008 to 492 Kg in 2010, but finally rose to 521 Kg in 2014. This shows that farmers are becoming more market-oriented despite the reduction of intensity of MP in 2010. The decision to produce improved chickpea increased from about 31 per cent in 2008 to 78 per cent in 2014. This shows the adoption of improved chickpea is increasing in rural Ethiopia.

Unlike the quantity sold in the market, the quantity of chickpea produced dropped from 1361.7 Kg in 2008 to 1018.13 Kg in 2010 and increased to 1188.01 Kg in 2014, which was still lower than the mean yield in 2008. The drop in 2010 can be attributed to the low replenishment rates of the improved chickpea varieties. In sum, the above results suggest that for Ethiopian households, the production and consumption decisions of chickpea farmers may

\textsuperscript{5} These are USD Purchasing Power Parity (PPP). All subsequent USD are also USD PPP.
be non-separable. Chickpea being a staple food crop in Ethiopia, excess production is only marketed after meeting household consumption demands.

5.3. Econometric results and discussion

5.3.1. Endogeneity

Here, we focus the discussion on the estimation results from the TH as the likelihood ratio test suggests it to be a better fit to the data than the DH ($p = 0.00$). That notwithstanding, we cross-check the robustness of results with the DH in the next section.

Testing for the endogeneity of adoption using the CF approach, we regress adoption on all covariates in the structural model and the ward adoption rate, to obtain residuals for adoption (for this result, see Table A1 in the appendix). The $p$-values for the residual coefficient of adoption in the second and third hurdles indicate that it is statistically significant, as shown in Table 2. We,

| Hurdle 2 MP decision | Coefficient | $p$-value | Conclusion             |
|----------------------|-------------|-----------|------------------------|
| Residual for adoption| 0.007       | 0.000     | Exogeneity rejected     |
| IMR                  | 0.300       | 0.000     | No correlation rejected |

| Hurdle 3 Sales level | Coefficient | $p$-value | Conclusion             |
|----------------------|-------------|-----------|------------------------|
| Residual for adoption| 0.642       | 0.000     | Exogeneity rejected     |
| IMR                  | 727.33      | 0.563     | No correlation not rejected |
therefore, include the residual term for adoption in both the second and third hurdles to control for endogeneity.

Furthermore, testing the conditional uncorrelated errors assumption, we generate the inverse mills ratio (IMR), which allows us to test the possible correlation of the error terms between the various hurdles. Following the test results in Table 2, we include the IMR only in the second hurdle to control for this correlation. Our ER are also in order. While ownership of agricultural tools is conceptually and empirically relevant\(^6\) in the first hurdle, it is conceptually not relevant for the second hurdle. Access to market information is also statistically significant in the second hurdle, but conceptually irrelevant in the third hurdle.\(^7\) While the two ERs are drivers of production and MP, respectively (as shown in Tables 3 and 4), both are not statistically significant when added as additional variables in the second and third hurdles, respectively, as shown in Table A4 in the appendix.

### 5.3.2. Factors affecting the decision to produce chickpea in Ethiopia

Table 3 presents the maximum likelihood estimates of the first tier of the TH model, i.e. the decision to produce chickpeas. Male-headed households are more likely to engage in chickpea production with a 0.4 per cent higher likelihood of producing chickpeas than female-headed households. This can be attributed to the various labour-intensive activities involved in the cultivation of chickpeas such as land preparation, planting, weeding, and harvesting. Moreover, male farmers are usually better networked in society, which could explain their access to information on new production techniques compared with their female counterparts. Furthermore, male farmers may have better access to land and other productive farm resources than female farmers (Michler et al., 2019; Verkaart et al., 2017). Price was found to have the expected positive relationship.

It is no surprise that TLU has a negative relationship with the probability of producing chickpea. This suggests that livestock keeping competes with crop production, supporting some form of specialisation. Land as the key input for agricultural production is significant at the 1 per cent level of probability and positively associated with the likelihood of chickpea production. Economically, one additional hectare of land increases the likelihood of chickpea cultivation by 4.9 per cent.

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\(^6\) It is statistically significant at the 10 per cent level of probability.

\(^7\) Access to market information is a form of fixed transaction cost which can be argued to only influence the decision of the household to participate in markets. Once the fixed transaction cost items have been passed, households only incur proportional transaction cost which is variant to the sales level. Previous literature (Key, Sadoulet and Janvry, 2000; Ouma et al., 2010; Woldeyohanes, Heckelei and Surry, 2017) supports this view.
Table 3. Drivers of chickpea production

| Variable                                | Average Partial Effect (APE) |
|-----------------------------------------|-----------------------------|
| Head age (years)                        | −0.004                      |
| Head gender (male = 1)                  | 0.044 (0.025)***            |
| Head education (years of schooling)     | −0.005 (0.003)              |
| Area of cultivation (hectares)         | 0.049 (0.009)***            |
| Total household asset (000 USD)         | 0.005 (0.004)               |
| Livestock ownership (TLU)               | −0.006 (0.003)**            |
| Off-farm income (000 USD)               | 0.001 (0.007)               |
| Access to market information (yes = 1)  | 0.229 (0.019)***            |
| Ownership of agricultural tools (yes = 1)| 0.173 (0.093)*             |
| District price of chickpea (USD/kg)     | 0.351 (0.049)***            |
| Walking distance to market (km)         | −0.002 (0.001)**            |
| Year dummies                            | Yes                         |
| Ward dummies                            | Yes                         |
| Log-likelihood                          | −642.769                    |
| Prob (Chi²)                             | 0.0000                      |
| Pseudo-R²                               | 0.2603                      |
| Number of observations                  | 1842                        |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors (in parentheses) are obtained by bootstrapping. The second hurdle is estimated with a Probit-CRE, while the third hurdle is estimated with a Truncreg-CRE.

5.3.3. CRE estimates of the determinants of MP and intensity of participation

Table 4 presents the average partial effects of the various variables influencing the household’s decision to sell in the market and the expected sales quantity conditional on participation. The coefficient for adoption is expectedly positive and significantly related to the MP decision. On average, the adoption of an improved chickpea variety leads to an increase in the likelihood of the household participating in markets by 8.4 per cent. Conditional on participating in the market, adoption shows a positive and significant impact (p < 0.01) on the quantity of chickpea sold in the market, which is consistent with expectations and a previous study on maize marketing in Kenya (Alene et al., 2008).
### Table 4. CRE<sup>a</sup> model of chickpea MP and volume of sale

| Variable                                      | Chickpea MP (APE)    | Sales volume (CAPE) |
|-----------------------------------------------|----------------------|---------------------|
| Adoption (yes = 1)                            | 0.084*** (0.024)     | 802.715*** (287.503) |
| Head age (years)                              | 0.009 (0.007)        | −8.544* (4.993)     |
| Head gender (male = 1)                        | −0.018 (0.033)       | 104.861 (177.817)   |
| Head education (years of schooling)           | −0.005 (0.003)       | 38.106** (17.372)   |
| Area of cultivation (hectares)                | 0.005 (0.007)        | 76.142 (77.714)     |
| Total household asset (000 USD)               | −0.009* (0.005)      | 9.457** (0.030)     |
| Livestock ownership (TLU)                     | −0.004 (0.002)       | 18.697 (29.605)     |
| Off-farm income (000 USD)                     | 0.007 (0.007)        | −6.298* (0.063)     |
| Access to market information (yes = 1)        | 0.237*** (0.032)     |                     |
| District price of chickpea (USD/kg)           | 0.233*** (0.043)     | 2594.577*** (530.210) |
| Walking distance to market (km)               | −0.003** (0.001)     | −11.294 (9.763)     |
| Residual for adoption                         | 0.007*** (0.001)     | 0.642*** (0.058)    |
| IMR                                           | 0.300*** (0.020)     | 727.33 (1047.302)   |
| Year dummies                                  | Yes                  |                     |
| Ward dummies                                  | Yes                  |                     |
| Log likelihood                                | −657.726 (9135.085)  |                     |
| Prob (Chi²)                                   | 0.000                | 0.000               |
| Pseudo-R<sup>2</sup>                          | 0.4349               |                     |
| Number of observations                        | 1510                 | 1237                |

**Notes:** ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors (in parentheses) are obtained by bootstrapping.

<sup>a</sup>The second hurdle is estimated with a Probit-CRE, while the third hurdle is estimated with a Truncreg-CRE.

Walking distance to markets, an aspect of proportional TC, has the expected negative influence on a household’s decision to participate in the market. Previous studies on smallholder commercialisation had similar insights (Alene et al., 2008; Key, Sadoulet and Janvry, 2000). The longer the walking distance to markets, the lower the probability of a household participating in markets. Distance to markets thus acts as a disincentive to MP. Access to market information also enables households to overcome the information barrier and participate in markets with lower uncertainty. Total household asset negatively influences the decision to sell in markets indicating that higher levels of
Three hurdles towards commercialisation

As highlighted earlier, a key strength of our TH model lies in its ability to model factors explaining the production decision of households, which is not possible when using a DH model. Apart from the already mentioned likelihood ratio test supporting the TH as opposed to the DH model, we highlight some differences between the results of the TH and DH models (see Table A3 in the appendix for the latter). First, some variables such as walking distance to the market and off-farm income show no statistically significant relationships with commercialisation in the DH model. More importantly, although we obtain significant and same-sign relationships for adoption, the magnitudes are different. Whereas the coefficient in the TH model is 0.08, the coefficient in the DH is 0.25, indicating overestimation of the effect of adoption on commercialisation in the DH. In summary, it matters for the core results of our analysis to use the TH model over the DH model.

5.4. Estimating the TH model matters

As highlighted earlier, a key strength of our TH model lies in its ability to model factors explaining the production decision of households, which is not possible when using a DH model. Apart from the already mentioned likelihood ratio test supporting the TH as opposed to the DH model, we highlight some differences between the results of the TH and DH models (see Table A3 in the appendix for the latter). First, some variables such as walking distance to the market and off-farm income show no statistically significant relationships with commercialisation in the DH model. More importantly, although we obtain significant and same-sign relationships for adoption, the magnitudes are different. Whereas the coefficient in the TH model is 0.08, the coefficient in the DH is 0.25, indicating overestimation of the effect of adoption on commercialisation in the DH. In summary, it matters for the core results of our analysis to use the TH model over the DH model.

5.5. Robustness checks

As highlighted earlier, a key strength of our TH model lies in its ability to model factors explaining the production decision of households, which is not possible when using a DH model. Apart from the already mentioned likelihood ratio test supporting the TH as opposed to the DH model, we highlight some differences between the results of the TH and DH models (see Table A3 in the appendix for the latter). First, some variables such as walking distance to the market and off-farm income show no statistically significant relationships with commercialisation in the DH model. More importantly, although we obtain significant and same-sign relationships for adoption, the magnitudes are different. Whereas the coefficient in the TH model is 0.08, the coefficient in the DH is 0.25, indicating overestimation of the effect of adoption on commercialisation in the DH. In summary, it matters for the core results of our analysis to use the TH model over the DH model.

We perform a battery of robustness checks to confirm and strengthen the findings. We begin by testing an alternative specification using ordinary least squares in the framework of a linear probability model (LPM). Following the recommendation of Angrist and Pischke (2008), the LPM offers some advantages over non-linear estimators. In specifying the LPM, we relax the dependency assumption between the hurdles following Smith (2003). The results of the LPM are presented in Table A5 in the appendix. From the estimations, the LPM predicts beyond the unit interval but offers similar results with the use of the probit model. This therefore corroborates and strengthens the empirical findings based on the nonlinear probit models suggesting that identification
does not depend on the choice of functional form. Also, despite relaxing the dependency/error correlation between the hurdles, the magnitude and statistical significance of our key variable, adoption, remains quite consistent enabling us to maintain the finding that adoption has a positive impact on smallholder commercialisation.

Additionally, we also performed a double selection lasso\(^8\) linear regression, which provides valid inferences on the effect of a treatment variable in the presence of non-Gaussian and heteroscedastic errors (Belloni, Chernozhukov and Hansen, 2014). This method is heteroscedasticity robust even when selection is not perfect. We also estimated a partialing-out estimator, but only report the double selection in Table A6 in the appendix given that the point estimates are almost the same. Regarding the adoption effect, the estimates are consistent with the estimates from both the non-linear models and the LPM. The adoption of improved chickpea positively affects MP and the intensity of that participation.

For a closer look at TC, we add possibly relevant interactions between some variables such as distance to markets, market information and market price. From the interactions as shown in Table A7, price seems to be a strong determinant of smallholder commercialisation. In the MP hurdle, it depicts a positive effect when combined with information access. Walking distance deters farmers to markets, but when interacted with price, the coefficient becomes positive although not significant. With regard to the quantity sold, interacting price with distance to market is again positive and significant. These findings confirm the role of TC in smallholder commercialisation.

Finally, to further confirm the strength of our identification strategy, we used the temporally lagged average ward adoption rates as an alternative IV in the place of the average ward adoption rates. The results (see Table A8) are again consistent both in magnitudes and in direction with the ones above confirming the role of adoption of improved chickpea varieties in commercialisation.

### 6. Conclusion

Despite advances in the theoretical and empirical analysis of smallholder commercialisation in Africa, little attention is devoted to how the adoption of improved technologies could support this transition. Most studies focus on the role of TC and asset holdings. We hypothesise that smallholder commercialisation depends not only on an efficient output market but also on the availability of improved technologies and other production shifters that are often designed to increase profitability and productivity. For a more representative analysis, we used a TH model to account for the fact that a segment of the study population does not produce chickpeas. As a robustness check, we tested the standard DH model against the TH and show that the TH model is preferred. Our findings further reveal that looking beyond a two-staged MP decision of households adds relevant insights into the farmers’ decision-making process.

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\(^8\) LASSO stands for Least Absolute Shrinkage and Selections Operator. It is a machine learning tool used for prediction, inferences and model selection.
This is even more important when the prior decision is incomplete. Not accounting for the initial decisions may lead to biased estimates about the prevailing constraints to commercialisation.

The econometric analysis highlights the positive impact of improved chickpea adoption on smallholder production and commercialisation in Ethiopia. Thus, this study complements earlier results on the important role agricultural technologies such as improved varieties could play in improving the outcomes of smallholder farming. The envisioned transition towards more commercial farming systems is highlighted here as it provides evidence on the critical step within the implicit theory of change towards the earlier found welfare improvements. The results indicate that modern chickpea varieties do support a market-oriented development pathway in this region of Ethiopia. Building on and adding to earlier results (Michler et al., 2019; Verkaart et al., 2017, 2019), this study highlights that the link and ease of access to output markets play critical facilitating roles in this process and should therefore be explicitly considered in future efforts to scale the varieties to more farmers. The improved profits and welfare outcomes are facilitated by the commercialisation of production being one of those critical ingredients of a ‘recipe for success’ that should not be mistaken (Verkaart et al., 2019).

Our results also highlight important implications for future research. Our analysis may be context-specific and investigation of the mechanisms we found should be incorporated in future analysis of the impacts of modern agricultural technologies. The learning provided by the analysis may be relevant to many different smallholder farm systems where market access is hampered by not only inefficient rural institutions and infrastructure but also production side constraints. In the absence of a reliable market link that is accessible to smallholder farmers, the theorised improvements in welfare outcomes based on the adoption of improved technologies may not hold and other solutions would be required to support less well-connected communities.

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Appendix

Table A1. Reduced form model of the factors influencing adoption

| Variable                              | Average partial effect (APE) |
|---------------------------------------|-----------------------------|
| Ward adoption rate (%)                | 0.772***                    |
|                                       | (0.088)                     |
| Head age (years)                      | −0.0015*                   |
|                                       | (0.0009)                    |
| Head gender (male = 1)                | 0.029                       |
|                                       | (0.036)                     |
| Head education (years of schooling)   | 0.002                       |
|                                       | (0.004)                     |
| Area of cultivation (hectares)        | 0.011                       |
|                                       | (0.012)                     |
| Total household asset (000 USD)       | 0.018*                      |
|                                       | (0.009)                     |
| Livestock ownership (TLU)             | 0.004                       |
|                                       | (0.004)                     |
| Off-farm income (000 USD)             | −0.001                      |
|                                       | (0.001)                     |
| Access to market information (yes = 1)| 0.229***                   |
|                                       | (0.019)                     |
| District price of chickpea (USD/kg)   | 0.142*                      |
|                                       | (0.077)                     |
| Walking distance to market (km)       | −0.003**                    |
|                                       | (0.001)                     |
| Year dummies                          | Yes                         |
| Ward dummies                          | Yes                         |
| Log likelihood                        | −945.713                    |
| Prob (χ²)                             | 0.0000                      |
| Pseudo-\(R^2\)                       | 0.2247                      |
| Number of observations                | 1842                        |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors (in parentheses) are obtained by bootstrapping.

Table A2. Test of attrition bias

| Variable               | Coefficient | S.E  |
|------------------------|-------------|------|
| Head gender            | −0.0093     | 0.3109|
| Head age               | 0.0064      | 0.0160|
| Total production       | −0.3056     | 0.5316|
| Total household asset  | 0.0001      | 0.0004|
| Market price           | −0.1479     | 0.1760|

(continued)
### Table A2. (Continued)

| Variable                      | Coefficient | S.E  |
|-------------------------------|-------------|------|
| Livestock owned              | −0.0206     | 0.0245 |
| Distance to market            | 0.0070      | 0.0104 |
| Head education                | 0.0430      | 0.0904 |
| Area of cultivation           | 0.0427      | 0.0283 |
| Off farm income               | −0.0002     | 0.0007 |
| Lume-ejere†                   | 0.2283      | 0.2800 |
| Minjar-shenkora†              | −0.1609     | 0.2922 |
| Sample size                   | 700         |      |
| Pseudo-R²                     | 0.0329      |      |
| Log-likelihood                | −217.87 (0.3035) | |

*Source: Analysis based on 2008, 2010 and 2014 ICRISAT survey data.*

### Table A3. Results of a DH model of commercialisation

| Variable                                | Chickpea MP (APE) | Sales volume (CAPE) |
|-----------------------------------------|-------------------|---------------------|
| Adoption (Yes = 1)                      | 0.251***          | 4412.574***         |
| Head age (years)                        | 0.001             | −50.643***          |
| Head gender (male = 1)                  | −0.006            | 944.403             |
| Head education (years of schooling)     | −0.006            | 106.217*            |
| Area of cultivation (hectares)          | 0.002             | 359.482***          |
| Total household asset (000 USD)         | −0.015***         | 8.604*              |
| Livestock ownership (TLU)               | −0.007**          | 228.521**           |
| Off-farm income (000 USD)               | 0.008             | 5.540               |
| Access to market information (Yes = 1)  | 0.125***          | 0.765***            |
| District price of chickpea (USD/kg)     | 0.279***          | 7139.902***         |
| Walking distance to market (km)         | −0.002            | −89.822**           |
| Residual for adoption                   | 0.0001***         | 0.765***            |
| Year dummies                            | Yes               | Yes                 |

(continued)
Table A3. (Continued)

| Variable                  | Chickpea MP (APE) | Sales volume (CAPE) |
|---------------------------|-------------------|---------------------|
| Ward dummies              | Yes               | Yes                 |
| Log likelihood            | $-795.339$        | $-9292.755$         |
| Prob (Chi²)               | 0.000             | 0.000               |
| Pseudo-R²                 | 0.3167            |                     |
| Number of observations    | 1842              | 1237                |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors (in parentheses) are obtained by bootstrapping.

Table A4. Correlation analysis of exclusion restrictions

| Variable                  | Chickpea MP (APE) | Sales volume (CAPE) |
|---------------------------|-------------------|---------------------|
| Owns agricultural tools   | 0.503             | 637.047             |
| (0.490)                   |                   | (1889.999)          |
| Access to market          |                   |                     |
| information               |                   |                     |
| Wald test                 | 269.10***         | 73.76***            |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Table A5. Linear estimation of the three hurdles

| Variable                  | Participation | MP               | Sales volume |
|---------------------------|---------------|------------------|--------------|
| Adoption (Yes = 1)        | 0.108***      | 751.371***       |
| (head age (years))        | (0.031)       | (302.607)        |
| Head gender (male = 1)    | 0.060*        | 103.713           |
| (head education (years of schooling)) | (0.034) | (170.778) |
| Area of cultivation (hectares) | 0.025*** | 75.723            |
| (head household asset (000 USD)) | (0.006) | (83.991)          |
| Livestock ownership (TLU) | 2.37e-06      | 2.37e-06          |
| (off-farm income (000 USD)) | 8.77e-07     | 8.77e-07          |

(continued)
### Table A5. (Continued)

| Variable                          | Participation | MP       | Sales volume |
|-----------------------------------|---------------|----------|--------------|
| Access to market information     | 0.373***      | 0.153*** | 303.169      |
| (Yes = 1)                         | (0.042)       | (0.058)  | (382.877)    |
| District price of chickpea (USD/kg) | 0.458***      | 0.028    | 2527.352***  |
| (Yes = 1)                         | (0.054)       | (0.065)  | (652.145)    |
| Walking distance to market (km)   | −0.002**      | −0.002   | −11.297      |
|                                  | (0.001)       | (0.001)  | (10.354)     |
| Owns agricultural tools (Yes = 1) | 0.261         | −0.076** | 379.576      |
|                                  | (0.217)       | (0.031)  | (485.580)    |
| Residual for adoption            | 0.060***      | 0.643*** |              |
|                                  | (0.009)       | (0.062)  |              |
| Ward dummies                     | Yes           | Yes      | Yes          |
| Year dummies                     | Yes           | Yes      | Yes          |
| Wald test                        | 354.84***     | 183.03***| 153.01***    |
| Prob (Chi²)                      | 0.000         | 0.000    | 0.000        |
| Number of observations           | 1842          | 1510     | 1237         |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

### Table A6. Double selection lasso linear regression

| Variable                          | Chickpea MP (APE) | Sales volume (CAPE) |
|-----------------------------------|-------------------|---------------------|
| Adoption (Yes = 1)                | 0.445***          | 330.341***          |
|                                  | (0.026)           | (45.428)            |
| Year dummies                     | Yes               | Yes                 |
| Ward dummies                     | Yes               | Yes                 |
| Other controls                   | Yes               | Yes                 |
| Prob (Chi²)                      | 0.000             | 0.000               |
| Number of observations           | 1510              | 1237                |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses. In the double selection lasso linear model, all the other explanatory variables were offered as controls.

### Table A7. Interacting transaction cost variables

| Variable                          | Chickpea MP (APE) | Sales volume (CAPE) |
|-----------------------------------|-------------------|---------------------|
| Adoption (Yes = 1)                | 0.459***          | 440.742***          |
|                                  | (0.020)           | (49.432)            |
| Access to market information     | 0.631***          |                     |
| (Yes = 1)                         | (0.189)           |                     |
| District price of chickpea (USD/kg) | 0.470***      | 554.369***          |
|                                  | (0.120)           | (168.028)           |

(continued)
Table A7. (Continued)

| Variable                                      | Chickpea MP (APE) | Sales volume (CAPE) |
|-----------------------------------------------|-------------------|---------------------|
| Walking distance to market (km)               | −0.002            | −62.660***          |
|                                               | (0.009)           | (22.050)            |
| Price # distance to market                    | 0.001             | 43.672**            |
|                                               | (0.003)           | (17.314)            |
| Information # price                           | 0.333**           |                     |
|                                               | (0.132)           |                     |
| Information # distance to market              | −0.001            |                     |
|                                               | (0.005)           |                     |
| Year dummies                                  | Yes               | Yes                 |
| Ward dummies                                  | Yes               | Yes                 |
| Other controls                                | Yes               | Yes                 |
| Prob (Chi²)                                   | 0.000             | 0.000               |
| Number of observations                        | 1510              | 1237                |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Table A8. CRE model of chickpea MP and volume of sale with temporally lagged IV

| Variable                                      | Chickpea MP (APE) | Sales volume (CAPE) |
|-----------------------------------------------|-------------------|---------------------|
| Adoption (Yes = 1)                            | 0.138***          | 707.505***          |
|                                               | (0.028)           | (316.978)           |
| Access to market information (Yes = 1)        | 0.207***          |                     |
|                                               | (0.034)           |                     |
| District price of chickpea (USD/kg)           | 0.197***          | 3009.13***          |
|                                               | (0.056)           | (752.194)           |
| Walking distance to market (km)               | −0.003**          | 0.630               |
|                                               | (0.001)           | (9.074)             |
| Residual for adoption                         | 0.003**           | 0.659***            |
|                                               | (0.001)           | (0.085)             |
| IMR                                           | 0.265***          | −1409.06**          |
|                                               | (0.024)           | (763.210)           |
| Year dummies                                  | Yes               | Yes                 |
| Ward dummies                                  | Yes               | Yes                 |
| Other controls                                | Yes               | Yes                 |
| Log likelihood                                | −405.079          | −6290.882           |
| Prob (Chi²)                                   | 0.000             | 0.000               |
| Pseudo-R²                                     | 0.4604            |                     |
| Number of observations                        | 1011              | 859                 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors (in parentheses) are obtained by bootstrapping.