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The impact of beekeeping on household income: evidence from north-western Ethiopia

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ABSTRACT

The existing literature acknowledges the benefits of beekeeping as a livelihood diversification strategy and income source for farmers across the world. However, the impact of beekeeping on income at household level has rarely been quantified. Furthermore, the few existing studies provide conflicting evidence and the methods quantifying the impact of participating in beekeeping are not rigorous. In this study, we identify key determinants of such participation and quantify the impact of beekeeping on household income. We use a cross-sectional data set collected from 392 randomly selected households in north-western Ethiopia, employing the endogenous switching regression model with estimated treatment effects. Unlike the methods used by previous studies, the approach adopted here enabled the control of observed and unobserved heterogeneities that affect not only the decision to participate in beekeeping, but also income differences among households. The results show that there are important differences between beekeepers and non-beekeepers in terms of their skills and resource endowments. After these differences were controlled for, beekeeping participation was found to increase income by 3,418 Ethiopian Birr (ETB) per person, namely a 51% increase. Furthermore, it was estimated that households not participating in beekeeping could have increased their income by ETB 442 per person (an 11% increase) had they become beekeepers. These findings indicate that income gains from beekeeping participation are 22–44 percentage points higher than benefits reported by previous studies. Capitalising on the existing beekeeping policy, targeted beekeeping extension to farmers could contribute to closing gaps in skills and resource endowments and, hence, minimising differences in income.

1. Introduction

Across the globe, beekeeping provides several invaluable benefits to farming societies. It supports agricultural production by pollinating crops, thereby increasing pollinator-dependent crop yields. Bees' pollination services are worth USD 215 billion per annum worldwide (Smith et al., 2014). Beekeeping is a source of livelihood to millions of people (Adhikari, 2011; Amulen et al., 2017; Bradbear, 2009; Dossou et al., 2021; Hecklé et al., 2018; Hilmi et al., 2011; Hinton et al., 2020; Illgner et al., 1998; Lowore, 2020; Ribeiro et al., 2019; Schouten, 2020; Yap and Devlin, 2015). Beekeeping can make farmers' livelihoods more resilient by easing their credit constraints when coping with shocks. Income from beekeeping could also support investment in their agricultural inputs, pay for their children's schooling, and smoothing consumption. Another benefit is that beekeeping contributes to maintaining biodiversity (Krishnan et al., 2020). Furthermore, beekeepers could support forest conservation, as forests are key sources of forage for bees (Degu and Megerssa, 2020; Girma and Gardebroek, 2015; Ricketts and Shackleton, 2020; Wagner et al., 2019), while the medicinal and nutritional properties of beekeeping products contribute to farmers' nutrition and food security (Manyi-Loh et al., 2011; Smith et al., 2015; Teklewold et al., 2021). Finally, beekeeping can empower women and the youth as it requires minimal resources such as labour and water (Alebachew and Eshetie, 2020; Fuller, 2014; Mburu et al., 2017; Shackleton et al., 2011). However, despite the beekeeping sub-sector's potential aggregate-level benefits, the extent to which participating in beekeeping impacts on household income has not yet been rigorously quantified.

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The objective of this study is, firstly, to understand the determinants of participation in beekeeping and, secondly, to quantify the impact of such participation on household income in north-western Ethiopia. To this end, cross-sectional household survey data collected from the Amhara Region in 2018 were used. The study will help to broaden the empirical base of beekeeping's contribution to livelihoods. Moreover, income from participation in beekeeping is a key policy variable for designing strategies to improve the beekeeping sub-sector's performance and, thus, help reduce food insecurity and poverty. This study would contribute to policy design by revitalising the traditional agricultural extension system – given that extension services to beekeeping are limited in many developing countries, including Ethiopia – and by exploiting beekeeping's potential to generate employment, diversify livelihoods and reduce poverty.

Many studies focus on how livestock and crops contribute to household welfare; however, none of them analyse the specific contributions of beekeeping (Bradbear, 2009). The few studies that have analysed the impact of beekeeping on income and other livelihood outcomes report conflicting findings. For example, some argue that beekeeping is a desperate bid by the economically disadvantaged (Amulen et al., 2017), which suggests that beekeeping may not help to reduce poverty. Conversely, others argue that beekeeping increases farmers' income and welfare (Amulen et al., 2019; Chanthayod et al., 2017; Kassie et al., 2020; Nuesiri and Fombad, 2006; Schouten, 2020; Wagner et al., 2019; Yap and Devlin, 2015). The key weakness of these studies, irrespective of their findings on the benefits of beekeeping, is that their impact evaluation was not riogorous. Most of these studies use simple averages to compare beekeepers and non-beekeepers. Thus, although Amulen et al. (2017), for instance, conclude that beekeeping did not benefit the beekeepers they studied, they do not establish appropriate counterfactuals by controlling household characteristics such as managerial skills, which may affect both beekeeping and income simultaneously. Using simple averages may, therefore, have led to beekeeping's contribution to income being under- or overestimated.

The present study contributes to the current state of knowledge on the economics of beekeeping in three incremental ways. Firstly, the impact of beekeeping participation is estimated using the endogenous switching regression model with estimated treatment effects. Applying this model addresses a shortcoming in earlier studies, in that it enables counterfactual outcomes to be established to estimate the impact of beekeeping participation, once observed and unobserved household characteristics that may correlate with both beekeeping participation and income have been controlled for. Secondly, the extent to which beekeeping contributes directly to household income can be accounted for, as can its indirect benefits due to pollination and returns from productive investment in agricultural inputs such as fertilizers. Previous studies underestimated the impact of beekeeping not only because they did not account for such indirect benefits, but also because they did not control for unobserved differences among households. This highlights the importance of selecting appropriate estimation methods to avoid underestimating benefits. Thirdly, this research provides the first rigorous estimate of beekeeping's impact in the study areas. These findings could go some way towards meeting the growing demand by local governments for quantitative evidence on the benefits of beekeeping (and other natural resources such as wetlands) to make informed decisions and increase investment in targeted areas (Asmare et al., 2022).

The rest of the paper is structured as follows: Section 2 briefly describes the status of beekeeping in Ethiopia as well as the policy context, while Section 3 identifies the materials and methods employed in the study. Section 4 presents the results. Section 5 discusses the implications of the study findings and compares them with those of previous studies.

2. The state of beekeeping in Ethiopia and its policy context

Agriculture accounts for nearly 40% of Ethiopia's gross domestic product (GDP), employs 80% of the labour force, generates 90% of export earnings, and accounts for 30% of government tax revenue (NPC, 2016). The livestock sector contributes up to 20% to Ethiopia's GDP, while it offers a livelihood to 60–70% of the population (MOI, 2016). In respect of the country's agricultural GDP, beekeeping contributes 1.3% (Akessa, 2016). On average, beekeepers in Ethiopia produces 48,712 tonnes of honey and owns 5.89 million managed bee colonies (CSA, 2020). The country ranks first in honeybee colonies in Africa, fourth in beeswax production in the world, and tenth in honey production in the world (Girma and Gardebroek, 2015; Rivera et al., 2007). The beekeeping value chain creates jobs for nearly 2 million people in Ethiopia (Drost and Van Wijk, 2011). Beekeeping also offers substantial opportunities for many landless farmers – which includes many women and young people – to improve their livelihoods. The beekeeping sub-sector has therefore attracted both government and development partners' attention (NPC, 2016). Over the past eight years, for instance, the Mastercard Foundation has invested millions of dollars in the sub-sector to create jobs for around 70,000 unemployed young people (MF, 2020).

Beekeeping's potential to generate employment, increase foreign exchange earnings and sustain livelihoods is widely recognised. However, beekeeping is significantly affected by honeybee colony losses due to diseases and pests, the indiscriminate application of agrochemicals for crop protection, and poor-quality beekeeping products (Akessa, 2016; EIAR, 2017; Ejigu et al., 2009; Girma and Gardebroek, 2015; Gratzer et al., 2021; MOA-ILRI, 2013; Pirk et al., 2016; Tassew et al., 2018). These problems contribute to the sub-sector's low productivity, which is associated with the low adoption of modern beekeeping practices and technologies (CSA, 2020). To address the sub-sector's challenges, the Ethiopian Government introduced a Beekeeping Policy (FDRE, 2009). Although the Policy acknowledges the sub-sector's constraints, it obliges the sustainable management of apiculture resources. The aim was to ensure beekeeping could continue to contribute to the country's aspirations for economic development by reducing food insecurity and poverty. After the Policy's introduction, many companies emerged along the beekeeping value chain, including traders, beekeeping equipment producers, and honey and beeswax processors (Girma and Gardebroek, 2015).

3. Materials and methods

3.1. Study context and survey design

This study was conducted in the Amhara Region. Amhara contributes 23% to Ethiopia's total honey production and maintains about the same proportion of the country's total occupied beehives (CSA, 2020). Many farmers practise beekeeping as a supplementary income-generating activity. On average, beekeepers earn about USD 353 per year from selling honey (Ejigu et al., 2009). However, productivity remains small compared with the potential yield, which is about 40 kg per hive per year for transitional hives and about 60 kg for modern frame hives (Sebeho, 2015). Estimates show that beehive productivity is about 8 kg/colony/year in Amhara (CSA, 2020). Productivity is low partly because beekeeping is dominated by traditional low-input and -output practices: fewer than 5% of beekeepers own modern beehives (CSA, 2020).

Data were collected in the Amhara Region from 12 villages in the North Mecha (West Gojjam Zone), Machakel (East Gojjam Zone) and Dangila and Ankesha Districts (Awi Zone). These three Zones make up around 25% of Amhara's honey production and 41% of its beehives (CSA, 2020). The survey, conducted in 2018, constituted one-on-one interviews using a structured survey questionnaire administered by well-trained and experienced enumerators who spoke the local official language, Amharic. The survey covered a wide range of household- and village-level variables that influence beekeeping participation and income.

The study households were selected using a multi-stage sampling technique. The first stage involved selecting four districts with a high potential for beekeeping. Three villages from each district were then randomly selected, while the final stage entailed listing all beekeeper and non-beekeeper households in each selected village. This list of households served as a sampling frame from which a final 392 households were randomly selected for interviews. Of this final selection, 56% were beekeepers and 44% were not.

The study received ethical clearance from the Research Ethics Review Committee of *icipe*. Interviewed farmers were provided with sufficient information about the purpose of the research, which allowed them to make informed and independent decisions about their participation in the survey. Each respondent's oral consent was obtained before the interview started. This type of socio-economic research does not require formal ethics approval in Ethiopia.

3.2. Conceptual framework and estimation strategy

Participation in beekeeping might not be random: being a beekeeper could be influenced by observed as well as unobserved characteristics. For instance, beekeepers might be experienced and may even be wealthy. Such self-selection needs to be addressed when quantifying beekeeping's impact on income. The most widely used impact evaluation tools in non-experimental studies include using propensity score matching (PSM), instrumental variables (IVs), and endogenous switching regression (ESR) techniques. PSM assumes that, after controlling for observable characteristics, the choice of beekeeping as a livelihood strategy is random and uncorrelated with household income. PSM's key criticism is that systematic income differences between beekeepers and non-beekeepers may persist even after controlling for observed characteristics because there may be unobserved heterogeneity (Smith and Todd, 2005). An alternative, therefore, would be to employ the IV estimator. However, this estimator ignores the treatment variable's interaction with other explanatory variables. The explanatory variables' coefficients for beekeepers and non-beekeepers might differ (Di Falco et al., 2011; Kassie et al., 2018). Another alternative is the ESR model (Di Falco et al., 2011; Kassie et al., 2018; Lokshin and Sajaia, 2004). The ESR model relaxes the IV estimator's assumption by estimating separate regression models for beekeepers and non-beekeepers. In this way, each variable has a different coefficient for each respective group. Unlike PSM, the ESR model accounts for potential unobserved heterogeneity that might lead to estimation bias – not only through the non-linearity of the selection model, but also by using exclusion restrictions. Exclusion restrictions serve as IVs that affect the decision to participate in beekeeping, but such exclusion restrictions do not affect the outcome variable, namely, household income (Di Falco et al., 2011). Application of the ESR and the estimation of the various treatment effects is discussed in the next two sub-sections.

3.3. The ESR model

The current research was motivated by McFadden's random utility theory. This theory suggests that a rational person chooses something (here, to participate in beekeeping) if the choice provides the highest utility (benefit) among alternative choices (McFadden, 1974). The model denotes the benefits of participating in beekeeping by U_1 while the benefits of households that did not participate in beekeeping are denoted by U_0. Farmers will choose to participate in beekeeping if the benefit of participation is positive ($A_i^* = U_1 - U_0 > 0$). Assume A^* is a latent variable that captures the expected benefits to beekeepers and non-beekeepers (Di Falco et al., 2011). The latent variable is specified for each household i in Eq. (1) as follows:

$$A^*_i = \boldsymbol{Z}_i\alpha + \eta_i \quad \text{with } A_i = \begin{cases} 1 \; if \; A^*_i > 0 \\ 0 \; otherwise, \end{cases} \tag{1}$$

where $\boldsymbol{Z}$ represents vectors of variables that affect the decision to participate in beekeeping; η_i represents the error term; and household i chooses beekeeping ($A_i = 1$) if it experiences a positive benefit from it ($A_i^* > 0$).

In the second stage, the income of beekeepers and non-beekeepers are estimated separately. Eqs. (2) and (3) define these two ESR regimes:

$$\text{Regime } 1: Y_{1i} = \beta_1 \boldsymbol{X}_{1i} + \sigma_1 \widehat{\lambda}_{1i} + \varepsilon_{1i}, \; A_i = 1 \tag{2}$$

$$\text{Regime } 2: Y_{0i} = \beta_0 \boldsymbol{X}_{0i} + \sigma_0 \widehat{\lambda}_{0i} + \varepsilon_{0i}, \; A_i = 0, \tag{3}$$

where Y_{1i} and Y_{0i} are the income of household i; $\boldsymbol{X}$ is a vector of explanatory variables; $\widehat{\lambda}$ is the estimated inverse Mills' ratio obtained from Eq. (1); ε_{1i} and ε_{0i} are vectors of error terms with expected values of zero; and β_1 and β_0 are a vector of unknown parameters to be estimated.

In Eqs. (1), (2), and (3), the explanatory variables ($\boldsymbol{Z}$ and $\boldsymbol{X}$) were chosen based on insights from economic theory and previous studies on income determinants (Affognon et al., 2015; Alemu et al., 2016; Andaregie and Astatkie, 2021; Kassie et al., 2011; Schouten, 2020; Schouten et al., 2020). In addition to the non-linearity of the selection model of beekeeping participation (the inverse Mills' ratio), exclusion restrictions that serve as instruments in Eqs. (2) and (3) were used. Thus, the household's social network was used as an exclusion restriction. The *Social network* variable is a dummy variable that has a value of 1 if the household knows of friends and/or neighbours who have modern beehives, and 0 if not. Social networks are key in technology adoption because they facilitate the exchange of information and reduce the cost of accessing such information (Bandiera and Rasul, 2006; Di Falco and Bulte, 2013; Isham, 2002). Farmers who know of friends and/or neighbours who practise modern beekeeping are more likely to be beekeepers themselves, which affects the decision to be a beekeeper or not. Therefore, the *Social network* variable can capture inherent unobserved differences in the production potential and profitability of beekeeping.

3.4. Estimating the average treatment effects of participating in beekeeping

This-subsection shows how to estimate the actual and counterfactual outcomes of beekeeping participation are estimated, following the empirical and theoretical literature on impact evaluation (Carter and Milon, 2005; Di Falco et al., 2011; Heckman and Vytlacil, 2001). From Eqs. (2) and (3), conditional expectations can be computed by using Eqs. (4), (5), (6), and (7), as follows:

$$E(Y_{1i}|A_i = 1) = \boldsymbol{X}_{1i}\beta_1 + \sigma_1\widehat{\lambda}_{1i} \tag{4}$$

$$E(Y_{0i}|A_i = 0) = \boldsymbol{X}_{0i}\beta_0 + \sigma_0\widehat{\lambda}_{0i} \tag{5}$$

$$E(Y_{0i}|A_i = 1) = \boldsymbol{X}_{1i}\beta_0 + \sigma_0\widehat{\lambda}_{1i} \tag{6}$$

$$E(Y_{1i}|A_i = 0) = \boldsymbol{X}_{0i}\beta_1 + \sigma_1\widehat{\lambda}_{0i} \tag{7}$$

Eqs. (4) and (5) represent the actual expected household income observed in the sample, while Eqs. (6) and (7) signify the counterfactual expected household income. E signifies the expectation operator in the four equations.

Table 1 summarises the expected outcomes and the treatment effects. The treatment effect on the treated (***TT***), which estimates the impact of beekeeping participation on income for households that practise beekeeping, is the difference between Eqs. (4) and (6), namely –

Table 1. Outline of the expected outcomes and treatment effects of participation in beekeeping.

Sub-sample	Expected outcomes and decision stage		Treatment effects
	Beekeepers	Non-beekeepers	
Beekeepers	(a) $(Y_{1i}\|A_i = 1)$	(c) $E(Y_{0i}\|A_i = 1)$	Treated households (***TT***)
Non-beekeepers	(d) $E(Y_{1i}\|A_i = 0)$	(b) $E(Y_{0i}\|A_i = 0)$	Untreated households (***TU***)

Note: ***TT*** = Cell (a) minus cell (c). ***TU*** = Cell (d) minus cell (b).

Table 2. Definition of variables and summary statistics.

Variables	Beekeepers		Non-beekeepers		
	Mean (A)	Standard deviations	Mean (B)	Standard deviations	Difference (A – B)
Household income (ETB/person)	7,433	5,261	4,736	4,002	2,697***
Household size (number)	5.67	1.81	5.08	1.89	0.59***
Value of household assets (ETB)	6,345	6,948	2,625	4,073	3,720***
Livestock ownership (TLU)[a]	4.74	2.51	3.07	1.92	1.67***
Cell phone ownership (1/0)	0.58	0.49	0.46	0.50	0.122**
Residence location altitude (metres above sea level)	2,145	101	2,121	87	25**
Age of household head (years)	48.01	11.83	46.44	13.13	1.57
Household head reads and writes (1/0)	0.57	0.50	0.43	0.50	0.14***
Household head received beekeeping training (1/0)	0.16	0.37	0.05	0.22	0.11***
Household head has marketable skills (e.g. carpentry) (1/0)[b]	0.07	0.25	0.10	0.30	-0.032
Household head has access to market information (1/0)	0.45	0.50	0.51	0.50	-0.056
Household head is aware of bees' benefits to pollination (1/0)[c]	0.55	0.50	0.53	0.50	0.021
Household head knows of friends and/or neighbours practising beekeeping (1/0)	0.49	0.50	0.15	0.36	0.337***
Machakel (1/0)	0.29	0.46	0.08	0.27	
North Mecha (1/0)	0.17	0.38	0.39	0.49	
Dangila (1/0)	0.27	0.45	0.26	0.44	
Ankesha (1/0)	0.26	0.44	0.27	0.45	

[a] TLU = tropical livestock unit.
[b] *Marketable* skills are defined as those that the head of the household can use to earn additional income other than beekeeping or crop production (e.g. carpentry).
[c] The farmers were asked to answer *Yes/No* regarding whether they were aware of bees' benefits to pollination.

$$\boldsymbol{TT} = E(Y_{1i}|A_i = 1) - E(Y_{0i}|A_i = 1) = \boldsymbol{X}_{1i}(\beta_1 - \beta_0) + (\sigma_{1\eta} - \sigma_{0\eta})\lambda_{1i}, \quad (8)$$

Similarly, the treatment effect on the untreated (***TU***), which shows the impact of beekeeping participation for the households that did not practise beekeeping had they decided to be beekeepers, is the difference between Eqs. (7) and (5):

$$\boldsymbol{TU} = E(Y_{1i}|A_i = 0) - E(Y_{0i}|A_i = 0) = \boldsymbol{X}_{2i}(\beta_1 - \beta_0) + (\sigma_{1\eta} - \sigma_{0\eta})\lambda_{0i} \quad (9)$$

4. Results

4.1. Descriptive results

Table 2 offers a definition and summary statistics of the dependent and independent variables in this study. The average annual income per person was about ETB 7,433 in the sample households who participated in beekeeping, and about ETB 4,736 for non-beekeepers. This implies that beekeepers earn about ETB 2,697 per capita more than non-beekeepers. As the standard deviations in Table 2 indicate, the income of both beekeepers and non-beekeepers is highly variable. Even though beekeeping's direct contribution to overall income is relatively small (about 4% on average), farmers who practise beekeeping have a higher per-capita income than non-beekeepers throughout the income distribution (Figure 1). It seems that the differences observed in key household characteristics explain the differences in per-capita income obtained from various farming and non-farming activities. Beekeepers also have more household assets and livestock than their non-beekeeping counterparts. Furthermore, beekeepers are more likely than non-beekeepers to be literate and to own cell phones – both of which are important for accessing and analysing information. Cell phone ownership is also an indicator of wealth. Table 2 further shows that,

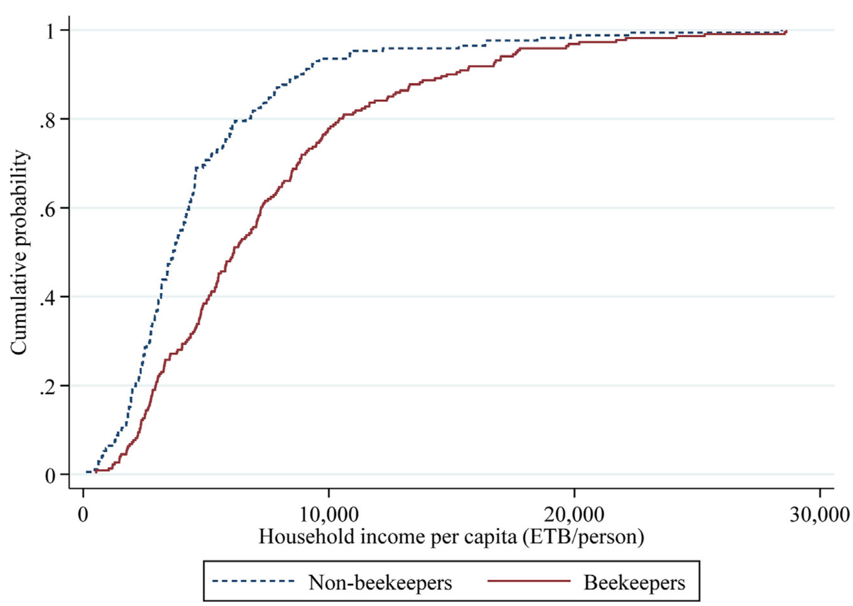

Figure 1. Cumulative distribution of income per person, by beekeeping status.

Table 3. Estimated parameters.

Explanatory variables	ESR model		
	First stage	Second stage (Income per person, log)[a]	
	Beekeepers (1/0)	Beekeepers	Non-beekeepers
	(1)	(2)	(3)
Household knows friends and/or neighbours practising beekeeping (1/0) (*Social network* variable)	0.811***		
	(0.171)		
Household characteristics			
Household size (log)	0.041	-0.663***	-0.740***
	(0.212)	(0.108)	(0.129)
Value of household assets (ETB) (log)	0.448***	0.288***	0.092**
	(0.085)	(0.052)	(0.038)
Livestock ownership (TLU) (log) [b]	0.223*	0.151***	0.058
	(0.127)	(0.056)	(0.052)
Cell phone ownership (1/0)[c]	-0.144	0.125	0.098
	(0.171)	(0.081)	(0.099)
Residence location altitude (metres above sea level, log)	3.516	-0.020	-3.546**
	(2.616)	(0.862)	(1.607)
Characteristics of the household head			
Age of household head (years) (log)	0.342	-0.091	-0.025
	(0.282)	(0.159)	(0.159)
Household head reads and writes (1/0)	0.096	0.021	0.096
	(0.164)	(0.077)	(0.107)
Household head received beekeeping training (1/0)	0.328	-0.124	-0.062
	(0.286)	(0.104)	(0.201)
Household head has marketable skills (1/0)	-0.291	-0.287	-0.453**
	(0.320)	(0.214)	(0.214)
Household head has access to market information (1/0) [c]	-0.152	0.028	-0.047
	(0.170)	(0.079)	(0.109)
Household head is aware of bees' benefits to pollination (1/0)	0.222	0.038	0.011
	(0.152)	(0.070)	(0.099)
North Mecha District (1/0) [d]	-0.586***	-0.383***	-1.112***
	(0.219)	(0.134)	(0.279)
Dangila District (1/0)	-0.582***	-0.411***	-0.620**
	(0.215)	(0.100)	(0.277)
Ankesha District (1/0)	-0.594***	-0.487***	-0.550**
	-0.586***	-0.383***	-1.112***
Constant	-31.524	7.936	36.170***
	(20.124)	(6.733)	(12.319)
Model statistics			
σ_i		0.517***	0.662***
		(0.028)	(0.076)
ρ_i		-0.128	-0.725***
		(0.209)	(0.258)
Likelihood-ratio test (χ^2)		8.85**	
Number of observations	392	392	392

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Robust standard errors in parentheses. The models in columns (1) to (3) were estimated using full information maximum likelihood. The unit of analysis is *Household.*

[a] The exchange rate was 26.1 ETB/USD in 2018.

[b] TLU = tropical livestock unit.

[c] *Cell phone ownership* and *Access to market information* variables were entered after empirically testing for the absence of multicollinearity. The variance inflation factor (VIF) was lower than 10 and the tolerance level (1/VIF) was above 0.1, confirming that multicollinearity was not a specification problem in the current data context.

[d] The comparison group for the district fixed effects was Machakel.

in terms of having received training in beekeeping, 11 percentage points more beekeepers than non-beekeepers. However, both groups of households have a similar level of marketable skills, and they had equal access to market information. In respect of being aware of the benefits of beekeeping for pollination, no noticeable differences were found between the two household groups.

4.2. Econometric results

Table 3 presents the estimated parameters of the ESR model. Column (1) shows the selection model in Eq. (1). The results show that the propensity to be beekeepers depends on the *Social network* variable used as an exclusion restriction. This result indicates that the *Social network* variable has picked up inherent differences in beekeeping choice which stem from unobserved factors that might affect both household income and participation in beekeeping. Thus, the coefficient indicates that farmers in a social network with a high adoption of modern beehives are more likely to be beekeepers themselves. Furthermore, the coefficients of assets and livestock ownership reveal that richer households seem to have a greater propensity to be beekeepers. The district fixed effects indicate that there might be geographical factors that influence the probability of participating in beekeeping.

Columns (2) and (3) in Table 3 report the ESR models in Eqs. (2) and (3). The likelihood-ratio test for joint independence indicates that a restricted specification with a single dummy variable using the ordinary least squares is rejected. Furthermore, the coefficients in columns (2) and (3) show heterogeneities among beekeepers and non-beekeepers. For instance, the coefficients of the value of household assets and livestock ownership for beekeepers are much higher than those for non-beekeepers.

4.3. Average treatment effects

Based on Eqs. (8) and (9), Table 4 shows the average treatment effects on beekeepers and non-beekeepers. The last column of Table 4 shows the estimated impact on beekeepers (***TT***) and non-beekeepers (***TU***), netted out observed and unobserved heterogeneities that may affect not only beekeeping participation but also household income. The average treatment effect on the treated households is about ETB 3,418. Table 4 further shows that non-beekeepers would have earned ETB 442 (11%) more per person than what they currently derive, had they decided to be beekeepers.

The econometric results reported in Table 4 capture both the direct and indirect impacts of beekeeping, which shows the potential of scaling beekeeping and supporting the sub-sector with new technologies and investment. Showing the pathways through which beekeeping increases income is beyond the scope of this study due to data limitations. Nonetheless, our data show two potential pathways. The first is that farmers may use beekeeping income to purchase productive inputs such as fertilisers. In the second pathway, beekeeping may benefit farming communities through pollination services. Figure 2 corroborates these potential pathways. Panel A of Figure 2 shows the cumulative distributions of fertiliser use between beekeepers and non-beekeepers. Figure 2 also reveals that investment in chemical fertilisers is much higher for beekeepers than that for non-beekeepers. Panel B of Figure 2 shows the value of pollinator-dependent crops by beekeeping status. The cumulative distribution illustrated in the figure shows that pollinator-dependent crop production for beekeepers is much higher than that for non-beekeepers.

5. Discussion and policy implications

The study used an ESR micro-econometric method to quantify the impact of beekeeping participation on household income in north-western Ethiopia. Income from participating in beekeeping is an important policy variable in designing strategies to improve the sub-sector's performance.

Table 4. Impact of participation in beekeeping on household income (ETB/person).

Sub-sample	Decision stage		Participation effects
	Beekeepers	Non-beekeepers	
Beekeepers	(a) 6,653	(c) 3,235	***TT*** = 3,418***
	(241)	(126)	(272)
Non-beekeepers	(d) 4,543	(b) 4,101	***TU*** = 442*
	(192)	(187)	(268)

Notes: Standard errors in parentheses. Treated households (***TT***) = Cell (a) minus cell (c). Untreated households (***TU***) = Cell (d) minus cell (b); ***p < 0.01; *p < 0.10.

For the first time, to the authors' knowledge, the contribution of beekeeping to rural income has been quantified. This was accomplished using a rigorous, non-experimental estimation approach that controlled for observed and unobserved factors that could jointly determine participation in beekeeping and changes in income. Thus, the study accounted for both the direct contribution that beekeeping makes to income as well as its indirect contribution, namely through pollination and additional investment in productive inputs.

The analysis produced three key findings. Firstly, significant differences were found in the observed household characteristics of beekeepers and non-beekeepers. Thus, the variables associated with resource endowments that could be used for additional investment, such as assets and access to training, were lower for non-beekeepers. These resource endowment and skill gaps could be exacerbated not only by the increased use of pesticides for crop protection – killing bees at the same time (Egan et al., 2020; Fikadu, 2020; Goulson et al., 2015; Gratzer et al., 2021; Lundin et al., 2021), but also by deforestation and the effects of climate change, which reduce forage for bees (Bradbear, 2009; Goulson et al., 2015). The promotion of sustainable beekeeping is needed to address these emerging problems as well as contribute, in turn, to achieving the sustainable development goals (Patel et al., 2021). A key entry point could be enforcing the current Beekeeping Policy, which already acknowledges the constraints of the beekeeping sub-sector (FDRE, 2009). Providing skills and entrepreneurship training could also help to close skill and resource endowment gaps.

Secondly, the results suggest that beekeeping is not a desperate economic activity by the poor for their survival. Beekeeping is an active sub-sector with great direct and indirect economic potential to contribute to rural livelihoods. For example, the income gains appear to be substantially larger than previous studies have estimated. In one by Amulen et al. (2019), beekeeping was found to contribute 7% of the total income in selected villages in Uganda, while a review of the literature in developing countries by Schouten (2020) found that income from beekeeping amounted to about 29% of annual cash earnings. However, these estimates did not consider the indirect benefits of beekeeping, such as increasing investment in agricultural inputs and pollination services. When these latter benefits were quantified in the current study, the gains from participation in beekeeping were found to be 22–44 percentage points greater than in the earlier studies (Amulen et al., 2019; Schouten, 2020). There is now sufficient evidence, therefore, to accept the research hypothesis that participation in beekeeping can bring about a significant economic impact on beekeepers' income. The previous studies underestimated the impact of beekeeping participation because they did not control for indirect benefits or observed and unobserved factors that might affect both participation and income. This gap underlines the importance of methodological rigour to avoid benefits from being underestimated.

Thirdly, the cumulative distributions of fertiliser use and the value of pollinator-dependent crops both demonstrate that the most likely pathways by means of which beekeeping benefits farmers are through investment in inputs and pollination services. This study's observations from the cumulative distributions is in line with those of previous studies on the pollination benefits of beekeeping in Ethiopia (Alebachew, 2018) and elsewhere (Baylis et al., 2021; Gallaia et al., 2009; Hung et al., 2018; Kasina et al., 2009; Klatt et al., 2013). A key caveat in the current study, however, is that, due to data limitations, it was not possible to do a full-fledged analysis to show the potential pathways (such as pollination services or using beekeeping income to invest in additional productive inputs) through which beekeeping benefits farming households. Future studies that may estimate beekeeping's impact may need a representative sample of pollinator-dependent and -independent crops as well as of bee colonies across production landscapes. Another caveat to the current study is that it did not uncover beekeeping's effect on crop quality. Therefore, future studies could focus on the benefits of beekeeping that relate to improving crop quality and human nutrition, diversifying

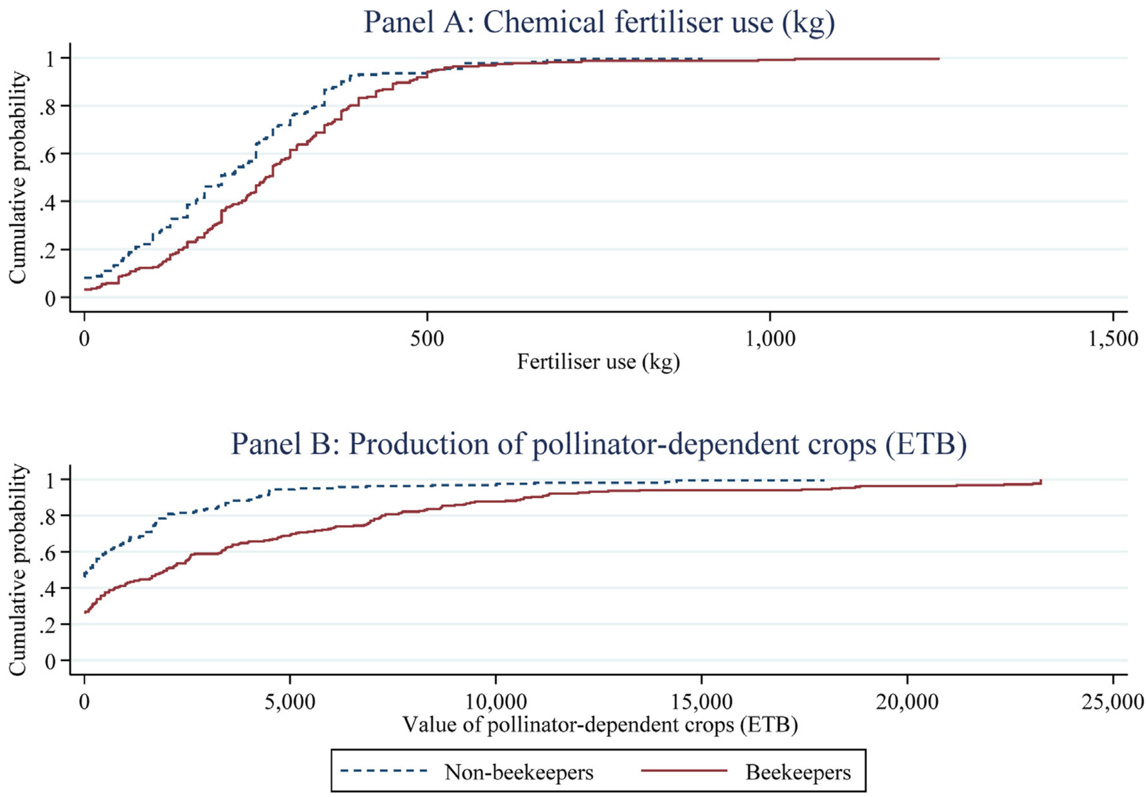

Figure 2. Use of chemical fertilisers and production of pollinator-dependent crops, by beekeeping status.

sources of income, and relaxing the credit constraints faced by smallholder farmers.

Declarations

Author contribution statement

Zewdu Abro: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Menale Kassie; Haymanot Alebel Tiku: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bedaso Taye; Workneh Ayalew: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Zemen Ayalew Ayele: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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