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Road accessibility and agricultural extension services in Malawi

Han Bum Lee[1*], Paul E. McNamara[2] and Hitomi Ho[3]

Abstract

Background In recognition of the potential importance of road access in the provision of and request for agricultural extension services, this study investigates whether and to what extent access to paved roads would influence farmers' access to extension services, using a nationally representative sample of households and communities in Malawi. Our study proposes an extension access measure that reflects the diversity of agricultural topics and extension service providers available in the village where farmers resided, which commonly is captured in a binary fashion of "contact" with extension agents.

Method The level of extension access is measured in the form of count data, and we employ a hurdle negative binomial regression model to account for unobserved farmer heterogeneity and excessive zeros that represent a group of farmers who received no extension services due to a lack of supply of extension opportunities in the village or a lack of demand.

Results We find a negative and non-linear relationship between access to paved roads and extension services, showing that, on average, the extent of access to extension services decreased by 14.1 percent as a farmer's residence was one log of distance away from the nearest paved road. Women farmers had considerably lower extension access scores by 24.3 percent than men, indicating the prevalence of the country's deeply rooted cultural and gender barriers. Furthermore, serving as lead farmers, human capital and economic characteristics, and extension resources available in the village—such as the number of extension agents and demonstration and farm trials—are identified as factors having a sizable contribution to determining the extent of extension access.

Conclusion Our study findings will provide empirical evidence that answers questions raised by past studies concerning the relationship among roads, agricultural extension, productivity, and other economic outcomes. Also, it will inform future research about the access to agricultural extension and agricultural development nexus.

Keywords Access to agricultural extension services, Rural road infrastructure, Hurdle negative binomial regression, Malawi

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Introduction

Malawi is a landlocked country with an economy driven predominantly by the agriculture sector, which accounted for 23 percent of the gross domestic product (GDP) and employed 76.4 percent of national employment in 2019 [81]. In Sub-Saharan Africa, only two and sixteen countries had a higher share of agriculture in employment and GDP, respectively, than did Malawi during the same period [81]. Therefore, it is critical to sustainably increase agricultural productivity to induce the country's economic development and reduce food insecurity and poverty.

Malawi experienced a significant decrease in economic growth from 5.7% in 2014 to 2.8% in 2015 [70]. The agriculture sector even recorded a negative growth rate of 2 percent. This low rate was largely the result of adverse weather conditions. Floods in southern regions followed by a countrywide drought contracted agricultural production over the 2014/15 growing season. As a result, one-third of maize production shrank, resulting in 2.8 million food-insecure people [70]. In fact, vulnerability to climate change has been criticized as a country's prolonged problem over the past several decades. Studies claimed that Malawi tended to lose a higher volume of crop yields from natural shocks relative to other Sub-Saharan African countries, and the extent to which those shocks impacted Malawi's agricultural production was mainly due to the lack or low adoption of risk management practices and technologies [e.g., 33, 37, 45, 46].

Agricultural extension and advisory services (hereafter referred to simply as agricultural extension services) are one of the most important areas in addressing the underlying challenges of achieving Malawi's agricultural development goals [64]. Traditionally, agricultural extension focuses on four broad objects: (i) disseminating new technologies and agronomic practices around the national staple food crops; (ii) increasing farm incomes through high-value crop production, especially for small-scale, landless, and indigenous farmers; (iii) empowering farmers by building social capital within the community; and (iv) strengthening farmers' capacity to use sustainable natural resource management practices [47, 77]. The promise of agricultural extension has been well documented in the literature [e.g., 3, 5, 9, 14, 16, 55, 65]. However, cautionary examples of poorly performing extension services exist as well, and a recent survey of returns to agricultural research (including extension) reported high rates of return (internal rate of return) with very wide variance for the return to investment into agricultural extension in Sub-Saharan Africa [57].

The government of Malawi has made significant strides in reforming extension policies in the country's history to achieve the aforementioned objectives of extension [30, 39]. The current system, launched by the government in 2000, is one of the most progressive agricultural extension strategies, in which multiple actors (extension service providers) are engaged in delivering accountability and responsiveness to smallholder farmers. Currently, in Malawi, there exist more than 120 agriculture-related organizations and programs that prioritize the delivery of extension services [61]. With the accompanying efforts of the government and multilateral organizations, access to extension services has been substantially increased. According to National Statistical Office (NSO), in 2005, only 13% of Malawi's farm households received advice from extension agents on crop production and input management [54]. On the other hand, more recent statistics, conducted by the International Food Policy Research Institute (IFPRI), presented that half of the farm households received some agriculture- and nutrition-related advice in the past 12 months (2015/16 cropping season). This figure was higher than in many other African countries [66]. However, despite increased access to extension access, agricultural productivity has been stagnating, and more than half of Malawians suffered from poverty in 2017 [61]. One-third of children under five were stunted, and 6.7 million people were in need of food assistance [61]. These increasingly built pressure to revisit the strategy and operation of the current agricultural extension system.

One of the major constraints facing the country's extension system is a few extension requests. About one in ten farmers who received advice requested additional extension services [61]. Dinar [19] and Frisvold et al. [27] asserted that the provision of and request for extension services are simultaneously determined; hence, farmers' lack of interest in requesting additional advice would reduce the corresponding supply of extension services, ending up with a lower equilibrium to which the demand and supply of extension services are converged. In considering that eight in ten farmers reported being "very satisfied" with extension services they received, and nine in ten said "the advice was something they wanted or needed" [66], the quality of advice might not be the main reason, causing this low request for extension services.

Another reason for this may relate to the development of infrastructure [e.g., 2, 16, 36, 72]. For example, poor road infrastructure may limit extension agents' ability to visit farmers, especially in remote rural villages. Specifically, traveling to—geographically hard to reach—villages would incur high transportation costs, thereby reducing the frequency of agents' visits to those villages. Farmers who live in hard-to-reach villages may not make further extension requests if they anticipate not receiving the services when needed (some crop practices and technologies are time-sensitive). In contrast, better access to roads would not only reduce agents' burden of transportation costs but also enhance farmers' access to markets—enabling them to lower various transaction costs associated with acquiring farm inputs (e.g., chemical fertilizer and hybrid seeds), hiring labors, and selling agricultural products—which in turn increase farmers' demands and adoption capabilities of agricultural technologies recommended by extension agents. Moreover, areas with a higher expected rate of return are likely to be prioritized for the investment in road infrastructure, while the rest areas, especially in remote rural villages, suffer from none or limited access to markets and public extension resources [9, 16]. This implies that those half farmers who reported no access to extension services—during the 2015/16 crop season—would include those who needed but could not receive the services due to no extension opportunity within the village.

On realizing the importance of road access in the dynamics of the supply and demand of extension services, this study investigates whether and to what extent access to paved roads would influence farmers' access to extension services, using a nationally represented sample of households and communities in Malawi. Our study proposes an extension access measure that reflects the diversity of agricultural topics and extension service providers available in the village where farmers resided, which is usually captured in a binary fashion of "contact" with extension agents. In specific, we construct an index based on nine different agricultural topics and nine modes of face-to-face and group-based extension services that farmers had experienced in the past 12 months. The level of extension access is measured in the form of count data, and we employ a hurdle negative binomial regression model to account for unobserved farmer heterogeneity and excessive zeros, representing a group of farmers who received no extension services due to the lack of extension opportunity in the village (details on the construction of the extension services index are provided in the section "Measurement of access to agricultural extension services").

The results indicate a significant and non-linear relationship between access to paved roads and extension services, showing that the extent of access to extension services decreased (by 14.1 percent) as a farmer's residence was one log of distance away from the nearest paved road. That is, a one-percent increase in distance to paved roads was correlated with a reduction in extension access scores of about 0.082%. We also find that women farmers had considerably lower extension access scores by 24.1 percent than men, indicating the prevalence of deeply rooted cultural barriers that reduced women's ability to access extension services. Furthermore, serving as lead farmers, human capital and economic characteristics, and extension resources available in the village—such as the number of extension agents and demonstration and farm trials—are identified as factors having a sizable contribution to determining the extent of extension access.

History of agricultural extension systems in Malawi

The history of Malawi's extension systems underwent three phases: colonial period, one-party rule, and democratic rule. In 1903, the colonial government brought in agricultural extension that distributed free cotton seeds and advised farmers on improved cotton production practices [39]. It then broadened to other export commodities (i.e., tobacco). The colonial-era extension system employed the top-down strategy, a one-way communication, that extension agents provided an array of agricultural information to farmers. Later in the 50 s, the concept of master farmers was incorporated into the mainstream of extension activities. In specific, extension agents offered intensive agricultural training to selected (master) farmers and had these farmers help to disseminate innovative technologies and motivate neighboring farmers to adopt them [39]. However, the master farmer approach was criticized for its selection of progressive farmers along with poor dissemination of improved technologies and information, which resulted in widening the gap in agricultural knowledge and resources between the master farmers and other smallholder farmers [62].

Extension systems after the country's independence shifted to a group approach in the 70 s (during the era of one-party rule), declaring to assist as many smallholder farmers as possible, as opposed to the master farmer approach of the colonial period. In trying to enhance the group approach, the government adopted the block extension system (BES), a modification of the World Bank's Training and Visit (T&V) system, in 1981. However, it did not take long for the Ministry of Agriculture to recognize that BES was only reaching the specialized farmer groups, leaving out the majority of subsistence farmers who were mostly resource-poor and women. In addition, every farmer received almost the same agricultural messages every year regardless of their economic and educational status and regional attributes where they lived [39]. This approach was against what had been recommended: extension services should focus on introducing more efficient farming systems that will increase farm income for different farmers through effectively using household, community, and natural resources [77].

The current agricultural extension policy, built on the principles of pluralistic, decentralized, and demand-driven extension delivery, was launched by the government in 2000. The advent of multiparty politics in 1994 gave ordinary Malawians a voice, and the top-down-based public extension systems began to collapse. Moreover, Malawians have witnessed new players—non-governmental organizations (NGOs) and private sector organizations, research institutes, and universities—joining into agricultural extension services, which were prerogative of the Ministry of Agriculture in the past two phases.

Literature review

In developing countries, eight in ten extremely poor people live in rural villages, and nearly two-thirds of them sustain their livelihoods from agricultural activities [11]. In addition, the growth in the agriculture sector over the others is predicted to be two to four times more effective in raising income among the poorest [11]. Studies have suggested that expanding the rural road network and agricultural extension services can play an essential role in creating an enabling environment that promotes agricultural productivity and poverty reduction.

Dercon et al. [16], utilizing panel data from 15 villages from 1994 to 2004, examined the impacts of public investment in improving access to all-weather roads and agricultural extension services on consumption growth and poverty in Ethiopia. The study found that receiving at least one extension visit reduced headcount poverty by 9.8 percentage points and increased consumption growth by 7.1 percent. Access to all-weather roads was also predicted to reduce poverty by 6.9 percentage points and increase consumption growth by 16.3 percent. Dercon et al. [16] asserted that better access to roads made it easier for farmers to acquire farm inputs and higher input and output prices, while agricultural extension services contributed to farmer's income and consumption through the facilitation of a technology transfer—informing farmers of new agricultural information—and adoption of the best technologies and practices.

More recent studies considered linking road accessibility with the provision of extension services rather than separate mechanisms affecting farmers' agricultural and economic developments. Shamdasani [72] showed that farmers in rural India, by accessing roads through national road-building programs, were more likely to invest in agricultural technologies, diversify crop portfolios, and adopt labor-intensive farm practices. One of the channels the author described as an effect of road accessibility was the increased ability of extension agents to reach farmers by reducing transportation costs of traveling to villages that had previously poor road infrastructure. Similarly, Aggarwal [2] found that, in India, the provision of paved roads, which connected rural villages to the nearby town, increased the adoption of agricultural technologies (i.e., chemical fertilizer and hybrid seeds), primarily explained by the benefits of access to markets and extension services. Although there are a series of studies examining the associative or causal relationships between rural roads and various individual and community-wide benefits [e.g., 35, 38, 74], only a few explained a potential role of agricultural extension in those relationships by granting the linkage between road accessibility and provision of extension services.

Besides access to roads, previous studies have identified a multitude of factors determining the provision and request for extension services. We classify them into six categories, including gender, human capital, resource endowment and non-farm employment, farmer organization, and extension resources within the village.

First, although the modality of extension delivery varies by country, women generally have less access to agricultural extension services [23, 58, 60, 63]. For example, in Malawi, seven percent of female-headed households received advice from extension agents relative to 13 percent of male-headed households [82]. In Ghana, less than two percent of female-headed households and female spouses of male-headed households accessed extension services relative to nearly 12 percent of male-headed households [83]. Similar results were found in Ethiopia though the gender gap in extension access was relatively smaller [83].

Studies highlighted several challenges in reaching women farmers. First, extension agents prefer to work with farmers who can control economic and productive resources and make production-related decisions within the household. This person is most commonly the male in a husband-wife household. Moreover, extension agents believe that delivered information would trickle down from the male household head to all other household members [23]. Therefore, extension agents do not recognize the need to make extension services more accessible for women, even though they are responsible for at least 40 percent of the agricultural labor in six African countries [20, 56]. Besides, many women experience restrictions on physical mobility beyond the family nucleus and interacting with male extension agents, considered a major constraint, limiting women's access to extension services and adoption of agricultural innovations, by which extension agents recommend [23, 40, 48, 60].

Second, human capital refers to the stock of knowledge, skills, and health embodied in people, making labor more productive and trending towards higher wages [7]. Investment in human capital—often through education and health—contributes to agricultural productivity [32, 53]. Specifically, educated and experienced farmers can better evaluate the usefulness of agricultural information received in the past, and this stock of information guides their future demand for extension services [8]. Moreover, extension agents are more likely to choose experienced farmers as contact persons to host agricultural activities such as farmer field days and demonstration plots to disseminate agricultural information to other farmers in their neighborhoods [28].

An equally important form of human capital as education is health and nutrition. People in good health generally have better intellectual capabilities, leading to higher labor productivity and income. On the other hand, undernutrition and diseases can result in reduced work capacity and a loss of days worked [13]. Strauss [75] estimated a Cobb–Douglas agricultural production function for farmers in Sierra Leone and utilized the average calorie intake as a proxy for effective labor. More studies by Deolalikar [15], Strauss and Thomas [76], and Schultz and Tansel [71] affirmed the nutrition-productivity relationship, using nutritional intake, weight-for-height, and other health conditions. Although the linkage between nutrition and access to the agricultural extension has not been explicitly established in the literature, poor health from inadequate nutrition and food intake presumably reduces farmers' capability in requesting extension services, processing information, and utilizing modern technologies.

Third, farmers' wealth—often measured by farm revenues, non-farm income, assets, and farm size—indicates their capacity not only to learn and adopt new agricultural technologies but also to absorb the risk of technology failure [24, 52]. For example, some agricultural technologies (e.g., chemical fertilizer and machinery) accompany high costs of purchasing inputs or hiring laborers if the technology is labor-intensive. Wealthier farmers are better able to afford such costs than resource-poor farmers who face several other needs, competing for already limited financial resources [21, 22]. Similarly, access to credit and the amount can increase farmers' ability to pay for transaction costs associated with undertaking investment in value-addition activities as recommended by extension agents.

In addition, non-farm employment is a reliable source of farm household income. Farmers face various risks in terms of uncertainty in the use of new technologies, agricultural pests and diseases, price volatility, and market failure. Non-farm employment is one of the informal mechanisms making it possible for subsistence farmers to insure against a risky environment and support their livelihoods [18, 69]. On the other hand, as the extent of farmers' engagement in non-farm employment increases, the amount of time they can contribute to farm activities decreases [12].

Fourth, small-scale farmers, by being a member of farmer organizations or cooperatives, can reduce asymmetries in accessing extension services, acquiring farm inputs, and marketing products through achieving economies of scale that are merely realized in a small-family farm setting [26, 43]. In Malawi, the ratio of farmers to government and non-government extension agents was roughly 1568 or 2232 to 1, which was significantly worse than in many other African countries [61]. This low extension agent-to-farmers ratio necessitates extension service providers to favor farmer organizations so as to reach many farmers at once [28].

Farmers' access to extension services is also determined by extension resources available in the village. Frisvold et al. [27] found that more community volunteers increased extension agents' site visits, whereas the number of extension agents in the community was not statically relevant. The types of commodities farmers were engaged in led to heterogeneous site visits of extension agents, plausibly explained by the nature of the crop and growing practices as well as geographic dispersion and remoteness of livestock and crop production. Some of these findings were parallel to Dinar [19] and Ragasa and Comstock [67], indicating the importance of controlling for village-wide extension resources in addition to individual characteristics.

In summary, many existing research that studied various benefits individuals and communities would accrue from the improvement in road accessibility stressed the role of better access to agricultural extension services (through improved road access) as an underlined mechanism to enhance farmers' agricultural knowledge and technology adoption without conclusive evidence. Moreover, as discussed throughout this section, there is a set of variables that were shown or not to be shown as determinants of the demand and supply of agricultural extension services across prior studies. This gap and inconsistency in the literature motivate the current study by answering questions of whether and to what extent access to paved roads and other factors would influence farmers' access to extension services in Malawi. The study findings will provide empirical evidence that answers questions raised by past studies concerning the relationship among roads, agricultural extension, productivity, and other economic outcomes. Also, it will inform future research about the access to agricultural extension and agricultural development nexus.

Dynamics of supply and demand of agricultural extension services

Previous extension literature asserted that the provision of and request for extension services are simultaneously determined [e.g., 19, 27]. We employ the framework of Frisvold et al. [27] to describe the dynamics of supply and demand of agricultural extension services. A farmer i requests extension services based on a cumulative stock of agricultural information provided by extension agents at time t, P_{it}, and other exogenous factors affecting costs and benefits of requesting extension services ($\boldsymbol{X_{it}}$). The demand for extension services, R_{it}, can be written as:

$$R_{it} = R_{it}(P_{it-1}, \boldsymbol{X_{it}}). \tag{1}$$

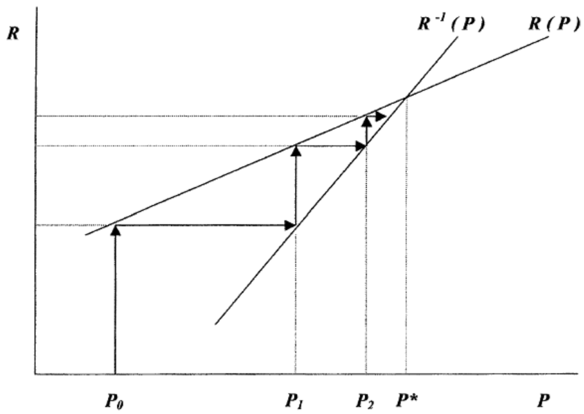

Fig. 1 Dynamics of supply and demand of agricultural extension services. Source: Frisvold et al. [27]

The benefits of requesting extension services depend on agricultural commodities and gross revenue (changes in relative commodity prices and expected yields before and after accessing extension services). Requesting extension services also incurs costs reflecting, but not limited to, farmers' opportunity costs of time, communication costs (e.g., telephone/mobile phone/internet), and transportation costs if one needs to travel to an extension office. In response to farmers' requests over the year, extension agents provide additional information:

$$P_{it} = P_{it}(R_{it}, \boldsymbol{Z_{it}}), \quad (2)$$

where $\boldsymbol{Z_{it}}$ is a vector of exogenous factors reflecting costs or constraints on supplying extension services such as mobility (e.g., access to paved roads, transportation, and fuel allowance), financial capacity, number of extension agents, and training and agricultural knowledge of extension agents. The increased stock of agricultural information through additional extension activities stimulates farmers to make subsequent requests for the services, and then extension agents respond correspondingly. This process is repeated until the cumulative extension demand and supply reach an equilibrium (Fig. 1).

Measurement of access to agricultural extension services

Most previous research measured access to extension services by a binary indicator of "contact" with extension agents, acquaintance with extension agents, or receipt of advice on agricultural production, marketing, or nutrition [59, 64, 68] or the number of extension visits received [9, 19, 21, 28]. However, these measures did not account for the diversity of agricultural topics and extension service providers available in the village where a farm household lived. Learners, in general, have different learning styles. Some of them prefer interacting with an extension agent individually to receive instruction tailored to their own needs, while others may emphasize cooperative learning, built on the belief that they learn better when they learn together. Moreover, extension service providers have a different philosophy of agricultural education and areas of specialty; hence, farmers who receive agricultural advice from diverse extension service providers may have a higher likelihood of understanding the usefulness of the information and utilizing it appropriately than those who receive advice from an agent. This gap in learning would widen when the farmer relies on the agent's advice in areas where the agent has limited knowledge. An equally important component describing access to extension services is the diversity in agricultural information. Specifically, the effect of receipt of extension services for farmers who accumulate knowledge and experience in various areas of agriculture such as production, marketing, and nutrition would be different from those who only receive advice on crop production.

In this research, we attempt to integrate such diversities in agricultural topics and extension service providers—measuring heterogeneous levels of information received through extension services, which would differentiate the effectiveness of extension services. We propose an extension access index based on nine different agricultural topics and nine modes of face-to-face and group-based extension services. Nine agricultural topics include agricultural processing; livestock; aquaculture; marketing/value chain; agro-processing/postharvest; other livelihoods; sustainable land management; environment/climate change; and health/nutrition. Nine extension service providers include government extension worker(s); private sector extension worker(s); NGO; farmer organization or other community-based organizations; lead farmer(s); other farmers, neighbors, or friends; farmer field schools; health workers; and hospital(s) or clinic(s). In our empirical implementation, we measure the level of agricultural extension access by counting the number of agricultural topics covered by different extension service providers in the past 12 months as written as:

$$Access\ Score_{lm} = \sum_{l=1}^{9}\sum_{m=1}^{9} A_{lm}, \quad (3)$$

where A_{lm} represents a binary indicator that equals 1 if a farmer received agricultural extension services from an extension provider (m) on the agricultural topic (l). For example, if a farmer received livestock-related extension services from multiple providers, including government extension worker(s) and lead farmer(s), and health/nutrition information from health worker(s) and clinic(s). The access score of this farmer would then be 4. If a farmer received advice/information on all nine agricultural

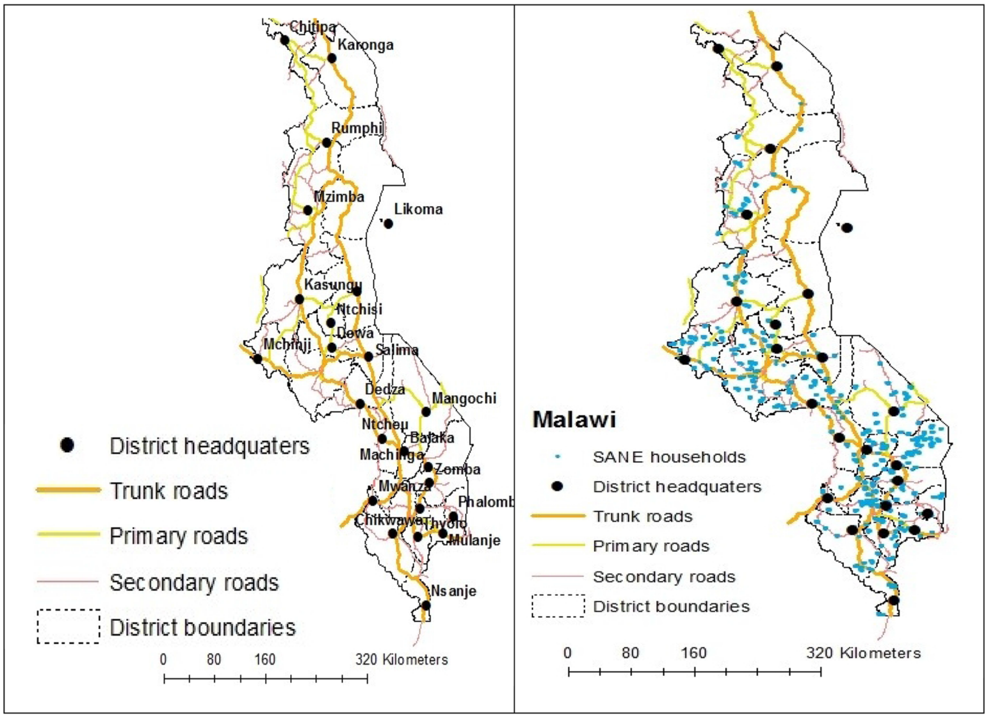

Fig. 2 Geography of roads in Malawi

topics from all nine extension providers, the access score of this farmer would be 81 (9 topics × 9 modes of providers). That being said, the access index ranges from 0 to 81. This index can be perceived as an equilibrium to which the provision of and request for extension services were converged.

Data source

This study used nationally representative household and community survey data collected during the 2016 cropping season (August–October) in Malawi by IFPRI and its partners.[1] The surveys covered 3001 households and 299 sections in 29 districts, excluding Likoma (Fig. 2). The survey used a multi-stage sampling strategy, which entailed multiple stages of random sampling based on the hierarchical structure of clusters within the population. The probability proportional to size (PPS) sampling was used to determine the number of communities and households in each district [51]. More specifically, the survey team randomly selected 299 sections at the first stage, and one community within each selected section was randomly chosen at the second stage. Finally, ten heads of households were interviewed from each selected community. The full list of the sections and households within these sections was generated with the assistance of the Ministry of Agriculture, Irrigation, and Water Development and community leaders. The survey team used tablet computers for the interview to minimize measurement errors and monitor daily data collection.

Empirical strategy

This study measures the level of access to extension services in the form of count data. The Poisson regression model is the most popular method for analyzing count data. The model assumes that the number of events y (access to extension services) for a farmer i follows a Poisson distribution with a conditional mean λ depending on a vector of the observable characteristics x_i as in Eq. (4):

$$Pr\left(y_i|\lambda_i\right) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}, \quad y = 0, 1, 2, \ldots, \tag{4}$$

where $\lambda_i = e^{x_i'\beta}$. The unique feature of the Poisson distribution is the equality of the conditional mean and variance [79]. However, our data revealed overdispersion, meaning that the variance was larger than the mean. For example, the extension access score is an average of 1.5

[1] The IFPRI collected the surveys with financial support from the Government of Flanders and the German agency for international development (GIZ) and survey support from the USAID-funded Strengthening Agricultural and Nutrition Extension (SANE) project led by University of Illinois at Urbana-Champaign.

out of 81, with a variance of 5.13. When overdispersion occurs in the data, the Poisson model understates the standard errors of the estimates, resulting in increased Type I error rates (false-positive results) [34].

Previous studies demonstrated that overdispersion is caused by unobserved heterogeneity and/or excessive zeros in the data. The heterogeneity indicates that each person has a different probability of access to extension services, which can be captured by the observable regressors. However, our study sample appeared to have various levels of access to extension services, making it difficult to capture all relevant characteristics. The negative binomial (NB) model can be used as an alternative to Poisson when omitted factors exist [31]. The NB model introduces an individual unobserved heterogeneity, ε_i, into the conditional mean of the Poisson distribution as in Eq. (5):

$$\widetilde{\lambda}_i = E\left(y_i|x_i\right) = e^{\left(x_i'\beta+\varepsilon_i\right)}, \quad (5)$$

where e^{ε_i} is assumed to be independent of x_i and has a gamma distribution with mean 1 and variance γ. Thereby, the NB distribution has the conditional mean of λ_i and the conditional variance of $\lambda_i(1+\gamma\lambda_i)$. In addition, the variance-mean ratio indicates that as γ approaches zero, y becomes a Poisson distribution, whereas the distribution will be more dispersed as γ becomes larger [73]:

$$\frac{Var(y_i)}{E(y_i)} = 1 + \gamma E\left(y_i\right). \quad (6)$$

The NB model is adequate for tackling the overdispersion problem arising from omitted heterogeneity; however, it does not address overdispersion caused by excess zeros in count data. Specifically, our data show that 48.6% of the study sample reported no access to extension services in the past 12 months (Fig. 3). Possible illustrations of zeros are as follows: social and cultural norms often restrict women from attending agricultural training outside the family nucleus or interacting with male extension agents who predominate in most extension settings. Women affected by cultural norms would then be disadvantaged by inadequate access to agricultural information and training even though the opportunity existed. In addition, if there were none or only a few extension agents assigned in the community, the chance of receiving advice from them might be little or none. Moreover, poor access to roads could limit the ability of extension agents to reach farmers in remote rural areas.

To account for the unobserved heterogeneity and the excess of zeros in our model, we use the hurdle negative binomial logit model (HNBL). The hurdle model, also known as the two-part model, combines a dichotomous model for the binary outcome of the count being below or above the hurdle, with a truncated model for outcomes above the hurdle [79]. In our study context, the hurdle model can distinguish the decisions between participation in extension services (hurdle at zero) and the extent of access to various types of extension services (positive counts).

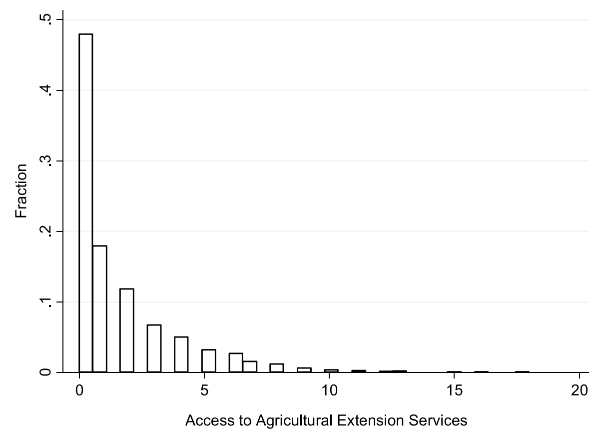

Fig. 3 Distribution of access to extension services scores

The probability distribution of the hurdle-at-zero model is given by:

$$f\left(y_i = 0\right) = f_1(0) \quad (7)$$

$$f\left(y_i \geq 1\right) = \frac{1-f_1(0)}{1-f_2(0)} f_2\left(y_i\right) = \theta f_2\left(y_i\right),$$

where f_1 and f_2 are probability functions of a zero outcome (e.g., logit) and positive integers (e.g., NB), respectively. The numerator of θ indicates the probability of crossing the hurdle and the denominator is a normalization that accounts for the truncation of f_2. Then, the conditional mean of the hurdle model can be written as:$E\left(y_i|x_i\right) = \theta E_2\left(y_i\right)$. If θ exceeds 1 (that is, the probability of crossing the hurdle is greater than the sum of the probabilities of positive outcomes), the mean of the hurdle model is greater than the mean of the standard model, which is NB in our study. On the other hand, if θ is less than 1, the mean of the hurdle model is smaller than the mean obtained from the NB model. The conditional mean of the hurdle negative binomial logit model can be defined as in Eq. (8):

$$E\left(y_i|x\right) = \lambda_i\left[1-(1+\gamma\lambda_i)^{-\frac{1}{\gamma}}\right]^{-1}, \quad (8)$$

where $\lambda_i = e^{\left(x_i'\beta\right)}$. The two-stage decisions of the model are functionally independent, thus achieving maximum likelihood (ML) estimation by separately maximizing the two terms in the likelihood: zeros and positive counts. To implement the hurdle negative binomial logit model, we define a vector of explanatory variables, described in the following section and Table 1, and the same set of explanatory variables is utilized in both stages—participation and intensive margins—of the model.

Our empirical approach has a potential endogeneity problem in the model. More specifically, if the priority of investments in transportation infrastructure and allocation of extension resources were determined, for example, by the expected rate of return of an area, the political importance of an area, or residents' demand for roads and extension services, which were not accounted in the model, the estimated coefficient on access to paved roads can be inaccurately estimated. In addition, some factors could influence both the supply and demand for extension services in the same or opposite direction and, therefore, we conservatively interpret the estimated coefficients as the net association of those factors rather than a causal relationship on extension access.

Determinants of access to agricultural extension services

Studies found that, though the causality of the relationship is uncertain, access to extension services is a function of the farmer's gender [58, 60], human capital [8, 28], production of agricultural commodities [27, 67], economic and productive resources [21, 22, 24], risk preference [25, 44], communication tools [27], mobility and roads [2, 16, 36, 72], and extension resources within the village [19, 27, 67].

After reviewing a number of agricultural extension studies and information available in the dataset, we model access to extension services as a function of seven sets of characteristics: (i) farmer's demographic characteristics, (ii) human capital, (iii) resource and communication tools, (iv) farm characteristics, (v) risk-attitude and farmer organization, (vi) extension resources within the village, and (vii) access to paved roads and market.

Farmer's (head of household) demographic characteristics include age, gender, marital status, religion, and household size. Human capital is measured by years of schooling, years of farming experience, and household dietary diversity score (HDDS). Household resources are captured by household economic resources, cropland size, non-farm employment, and loan access. Communication tools are measured by owning a telephone, cell phone, or internet. Farm characteristics include serving as a lead farmer in the village, and types of agricultural commodities that the farmer produced, including crops of tree, maize, cereal, tuber, ben, groundnut, vegetable, tobacco, and livestock rearing. Risk attitude and farmer organization are captured by whether a farmer was considered risk-averse or not and the number of agricultural organizations the head was a member of. Extension resources within the village include the number of extension agents in the village, the number of agricultural projects implemented in the village over the last 5 years, and the number of demonstration plots and farm trials organized in the village over the last 5 years. Access to paved roads and market are captured by the distance from a farmer's residence to the nearest primary or trunk road, the existence of a market in the village, and the level of difficulty in accessing fertilizer.[2] Lastly, we control for regional characteristics that include USAID's Feed the Future Zone of Influence and regional dummies (i.e., northern, central, and southern regions). Table 1 presents the description and descriptive statistics of the variables used in this study.

Results

Table 2 presents the results of the Poisson and NB models. The results from the Poisson model show that the extent of access to extension services decreased as a farmer's residence was farther away from the nearest paved road. Also, more educated and wealthier farmers and farmers with greater dietary diversity tended to have higher extension access scores, while aged farmers had lower access scores. In addition, lead farmers and farmers who were members of farmer organizations or who owned communication tools were more likely to have higher extension access scores, while women and risk-averse farmers tended to have lower access scores than their counterparts. Furthermore, a set of agricultural commodities, the number of extension agents, demonstration plots, and farm trials were positively associated with extension access scores.

However, the presence of overdispersion and excessive zeros in our data may cause bias in model estimation, leading us to consider the NB and hurdle NB models. The NB model addresses overdispersion by introducing a dispersion parameter (γ) to account for unobserved heterogeneity in the data. Overall, the NB model results are similar to those obtained from the Poisson model, but three variables, including farmers' religion and production of groundnut and vegetable crops, lose their statistical significance. The likelihood ratio (LR) test rejects the null hypothesis, indicating that the overdispersion parameter is greater than zero; thus, the NB model outperforms Poisson. However, the NB model does not address overdispersion arising from excessive zeros.

Table 3 presents the results of the hurdle negative binomial logit model. As previously described, this model

[2] The primary and trunk roads are paved highways that connect district headquarters (Fig. 2).The GPS coordinates collected in the survey enable us to measure the distance from farmer's residence to the nearest paved road.

Table 1 Description and summary statistics of variables ($N = 2441$)

Variable	Description	Mean (Std. Dev.)
Demographic characteristics		
Age	Head of household (HH) age	41.06 (15.81)
Female	1 if a HH is female; 0 if otherwise	0.26 (0.44)
Married	1 if a HH is married; 0 if otherwise	0.79 (0.41)
Muslim	1 if a HH is Muslim; 0 if otherwise	0.19 (0.39)
Household size	Household size	5.13 (2.41)
Human capital		
Years of schooling	HH's years of schooling	5.77 (3.80)
Farming experience	HH's years of farming experience	13.70 (15.62)
HDDS[a]	Household dietary diversity score	4.78 (2.09)
Resource and communication tools		
Household economic resource	The summation of annual household income and the total value of the family's assets	55,615.84 (125,377.60)
Log of household economic resources		9.20 (2.98)
Cropland size	Cropland size	2.46 (2.03)
Log of cropland size		1.12 (0.48)
Loan access	1 if a HH has received a loan; 0 if otherwise	0.16 (0.37)
Non-farm employment	1 if a HH is involved in non-farm employment; 0 if otherwise	0.27 (0.44)
Communication tools	1 if a HH has communication tools (i.e., telephone/mobile phone/internet); 0 if otherwise	0.58 (0.49)
Farm characteristics		
Lead farmer	1 if a HH serves as a lead farmer; 0 if otherwise	0.16 (0.37)
Livestock	1 if a HH rears livestock; 0 if otherwise	0.70 (0.46)
Tree	1 if a HH produces a tree crop; 0 if otherwise	0.34 (0.47)
Maize	1 if a HH produces a maize crop; 0 if otherwise	0.93 (0.26)
Cereal	1 if a HH produces a cereal crop; 0 if otherwise	0.11 (0.32)
Tuber	1 if a HH produces a tuber crop; 0 if otherwise	0.09 (0.29)
Bean	1 if a HH produces a bean crop; 0 if otherwise	0.56 (0.50)
Groundnut	1 if a HH produces a groundnut crop; 0 if otherwise	0.30 (0.46)
Vegetable	1 if a HH produces a vegetable crop; 0 if otherwise	0.12 (0.32)
Tobacco	1 if a HH produces a tobacco crop; 0 if otherwise	0.10 (0.30)
Risk attitude and farmer organization		
Risk-averse	1 if a HH is risk-averse; 0 if otherwise	0.70 (0.46)
Farmer organization	A number of farmer organizations the HH are a member of	0.91 (1.14)
Mobility and access to fertilizer		
Difficulty in accessing fertilizer	HH's difficulty in accessing fertilizer (1—not serious to 4—very serious)	3.50 (0.98)
Market	1 if there is a market in the village; 0 if otherwise	0.07 (0.25)
Distance to paved roads	Distance from farmer's residence to paved roads	12.41 (12.19)
Log of distance to paved roads		2.17 (0.98)
Extension resources within the village		
Number of extension agents	The number of extension agents assigned in the village	1.20 (0.76)
Number of agricultural projects	The number of agricultural projects in the village in the past five years	3.10 (1.64)
Number of demonstration plots and farm trials	The number of demonstration plots and farm trials in the village in the past five years	2.00 (2.11)
Regional characteristics		
Feed the future zone of influence	1 if the area is Feed the Future Zone of Influence; 0 if otherwise	0.67 (0.47)
South Region	1 if the area is south region; 0 if otherwise	0.53 (0.50)
Central Region	1 if the area is central region; 0 if otherwise	0.41 (0.49)

Standard deviations are in parenthesis

[a] Household Dietary Diversity Score measures the number of different food groups (a total of 12 food groups) consumed over 24 h. HDDS ranged from 0 to 12, and the higher the score, the more diversified food groups the household consumed over 24 hours

Table 2 Poisson and NB model results

Variables	(1) Poisson	(2) NB
Age	− 0.008***	− 0.009***
	(0.002)	(0.00269)
Female	− 0.170***	− 0.172*
	(0.058)	(0.0910)
Married	0.075	0.0928
	(0.063)	(0.0984)
Muslim	− 0.102*	− 0.103
	(0.056)	(0.0844)
Household Size	0.027***	0.0309**
	(0.007)	(0.0126)
Years of schooling	0.022***	0.0286***
	(0.005)	(0.00871)
Farming experience	0.011***	0.0115***
	(0.002)	(0.00285)
HDDS	0.041***	0.0476***
	(0.009)	(0.0141)
Log of Household Economic Resources	0.051***	0.0590***
	(0.009)	(0.0123)
Log of Cropland Size	0.034	− 0.0183
	(0.040)	(0.0669)
Loan Access	0.045	0.0780
	(0.045)	(0.0763)
Off-Farm Employment	− 0.002	− 0.00512
	(0.051)	(0.0772)
Communication Tools	0.308***	0.277***
	(0.045)	(0.0683)
Lead Farmer	0.445***	0.472***
	(0.043)	(0.0743)
Livestock	0.219***	0.170**
	(0.047)	(0.0682)
Tree	0.364***	0.399***
	(0.035)	(0.0581)
Maize	0.265***	0.247**
	(0.087)	(0.123)
Cereal	− 0.165***	− 0.164*
	(0.060)	(0.0938)
Tuber	0.064	0.0364
	(0.050)	(0.0885)
Bean	0.199***	0.223***
	(0.037)	(0.0574)
Groundnut	0.066*	0.0663
	(0.037)	(0.0616)
Vegetable	0.119**	0.123
	(0.049)	(0.0830)
Tobacco	− 0.015	0.0585
	(0.057)	(0.0950)
Risk-Averse	− 0.101***	− 0.110*
	(0.039)	(0.0611)
Farmer Organization	0.110***	0.123***
	(0.022)	(0.0419)
Difficulty in Accessing Fertilizer	− 0.050***	− 0.0524*
	(0.016)	(0.0271)
Market	− 0.040	− 0.0542
	(0.035)	(0.0570)
Log of Distance to Paved Roads	− 0.175***	− 0.186***
	(0.018)	(0.0297)
Number of extension agents	0.107***	0.113***
	(0.020)	(0.0374)
Number of Agricultural Projects	− 0.007	− 0.00597
	(0.011)	(0.0178)
Number of Demonstration Plots and Farm Trials	0.053***	0.0491***
	(0.007)	(0.0131)
Feed the future zone of influence	0.501***	0.484***
	(0.044)	(0.0683)
South Region	− 0.345***	− 0.382***
	(0.077)	(0.128)
Central Region	− 0.312***	− 0.409***
	(0.076)	(0.127)
Constant	− 1.203***	− 1.147***
	(0.186)	(0.292)
γ		− 0.154**
		(0.067)
Observations	2441	2441

Standard errors are in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

relaxes the assumption that the zeroes and the positives come from the same data-generating process. In other words, it distinguishes the decisions between participation in extension services (hurdle at zero) and the extent of access to various types of extension services. The results of the logit model that predicts the event of crossing the hurdle show that the probability of a farmer accessing extension services decreased as their residences were farther away from the nearest paved road. Older farmers had a lower likelihood of crossing the hurdle (or access to extension services), parallel to the previous studies' findings that older farmers relied more on their accumulated knowledge than on requesting advice from extension agents [1]. In addition, a one-unit increase in HDDS was associated with a 9 percentage point increase in crossing the hurdle, providing evidence in support of a linkage between nutrition and participation decisions on agricultural extension. Moreover, lead farmers, farmers with higher educational attainment and longer farm experience, farmers with communication tools, and

Table 3 Hurdle Negative Binomial Logit model results

Variables	(1) Logit	(2) NB
Age	-0.012^{***}	-0.005
	(0.004)	(0.003)
Female	-0.042	-0.278^{***}
	(0.143)	(0.101)
Married	0.144	-0.008
	(0.154)	(0.109)
Muslim	-0.284^{**}	-0.006
	(0.137)	(0.092)
Household size	0.0482^{**}	0.022^{*}
	(0.022)	(0.013)
Years of schooling	0.027^{*}	0.026^{***}
	(0.015)	(0.009)
Farming experience	0.013^{***}	0.010^{***}
	(0.005)	(0.003)
HDDS	0.094^{***}	0.019
	(0.024)	(0.015)
Log of household economic resources	0.056^{***}	0.047^{***}
	(0.018)	(0.015)
Log of cropland size	-0.031	0.001
	(0.115)	(0.069)
Loan access	0.043	0.067
	(0.139)	(0.075)
Off-farm employment	-0.182	0.096
	(0.125)	(0.085)
Communication tools	0.304^{***}	0.210^{***}
	(0.107)	(0.077)
Lead farmer	0.883^{***}	0.304^{***}
	(0.155)	(0.070)
Livestock	0.248^{**}	0.073
	(0.106)	(0.078)
Tree	0.568^{***}	0.271^{***}
	(0.103)	(0.059)
Maize	0.169	0.275^{*}
	(0.188)	(0.145)
Cereal	-0.051	-0.236^{**}
	(0.153)	(0.100)
Tuber	-0.112	0.128
	(0.161)	(0.086)
Bean	0.370^{***}	0.110^{*}
	(0.096)	(0.061)
Groundnut	0.153	0.022
	(0.107)	(0.062)
Vegetable	0.249^{*}	0.065
	(0.146)	(0.083)
Tobacco	0.312^{*}	-0.103
	(0.170)	(0.095)
Risk-averse	-0.028	-0.117^{*}
	(0.100)	(0.065)
Farmer Organization	0.147^{*}	0.118^{***}
	(0.084)	(0.039)
Difficulty in accessing fertilizer	-0.075	-0.038
	(0.048)	(0.027)
Market	-0.021	-0.052
	(0.096)	(0.059)
Log of distance to paved roads	-0.204^{***}	-0.152^{***}
	(0.050)	(0.031)
Number of extension agents	0.145^{**}	0.082^{**}
	(0.063)	(0.037)
Number of agricultural projects	-0.032	0.014
	(0.029)	(0.019)
Number of demonstration plots and farm trials	0.047^{**}	0.046^{***}
	(0.022)	(0.013)
Feed the future zone of influence	0.891^{***}	0.163^{**}
	(0.113)	(0.075)
South Region	-1.169^{***}	0.084
	(0.230)	(0.130)
Central Region	-1.206^{***}	0.101
	(0.231)	(0.128)
Constant	-1.015^{**}	-0.662^{**}
	(0.478)	(0.323)
$\ln\gamma$		-1.008^{***}
		(0.142)
Observations	2441	2441

Standard errors are in parentheses

$^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$

farmers who produced livestock, tree, beans, vegetable, and tobacco crops were more likely to cross the hurdle than their counterparts. Becoming a member of a farmer organization and some factors of extension resources within the village were positively associated with farmers' participation decisions on the services. Lastly, farmers who resided in southern and central regions relative to northern regions were predicted to have a higher likelihood of crossing the hurdle when the Feed the Future Zone of Influence was controlled.

The NB part of the model shows that the extent of farmers' access to extension services decreased by 14.1 percent for a one-log point increase in the distance between farmers' residences and the nearest paved road.[3] In other words, extension access scores would decline

[3] The incident rate ratio (IRR) is calculated by exponentiating the coefficient of interest. We subtract 1 from estimated IRR value to calculate the percentage change in extension access.

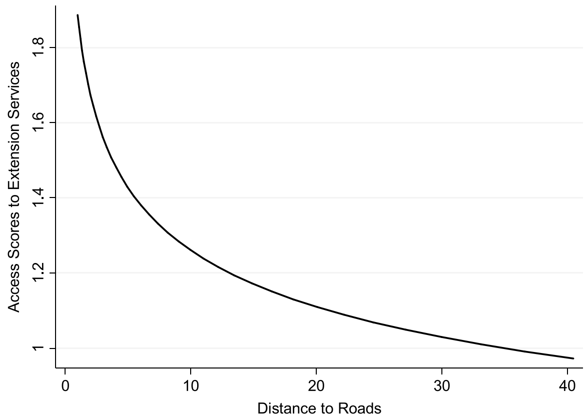

Fig. 4 Predicted extension access scores by distance (km) from farmer's residence to paved roads

by 14.1% as a result of an increase of 172% in distance to paved roads.[4] That is, a one-percent increase in distance to paved roads was correlated with a reduction in extension access scores of about 0.082% (=14.1/172). To help understand the effect of distance, we visualize the non-linear relationship between distance and access to extension services in Fig. 4. For example, as Fig. 4 shows, holding all other variables constant, a farmer located 1 km from the paved roads had an expected extension access score of about 1.8, while a farmer 10 km from the paved road had an expected access score of 1.25. The difference implies a 30% decrease in access due to the increased distance. The marginal decrease in extension access score is predicted to diminish as farmers lived farther away from paved roads. The extension agents spend a substantial amount of their time visiting farmers; thus, the poor road infrastructure, common in remote rural areas, could limit the agents' ability to reach farmers and bring the requisite inputs and technologies into the communities. Moreover, farmers farther away from paved roads tended to have limited access to markets, which in turn incurred higher transaction costs of input procurement and product marketing. Increased transaction costs were likely to be correlated with a decrease in farmers' demand and adoption capabilities of improved farm practices and technologies recommended by extension agents.

Women farmers were predicted to have considerably lower extension access scores by 24.3 percent than men, indicating the prevalence of deeply rooted barriers that reduced women's ability to access extension services. On the other hand, an additional year of schooling and farm experience was associated with an increase of 2.6 percent and 1 percent in access scores, respectively. Lead farmers and owning communication tools were substantially associated with an increase in extension access scores by 35.5 percent and 23.4 percent, respectively, relative to their counterparts.

Farmers engaged in tree, maize, and bean crop production were predicted to have greater extension access scores, which equaled 31.1 percent, 31.7 percent, and 11.6 percent, respectively. On the other hand, growing cereal crops was associated with a reduction of 21 percent in access scores. Even though we cannot explicitly explain the reasons underlying the opposite sign of the coefficients on different agricultural commodity variables, one plausible reason may be that farmers who produced agricultural commodities, in which the coefficients are negative, tended to live farther away from paved roads than other commodities with positive coefficients. Such descriptive observations lead us to raise a hypothesis that the interaction of distance and types of commodities grown might untangle confounding effects among commodities, distance, and extension access. Though the results are not shown for the sake of brevity, adding interaction terms between distance and agricultural commodities causes the cereal and its interaction variables to become insignificant. Coefficients on the interaction terms also indicate that extension access scores decreased for maize and vegetable farmers who lived farther away from the road, but their effects were smaller than the size of the coefficients on the maize and vegetable variables. Furthermore, some commodities might require more intensive management, stimulating more extension requests and service provision.

Household economic resources were positively associated with extension access scores, while other variables describing economic and productive resources were not statistically significant. In addition, farmers who belonged to more farmer organizations tended to have higher extension access scores, while risk-averse farmers had lower scores than their counterparts. Furthermore, the additional number of extension agents assigned in the community and demonstration or farm trials in the last 5 years, representing the previous relationship between extension agents and the community, were predicted to increase farmers' extension access scores by 8.5 percent and 4.7 percent, respectively. Finally, farmers who lived in USAID's Feed the Future project areas had a 17.7% higher extension access score than those outside the project areas, reflecting the agency's efforts to reach and train marginalized farmers. These results confirm findings from previous literature that identifies factors affecting

[4] Suppose a village resident had the mean extension access score of 8.75 km (or 2.17 in natural logarithm). It then increased distance to roads by 23.78 km or one more unit of logged distance to roads, representing 172% [=((23.78–8.75)/8.75) × 100].

extension access, introduced in the literature review section.

The Vuong test for non-nested models, introduced by Vuong [78], has been widely used to determine whether the hurdle-negative binomial model has a better fit than NB. However, the recent studies of Desmarais and Harden [17] and Wilson [80] criticized that the Vuong test is not appropriate to compare these two models because they are not nested. Instead, the Akaike Information Criterion (AIC) is suggested [42, 84]. We find that the AIC value of the hurdle model is smaller than NB for access to extension services. In addition, the *t*-test for the overdispersion parameter is statistically significant at the 1 percent level, indicating overdispersion even after the excessive zero issue is addressed. Altogether, AIC and *t*-test results suggest that the hurdle negative binomial model provides a better model fit over Poisson and NB models.

Discussion

Prior studies that examined individual and community-wide benefits of road accessibility in rural areas in the least developed countries anecdotally stressed the role of increased access to agricultural extension services (through improved road access) as an underlined channel that enhances farmers' agricultural knowledge and technology adoption. This study attempts to close this gap in this literature by answering questions of whether and to what extent access to paved roads would influence farmers' access to extension services in Malawi. Our findings indicate a negative and non-linear relationship between access to paved roads and extension services, showing that the extent of access to extension services decreased as a farmer's residence was farther away from the nearest paved road. We also find that greater household economic resources, higher human capital accumulation, and being a member of farmer organizations were associated with an increased extent of extension access, while older farmers or risk-averse farmers tended to have lower extension access scores than their counterparts. In addition, women farmers appeared to have considerably lower access scores than men farmers. Having communication tools and some farm characteristics such as serving as lead farmers and types of agricultural commodities—although the effects were heterogeneous across commodities—were positively associated with extension access scores. Lastly, extension resources available in the village, such as the number of extension agents and demonstration and farm trials, were positively associated with the extent of extension access.

This study advances the previous research in this area in a number of ways. First, many studies on agricultural extension services define access to agricultural extension services by a binary indicator of contact with or receipt of advice from extension agents or through farmer-based organizations [59, 64, 68]. This binary access/participation measurement often provides straightforward implications and methodological merit, especially for impact assessment studies that compare the outcome of interest between the treatment and control groups; however, it does not account for the diversity of agricultural topics and extension service providers available within the village. In addition, as a consequence of the binary access measurement, prior studies' scope of research tended to be limited to understanding determinants of participation in agricultural extension services. The central assumption behind this binary measurement neither allows for farmers' differential learning styles—e.g., peer-to-peer learning, one-on-one training with an extension agent, and other forms of cooperative learning—nor the heterogeneous quality of education among service providers. Our study extends previous work in this area by proposing a reasonable measure of extension access that incorporates a range of agricultural topics and types of extension service providers. We also employ a hurdle model that explores both the decisions between participation in extension services (hurdle at zero) and the extent of access to various types of extension services (positive counts), which add more richness to the analysis of understanding both stages of decisions.

More specifically, if we only focus on the determinants of the binary measurement of agricultural extension access, which is the logit part of regression in Table 3, we would conclude that there was no (statistically significant) gender difference in access to extension services during the analysis period. However, the NB part of the analysis reveals a significant gender inequity in accessing diverse agricultural topics from various service providers. In addition, variables such as age, religion, and nutrition status were shown to be statistically relevant to the binary access of extension services but did not influence their intensity levels. Over the past decade, with the accompanying efforts of the government and multilateral organizations, Malawians have experienced a substantial increase in agricultural extension services. These efforts might alleviate gender bias in the exposure to some types of agricultural extension services, which were criticized as a major barrier to agricultural development and sustainability over decades in most underdeveloped countries including Malawi. However, women's ability to learn diverse agricultural information (this might be partly explained by women's exclusion from particular farm livelihoods such as cash crops and large animals) and the ability to attend agricultural training outside the family nucleus or interact with male extension agents who predominate in most extension settings might still be limited. On the other hand, the distance to paved roads was predicted as a barrier in both the participation and intensity parts of extension access, providing broader insights into future extension education and service planning and development.

Although our study provides evidence that improvements in road infrastructure can help enhance farmers' access to agricultural extension services, the questions surrounding the cost-effectiveness of investment in road infrastructure still remain unanswered. Road construction and maintenance incur a substantial amount of money. According to the studies on road infrastructure costs, a small construction or upgrade of paved roads was estimated at MWK 170 million per land kilometer [49], with periodic maintenance costs at 2.2% of the road asset value [29]. On the other hand, improved rural roads and infrastructure can create economic opportunities through a range of mechanisms. Specifically, roads provide farmers with affordable access to both markets for agricultural outputs and modern inputs, enhancing their agricultural profits [16, 38]. In addition, extension workers, by reducing transportation costs and time, are capable of reaching a greater number of rural farmers and implementing more demonstration plots and field days [2, 72]. Moreover, since off-farm employment tends to be highly dependent on transportation, building rural roads can contribute to keeping residents' off-farm employment or starting new off-farm employment, which would simultaneously foster sustainable growth in small- and medium-sized enterprises [41]. Furthermore, road infrastructure is one of the essential elements determining the demand for tourism in Malawi, which targets its contribution to the GDP of 14.4 percent by 2040 [50]. The problems in estimating the cost–benefit of return on investment are that a wide range of social benefits accrue in the long-term and are not easily estimated.

Information, communication, and technology (ICT) has gained increasing attention as a solution to address limited extension services in remote rural areas and avoid the tremendous costs of road construction. ICT-based tools include computer, radio, television, and mobile phones, and their applications have features connecting farmers to diverse and timely information (e.g., market price information, new agricultural technologies, nutrition, health, and weather information) [4, 6]. However, ICT has several challenges, such as a lack of ICT infrastructure and financial capacity to spend on ICT innovations [6]. Specifically, most rural villages have no access to electricity and poor network connectivity, posing severe barriers to bringing agricultural and nutrition/health information into rural villages. Moreover, poor farmers cannot afford the costs of purchasing mobile phones, sim cards, and extension services rendered by ICT innovators. In addition, the use of ICT is considerably limited by illiteracy, while most illiterate farmers are smallholders and live in rural villages. Furthermore, some agricultural technologies are difficult to understand by listening to the radio—the most common form of ICT in Malawi [10]—raising questions about whether radio-led ICT is sufficient to replace extension agent visits regarding the use of complex modern technologies. That is, many aspects of costs and the effectiveness of ICT are still uncertain and require additional research dedicated to comparing the return on investments between expanding rural roads and ICT infrastructure.

Conclusion

Despite increased extension access in Malawi, farmers still suffer from low crop and livestock yields, chronic food shortages, and poverty. These increasingly built pressure to revisit the strategy and operation of the country's current agricultural extension system. Nevertheless, a majority of studies of agricultural extension in Malawi have focused on the effectiveness of agricultural technology adoption based on the notion that extension service providers are effectively operating to reach and deliver agricultural information to farmers. Although these impact studies could provide richer perspectives on the effectiveness of emerging agricultural technologies, more fundamental issues that the government and other stakeholders may need to be aware of are the limited geographical coverage of extension services, gender bias in access to extension services, and other individual and structural barriers that could limit farmers' ability to access and utilize the services.

Our study finds that road access strongly influences access to extension services on both the extensive (0/1) and intensive (1 to 81) margins. In addition, our measure of extension service access captures the richness and variety of extension service offerings potentially available to farmers in Malawi. Examining both the 0/1 margin and the extensive margin shows the differing effects of variables such as gender and helps to explain some of the continuing gender bias found in Malawian agriculture. Future research might extend this approach and work to address the issue of the quality of extension services, and it may apply the access measure implemented here to other contexts.

Abbreviations

AFDB	African Development Bank
AIC	Akaike Information Criterion
BES	Block extension system
FAO	Food and Agriculture Organization of the United Nation
GDP	Gross domestic product
HDDS	Household Dietary Diversity Score
ICT	Information, Communication, and Technology

IFPRI	International Food Policy Research Institute
LR	Likelihood ratio
NB	Negative binomial
NGO	Non-Governmental Organizations
NSO	National Statistical Office
PPS	Probability proportional to size
T&V	Training and Visit

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Author contributions
HBL, PM, and HH were engaged in all aspects of this study regarding data administration and cleaning, data analyses, result interpretation, and paper writing. All authors read and approved the final manuscript.

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Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
This study was approved by the Institutional Review Board at IFPRI and local IRB in Malawi. The documents will be available upon request.

Consent for publication
Not applicable.

Competing interests
The authors hereby declare we have no conflicts of interest related to this manuscript.

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