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Stephan Klasen, Tukae Mbegalo

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Platz der Göttinger Sieben 5 · 37073 Goettingen · Germany
Phone: +49-(0)551-3921660 · Fax: +49-(0)551-3914059

Email: crc-peg@uni-goettingen.de Web: http://www.uni-goettingen.de/crc-peg

The Impact of Livestock Ownership on Solar Home System Adoption in the Northern and Western Regions of Rural Tanzania

Stephan Klasen[*] and Tukae Mbegalo[†]

Abstract

Livestock has been hypothesized to be one of the major buffer stocks for consumption smoothing in rural areas of developing countries. It is therefore hard for poor farmers in the developing world to finance large investments. We test the latter by estimating a latent variable model of solar home systems. We use off-grid household data from four districts of mainland rural Tanzania. Results indicate that solar adoption is higher for livestock owners than non-livestock owners and that these differences increase as household expenditure increases, but there is no statistical difference at lower- and some middle-expenditure levels. We argue that poor families tend to keep small livestock, which may not generate enough income for investment. They may also decide to accumulate livestock due to a lack of incentives to invest in solar. Furthermore, solar prevalence plays a role in the observed differences of solar adoption. Thus, solar investment financed through livestock will also depend on whether households have enough information on solar technology. In principle, if solar is to spread within a community, households will have to have information on the upfront costs and maintenance costs and the social and economic benefits of solar technology.

Keywords: Livestock, Modern Consumer Goods, Solar Adoption and Solar Home Systems

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[*] Professor, Georg-August University of Goettingen, Germany

[†] Department of economics, Georg-August University of Goettingen, Platz der Göttinger Sieben 5, 37073 Goettingen, Germany; tukae.mbegalo@stud.uni-goettingen.de or tambegalo@mzumbe.ac.tz

1.0 Introduction

Livestock has been hypothesized to be one of the major buffer stocks or consumption smoothing in rural areas of developing countries. Deaton's (1990 and 1991) theoretical model of optimal saving in the absence of formal insurance mechanisms and credit markets predicts that households facing idiosyncratic and covariate shocks will use liquid assets, such as livestock, for self-insurance. Households are arguably able to smooth consumption in the event of unanticipated income shocks. However as evidence suggests, the need to hold savings as a precautionary measure discourages poor farmers from undertaking profitable investments that they could theoretically undertake, thus they remain trapped in poverty (Fafchamps and Pender, 1997; Zimmerman and Carter, 2003). As such, the salient feature of the optimal saving hypothesis for precautionary savings, particularly for the poor, is the lack of formal financing institutions to insure risk.

Although, livestock is generally less frequently used as a loan than livestock gifts in Eastern African pastoralist societies (Heffernan and Misturelli, 2000), livestock or herds in the developing world are the security asset influencing access to informal credit arrangement and also a key source of collateral for the poor, enabling them to obtain access to capital and business loans (IFAD, 2004). As much as livestock is an important capital asset, it also plays a key role in the informal credit market. Consequently, it might not only need to be a form of precautionary savings but also a viable asset which may potentially facilitate investment in a solar home system that requires both up-front and maintenance costs. As a result, it can propel households out of abject poverty and into the benefits of market economies. While, it has long been known that poor farmers in the developing world find it hard to finance large investments (McKinnon, 1974), little is known about the effect of livestock ownership-sales on self-financed large investment such as solar home systems. Therefore, the main goal of this paper is to determine whether farmers can self-finance solar home systems through livestock ownership.

Moreover, the association of livestock income and adoption behavior on home solar systems might be of particular interest if it is in line with the energy ladder hypothesis. Energy researchers posited a hierarchical relationship of fuel types that a household follows with rising economic status (Hosier and Dowd , 1987). The energy ladder hypothesis emerged as an extension from consumer economic theory to energy, assuming that households act as utility maximizing neoclassical consumers. Thus, by increasing livestock income, we expect a consumer to choose to purchase more modern energy sources, implying that they theoretically tend to consume less of an inferior good such as charcoal and wood. However, there is little research on the energy ladder hypothesis that focuses on solar energy and livestock in Tanzania.

There are two major issues that may be critical for households in deciding to invest in solar through livestock ownership. First, solar adoption can depend on whether a household would generally prefer modern consumer goods (e.g. access to a mobile phone or iron roofing for their home), which may correspond with a preference for solar energy technology as a modern energy source. In addition, the rapid spread of mobile phones has been a major factor behind the demand for solar home systems in the context of off-grid electrified households (Ondraczek J. , 2013). Second, a modern energy choice with respect to income, may also depend on whether a household has enough information on the costs, benefits and technological aspects of a solar home system. We assume that information can be derived from solar diffusion locally. Therefore, this paper also aims to examining livestock ownership and the energy ladder hypothesis in the context of solar energy as well as how socio-economic variables affect modern household energy use. It attempts to answer the following research questions:

1. Does livestock ownership have any positive influence on solar adoption and to what extent does livestock ownership affect solar adoption in Tanzania?
2. Does the pattern of solar adoption in Tanzania follow the energy ladder hypothesis?
3. Does livestock ownership have any positive effect on the consumption of modern goods such as mobile phones and iron roofing?
4. Does solar spillover among the community and does this have any positive effect on solar adoption among households in the community?

To answer these questions, we use off-grid survey data collected from four districts in the Kagera and Rukwa regions. These study areas are among an area with low electric coverage in mainland Tanzania. Data from a total of 1000 rural households was collected from the Ngara, Biharamulo, Nsimbo and Mpanda districts. In order to analyze the influence of livestock ownership on solar energy choices, we first regress livestock ownership, regional fixed-effect and other explanatory variables onto a solar home system binary variable. Indeed, the predicted probability of solar is higher for households who own livestock than for those who do not own livestock. Furthermore, we find that at lower expenditure levels, the difference between predicted probabilities for livestock owners and non-livestock owners, is very small and statistically insignificant, implying that livestock owners can hardly invest in solar if their consumption level is low. In addition, we find evidence of the energy ladder hypotheses, indicating that as total expenditure increases, households tend to adopt more solar energy sources.

We then turn to the third question and ask whether livestock owners who prefer "modern consumer goods" can also invest in solar. This question is of particular interest as far as policy implications are concerned. First, if the hypothesis is true then one may argue that livestock savings or more specifically that sales can be extended to non-precautionary savings, which may eventually have implications for poverty reduction rather than keeping households in a poverty trap through precautionary savings. Second, an individual who adopts modern goods, for example mobile phone technology, by financing it through livestock revenue is more likely to adopt solar energy technology. Then, buying a mobile phone or other modern goods, such as investing in iron roofing, would then reflect the desire to consume other modern goods such as solar home systems. Likewise, in the multi-dimensional poverty indicator for living standard, a person is deprived if they do not have access to electricity (UNDP, 2010). But what if a household's currently observed poverty status (without access to modern energy) has several cattle and goat assets? Still this household is considered poor by the standard of living definition of the multinational poverty indicators. However, it could be that households prefer livestock savings as opposed to the consumption of modern goods, such as solar home systems, for the reason that livestock is perceived as an indication of wealth in many rural areas.

Accordingly, in order to answer our third question, we regress two selected binary outcome variables: iron roofing investment and access to a mobile phone onto livestock ownership. The results indicate that livestock ownership has a positive effect for modern consumer goods. However, one might argue that household consumption can be highly correlated with income (livestock sales). For brevity, let us say supplementary income derived from the sale of cattle, goats and sheep etc. is higher for livestock owners than for non-livestock owners. Therefore, livestock owners are expected to have higher household consumption levels including purchasing more assets and durable materials than non-livestock owners. However, we argue that the income effect alone can only be true if the predicted probability of solar adoption is always higher for livestock owners than for non-livestock owners across different household expenditure levels. Nevertheless, we find that at higher expenditure levels the differences between the predicted probabilities for livestock and non-livestock owners is less pronounced and are statistically insignificant for mobile phone access and iron roofing investment.

Finally, the variable for solar prevalence is highly significant and the average marginal effect of solar for livestock owners increases by almost twice as much once the prevalence variable is not controlled for in the model. This finding suggests that solar adoption depends not only on income from livestock sales but also on solar diffusion within the village.

This paper proceeds as follows: Section 2 provides a background for the significant role of electricity on economic growth, the challenge and financing constraints of renewable energy projects and credit constraints among rural households and individuals who finance solar investment through livestock assets. Section 3 describes the significance of the research study area, data and sampling procedure based on field work. Also, we briefly provide descriptive statistics and present the expected signs of the independent variable's influence on solar adoption. Section 4 presents our empirical results. Section 5 concludes and discusses the policy implications.

2.0 Research Background

Adequate and regular access to modern energy may be one of the most important factors which can support economic growth and reduce poverty in sub-Saharan Africa (Deichmann et al. 2011). Policy makers around the global believe that access to electricity is a necessary requirement for sustainable development. For instance, the Multidimensional Poverty Index first published by the UNDP (2010) indicates that a lack of access to electricity is a direct indicator of poverty in the dimension of living standards. Today, nearly 1.3 billion people around the world do not have access to electricity and of those, over 600 million people live in sub-Saharan Africa (Amoah, 2014; Brew-Hammond, 2010)**.** While many developing countries have set a goal to achieve universal electricity coverage, and acknowledge its importance for national productivity and poverty reduction, the current level of investment in sub-Sahara Africa of approximately US$8 billion a year is inadequate in overcoming existing shortages in the region's current electric system and is also insufficient in increasing supply to meet future demand that will only continue to grow (Scott, 2015). Mini-grids and stand-alone power systems have been an essential component of power sector plans to include off-grid electricity. Nevertheless, solar energy as a source of electricity is promoted by many stake holders and policy makers as a decentralized and clean solution that requires minimal infrastructure investment to reaching homes and small firms in rural areas (Deichmann et.al, 2011; Wamukonya, 2007).

The solar PV market has been growing since the early 2000s (IEA, 2010). Today, solar home systems have been expanding due to the large reductions in cost for solar panels. Over the last ten years, the price of PV solar panels has declined by approximately 50%, largely due to increasing production in China and significant technological breakthroughs (see Amoah, 2014; Ondraczek J. , 2014). According to Bradford (2006) the social, environmental and economic benefits of solar technology for off-grid and isolated communities are robust. Amoah (2014) indicates that the price of solar is relative cheaper by 20 cents per kWh than power from diesel generators, which operate at a cost of approximately $1 per kWh for many rural Africans. In addition, the quality of solar products, such as solar lamps, now outperform commonly used kerosene lanterns in developing countries. Furthermore, he pointed out that solar energy gives off-grid households and small firms the power to control their solar electricity generation, which is in contrast to the unreliable sources of electric power that are exemplified by frequent blackouts especially in Ghana, Nigeria and Tanzania. However, the demand for a solar system in rural regions is increasing less rapidly due to the small commercial market of solar penetration. Commercialized solar is mostly concentrated in economically strong areas, such as in urban, peri-urban and major towns in rural areas (Kassenga, 2008), even though the majority of Africans can hardly afford the up-front costs of solar panels. The initial investment costs of solar are very high for rural residents due to the fact that the majority of the rural population is poor. Indeed, about 90% of the lifetime costs of a solar system is paid up-front at the time of installation, which is beyond the reach of most people in Africa (Bradford, 2006).

A lack of financing is one of the largest barriers in the spread of solar technology in Africa and constrains a government's ability to develop the human capital necessary for the technology to spread **(**World Bank, 1998; 2008)**.** In most cases, financing renewable projects include support for solar diffusion, but these projects often require substantial amounts of money. Due to multiple reasons, including the risk of investment, renewable energy projects have so far had a poor reputation within the financing community. While individual solar investment for rural households can be financed through loans from micro banks and commercial banks, in many rural regions, financial markets are absent or non-existent (see also, World Bank, 2008, P75**)**. Even where they do exist, credit for the poor is constrained due to a lack of 'formal collateral'.

Nevertheless, livestock is an important asset in Africa, helping improve the nutritional status of their owners and contributing to economic growth. A key feature of livestock in Africa is that they fulfill multiple roles, ranging from providing manure, milk and meat, to power and drought power, and insurance. A portion of the literature in the African context, assert the precautionary savings of livestock inventories as an insurance substitute during risky events, though it is still contested that livestock is an imperfect form of buffer saving (eg. Carter and Lybbert, 2012 ; Rosenzweig and Wolpin, 1993; Verpoorten, 2009). The key feature of liquidity in this form of savings in rural areas is due to the lack of formal credit markets among rural citizens. However, livestock assets can be used as informal collateral within community credit exchanges. The multipurpose functioning of livestock hypothetically can be used to subsidize non-precautionary and economic investment, such as solar home systems, without being confined to consumption smoothing only during risky events. Indeed, the literature is only rich in imperfect and/or livestock savings as important assets to smooth consumption in the event of drought and other income shocks. Nevertheless, little research exists beyond these strands. Therefore, this paper's contribution to the existing literature is an analysis of livestock ownership as a major asset to improve living standards, and more specifically, solar energy adoption among poor rural households in Tanzania.

3.0 Significance of the Research Study Area

Tanzania is a good example of an African country with a serious shortage of electric energy. Its energy consumption per capita in 2013 stands at only 89.5 kWh per annum which is very low compared to energy consumption in the other counties around the world (World Bank, 2016). Indeed, the proportion of the population with access to electricity in Tanzania is very low. Overall, only 21% of the Tanzanian population has access to electricity, but in rural regions where more than 70% of the population lives, the situation is even worse with only 7% (GreenMax, 2013). According to the GreenMax (2013) report, the coverage of the national grid is only pronounced in major cities, such as Dar es salaam, which has the greatest access with 59% of all households having electricity coverage. However, some regions lag far behind, with Kagera, Kigoma, Lindi, Manyara, Mtwara, Mwanza, Rukwa and Shinyanga all having less than 5% coverage. Over the last five years, the government of Tanzania has had the goal of achieving universal access to electricity through expanding the national grid. By 2020, 50% of the population is expected to have access to electricity, and further increasing to 75% by 2035. However, electrification is progressing at a slow pace when compared with national demand. The 2015/2016 target of electrification to reach 30% of population has not been achieved thus so far. However, off-grid households can be reached by solar energy generation. As Collier and Venables (2012) argue, solar energy generation has the potential to provide electricity for off grid households and small firms who are experiencing extreme shortages of electricity. While PV market growth has been expanding in the last two decades (Ondraczek J. , 2013), the majority of the rural poor cannot afford the upfront investment and maintenance costs.

Individuals can rely on financing solar energy through financial institutions available in the country. However, access to banking and financial services continues to be difficult, especially for farmers, rural and poor households and women. Most Africans have limited access to commercial banks (Meyer 2015).Microfinance institutions supply financial services to the poor, but do not yet reach most enterprises and poor households in semi-urban and rural areas where bank branches are scarce. On the other hand, livestock as a source of income can be used to finance investment in solar energy.

Indeed, most rural households in Tanzania are involved in agricultural activities such as livestock. According to Covarrubias et al. (2012) three-fifths of rural households earn income from livestock husbandry and agricultural activities (crop, livestock, and agricultural wage labour), which when combined amount to 70 percent of the total income of rural households (53 percent from crop production, 13 percent from livestock). Similarly, there is recognition that livestock is a major agricultural activity in the country, which contributes to the national economic development agenda. The government proposed a National Livestock Policy in 2006, which articulates that livestock farming has an important role to play in achieving the development goals of national growth, reducing poverty and reducing inequalities among Tanzanians by increasing their incomes and employment opportunities (Covarrubias et al. 2012)**.** In addition, a Livestock Sector Development Strategy (LSDS) was formulated in 2010 to operationalize the national Livestock Policy (URT, 2011).

3.1 Data and Descriptive Statistics

Data was collected from four district areas in the Tanzanian mainland. Two of them, Biharamulo and Ngara district, are located in northern Tanzania at the border with Rwanda (Kagera region) and the other two, Nsimbo and Mpanda districts, are situated in the West of the country at the Congolese border (Katavi region). Within these four districts, Ngara, Biharamulo, Nsimbo and Mpanda, the communities targeted by the ORIO intervention were identified, i.e. TANESCO and REA sites. The planned electricity grids mostly cover only parts of villages that span several kilometers with scattered households and different sub-villages. A total of 100 villages were visited with 10 household in each sub village, which produced a sample of 1000 non grid-electrified rural households. Households were asked on electric energy choices, the quantity demanded and the price of electric fuel for their corresponding choices. For the solar home systems (SHS), households were asked about their initial investment and repairing costs. The Solar home systems includes all households with photovoltaic system or solar PV power system and small solar power kits installed in their homes. The descriptive statistics are shown in Table 1.

4.0. Results and Discussion

4.1 The Influence of Livestock on Solar Adoption

In this section we analyze the influence of livestock on solar adoption among household. We begin our analysis by examining how household expenditure varies with solar adoption. We use a dummy for solar home systems as the dependent variable in the baseline model. In Table 2, as expected, household expenditure has a positive effect on solar adoption. The average marginal effect of household expenditure indicates that a percentage increase of household expenditure increases the probability of household to choose a modern energy source by about 3%. Although our research setting is limited to only one energy choice, the implication of our results is consistent with the energy ladder hypothesis, which states that as households gain socioeconomic status, they adopt technologies that are efficient and less costly and polluting. Supposedly, they abandoned lower energy sources such as such as dung, fuel wood and charcoal (Smith, 1987; Barnes and Floor, 1996). To further illustrate this point, we plot the predicted probabilities of solar adoption over different levels of expenditure. Figure 1a suggests that solar adoption rises at a slow pace at lower expenditure levels, but gradually rises at middle, and even more rapidly, at high expenditure levels. Indeed, solar energy adoption across expenditure levels mostly mimics the dynamics of energy use in families of varying incomes by what is commonly referred to as the ‘energy ladder” model for household decisions, to substitute or to switch between available fuels (see , Smith, 1987; Hosier and Dowd, 1987; Leach, 1992). However, the nature of the curves, illustrated here for the predicted margins, might be attributed to the log-linear modeling of household expenditure. Hence, we include the square term of expenditure and re-estimate the nonlinear model for the sake of a robustness check of the functional form specification of the logarithm of household expenditure in the model. As figure 1b suggests, there is no functional form misspecification of log-linear household expenditure. Therefore, our curves for the predicted margins might not be influenced by log-expenditure modeling. While the magnitude of the effect of expenditure on solar adoption dropped when we include its square term, we observe the same pattern of association between solar adoption and household expenditure that is, as income status increases, households tend to increase their adoption of modern energy sources. Thus, all specifications predict the effect on solar adoption consistently with the energy ladder hypothesis. Nonetheless, we adopt the log of expenditure household specification without its square term, because we believe that expenditure as a proxy for income is always skewed and can be better captured by a logarithmic transformation. In addition, the model itself is nonlinear and the square term is statistically insignificant in the model.

As mentioned above, when income rises households are more likely to move away from using traditional fuels, such as wood, and transitional fuels to modern fuels. In our case, the modern fuel is a home solar system, because the sampled households are from off-grid areas, meaning that solar is the only available modern energy choice at their higher energy ladder. Normally at higher expenditure levels, households would have other choices such as electricity from the grid (Leach, 1992). In what looks to be similar areas of studies, Mekonnen and Kohlin (2009) find that households with higher expenditure levels are less likely to use solid fuels only, but cannot attribute the switch from non-solid fuels to a mix of solid and non-solid fuels to household expenditures alone**.** Heltberg (2005) shows that household expenditure is insignificant for fuel switching in rural areas. Our results slightly deviate from the existing studies, which found household expenditure to be less likely associated with energy choice**.** The main reason for these inconsistent findings is that the scope of this study is only limited to the investment in solar home system rather than fuel switching. Indeed, our discussion is based on higher ranked fuels, which are perceived to signify higher economic status. Now it is not surprising that households with higher expenditures are associated with adopting of solar home systems.

Theoretically, the important feature of the energy ladder hypothesis is that energy choice crucially depends on a household's income level. We analyze the influence of income on solar adoption by categorizing households by those with livestock and without livestock. Before we proceed, there are two issues which should be noted that are vital for interpreting the results. First, in our sample we observed that no household had loans to finance solar investment, so we can deduce that solar investment was financed through either income from livestock or non-livestock financing. Second, since the main activity of most rural households in developing countries is farming, including livestock, then livestock owners earn income in wages and income derived from the sale of livestock products, while non-livestock owners earn income in wages and income derived from the sale of farm products. These categorizations are important because the way households earn their income characterizes their economic status, which is eventually reflected in household spending such as fuel switching.

Results of the effect of livestock on solar adoption are also found in Table 2. It suggests that livestock ownership has a positive influence on solar adoption. Holding other factors constant, the probability that households adopt solar energy sources is 3% higher for households who keep livestock than households who do not keep livestock. Livestock as a capital asset can contribute to improved income and wellbeing of the farm family. Therefore, household income from livestock sales is most likely used to finance the initial investment and maintenance costs of solar energy. As already explained, income is a key factor contributing to climbing the energy ladder. Seemingly, livestock sales supplement household income derived from farming and wage income, which implies a tendency for income to be larger for the livestock keepers than for the non-livestock keepers. The income effect, as explained by the livestock owners, plays a significant role in livestock keeping for rural poor people by improving their standard of living. Likewise, our results are particularly important for understand the contribution made by the different sources of income and how they are used for large economic investments. It is has been perceived that households who have stable income derived from wages/salary have a positive impact on the probability of using LPG instead of other fuels, while farming households are less likely to use LPG only (see Rao and Reddy, 2007; Heltberg, 2004). Our results indicate that the probability of solar adoption is higher for households with stable incomes from livestock (the sampled livestock owners include wage income) than households with unstable income without livestock (the sampled farming and wage income).

Furthermore, we plot the probabilities of the predicted margins of solar home system with per capita household expenditure between livestock and non-livestock owners. Figure 2a indicates that the predicted probabilities of solar adoption are higher for livestock owners than for non-livestock owners across per capita household expenditure. Indeed, the probabilities increase much more rapidly at higher expenditure levels for livestock owners than for non-livestock owners[1]. However, at lower expenditure levels, the differences of the predicted margins between livestock owners and non-livestock owners are less pronounced. This implies that the poor find it hard to invest in solar, regardless of whether they own livestock or not. Furthermore, we examine the marginal effects of the probabilities of livestock on solar adoption across per capita expenditure (see figure 3). We find that at low expenditures, the marginal effects are statistically insignificant as indicated by the horizontal line crossing the confidence intervals of the marginal effects of the first three expenditure values. There could be two possible explanations here. First, poor households tend to own small livestock, such as rabbits, chickens and goats, while wealthier ones tend to own larger animals, such as cattle, which usually generate higher income from sales than small animals. Second, it is more likely that the income effect alone does not influences solar adoption through livestock sales/income. If income from livestock sales alone plays a predominant role on adoption, we would expected an increases of "livestock income" to have major effects on solar adoption, even at lower expenditure levels, and thus we would observe significant differences in adoption between livestock and non-livestock across all expenditure levels. At lower expenditure levels, livestock owners are probably confronted with a desire for consuming modern goods over livestock savings, making them hard to forgo livestock for solar investment. In the next

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[1] As already been explained, we include the square term of expenditure in the model to see if it will alter the pattern of solar adoption on livestock and non-stock owners. Figure 2b suggests that the square tem of expenditure does not alter the solar adoption pattern significantly implying that even when expenditure square is included in the model the effect of household expenditure on solar adoption between livestock and non-livestock owners is consistency. Nonetheless, we adopt the log household expenditure simply because it consistently predict the energy source choice, in this case is the adoption of the solar energy source. In addition, we believe that the marginal utility of consuming modern energy increases with increase in level of income. Hence, there is no reason really that households should be less attracted into modern energy usage after reaching a certain level of income.

section, we will explain how this can be possible based on the consumption of modern goods such as mobile phones and iron roofing.

4.2 Livestock and Modern Consumer Goods

In this section we explain the hypothesis that if households can finance modern consumer goods through livestock, they can also finance an investment into solar energy. To explain this hypothesis, we first estimate the extended model by regressing iron roofing and mobile phones onto solar adoption. This step is important because it allows us to explore the association between modern consumption and solar adoption. It also provides a good deal of the robustness check for the estimation of the baseline model. A reason for including these modern goods in the estimation in the first place, is that the type of roofing material can be a good proxy for determining the economic situation of a household as well as their status in the community. Housing is one of the most important indicators of inter-household wealth differences (Castro et al. 1981). There is significant differences between the types and quality of housing, which can be seen through the roofing material chosen. Poorer households tend to use roofing materials for their houses, which can be gathered at little to no cost, other than family labour (see Castro et al. 1981). On the other hand, materials which are processed and purchased, such as corrugated iron sheets are more frequently found on the homes of wealthier households.

Second, livestock is one of the most lucrative and important investments in rural areas in developing countries; whereas, iron roofing is a wealth indicator based on expenditure. Thus, we further regress livestock on iron roofing and mobile phone accessibility separately, so as to examine the predicted margins of the livestock across different expenditure levels on these variables and compare them with the baseline model's[2] estimates of solar adoption. This comparison is crucial for the close examination of livestock owners' desire to consume modern goods**.** The result of the first regression estimation of the extended model is found in Table 3. It suggests that both mobile phone accessibility and iron roofing have an influence on solar adoption. Households who have iron roofing in their homes, have a 51% probability of adopting solar technology and the probability for those who have access to mobile phones remain at 46%. Furthermore, corrugated iron roofing has the largest effect, more than livestock ownership and mobile phone accessibility. Iron roofing is much more significantly associated with solar adoption as compared to livestock, which is significant only at the 10% level. A likely reason for this is that most houses with corrugated iron roofs are economically well-off, more than those without iron roofing. Since livestock ownership and iron roofing are assets that correlate

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[2] The baseline model estimates solar adoption without including iron roofing and mobile phone in the right hand side.

with household wealth, then the higher probability estimates of iron roofing as compared to livestock essentially reflect the higher economic value of this asset. The higher degree of association between mobile phone accessibility and solar adoption is attributed to the fact that mobile phone charging is a key consideration in determining demand in rural areas. Indeed, mobile phones are big contributors to economic growth in rural communities, but for off-grid households, charging a mobile phone is a big challenge. Mobile phone charging is expensive and time consuming, as it can require walking miles away to the nearest town centre. Hence, solar energy can facilitate mobile phone charging at home at a relatively low cost.

Comparing our estimates with the estimated baseline model, reveals that the odds of solar adoption when households change from non-livestock to livestock ownership dropped by 8% when both iron roofing and mobile phone accessibility are controlled for in the model. If only iron roofing is excluded in the model, the probability dropped by only 1% indicating that the presence of iron roofing in a household is strongly correlated with solar adoption and in the process, scales down the degree of influence of livestock ownership on solar adoption. Nonetheless, income from livestock is strongly correlated with iron roofing for obvious reasons; hence, only livestock is included in the regressions as it is a more visible source of income to finance solar investment. Also, as our variable of interest is a wealth based index of capital that differentiates itself from iron roofing which is based on expenditure. For mobile phone accessibility, it does not matter because including it in the model does not significantly change the coefficient for livestock.

Unlike mobile phone accessibility, which was a luxury and a privilege good that has recently become a basic necessity in many parts of Africa (Aker and Mbiti, 2010), iron roofing investment has higher income elasticities for most poor Africans. It is considered to be a luxury commodity for most rural Africans. Nevertheless, corrugated iron sheeting is commonly known roofing material for most Africans. Both of these variables are known to the most rural Africans. Then, if stable income derived from wages or a salary is positively correlated to such a variable, we can expect livestock ownership –i.e. 'stable income'-- to be also positively correlated to the outcome variables. Also, if household income from livestock is used to finance investment for modern goods, such as iron roofing and/or mobile phone access, there will be a high likelihood for the same to be invested into solar technology. To establish this association, we regress livestock ownership onto iron roof investment and access to a mobile phone variables. Results in Table 4a indicate that livestock ownership is positively related to the access of a mobile phone and investing in iron roofing. The average marginal effect of livestock ownership on the outcome variables are 8% for iron roofing and 8% for mobile phone access (Table

4b) and are statistically significant at the 5% level. Indeed, the extent to which livestock income influences the consumption of modern goods is substantial.

While it is clear in the previous regressions that livestock promotes solar adoption, the intriguing part of this finding is that based on the predicted margins of the livestock across expenditure levels, which can explain why at lower expenditure levels in the baseline model, the differences in the predicted margins between livestock owners and non-livestock owners on solar adoption are less pronounced (see figure 2a, 2b and 3). As we have briefly mentioned, this could be explained by household desire to consume modern goods, such as mobile phones and iron roofing over livestock sales/income so that households can invest in a solar home system. Thus, we plot the predicted margins of livestock owners and non-livestock owners with respect to household expenditure on mobile phones and iron roofing as presented in Figures 4a and 4b. We find that the predicted margin probabilities are higher for livestock owners than non-livestock owners across all expenditure levels. However, at the higher expenditure level, the difference of the predicted margins converge and the marginal effect is statistically insignificant, implying that at higher expenditure levels both livestock and non-livestock owners are more likely to increase their consumption of modern goods (figures 4c and 4d)[3].

Now, we turn to our previous observation to explain in greater detail why at some lower expenditure levels the marginal effect of livestock on solar adoption is statistically insignificant, meaning that there is not any substantial difference of adoption between the two groups. Although iron roofing has long symbolized economic status in most parts of the developing world, mobile phone technologies have rapidly spread in Africa. Most people in rural areas own mobile phones, even in places where grid connection is limited. A mobile phone is considered to be a frontier telecommunication technology rooted in the developing world, particularly in Africa, which among rural poor is considered to be crucial for poverty reduction. While several factors explain the spread of mobile phones in Africa, the key explanatory factors include: income per capita or the relative prices of the handsets and calls (there are high price elasticities of demand). Therefore, farmers will adopt a mobile phone when income rises. Nevertheless, access to a mobile phone is increasingly becoming a key driver of social economic development.

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[3] We also include the square of expenditure in the estimations for the purpose of checking whether the estimated predicted margins are the result of log-linear modeling. Figures 4e and 4f show consistency results when square terms are included in the estimations.

However, solar technology adoption in the developing world is low for several reasons, which we have explained. Unlike mobile phones, solar home technology can in some cases be perceived to be less important in a society, and therefore even if income is higher for livestock owners, the investment into solar would depend on the perceived benefit and whether it carries any economic status in the society. As such, if livestock owners are less likely to invest in solar for some expenditure levels, then it should be attributed to what an individual's endowment, their knowledge and the perceived benefits of modern consumer goods so that they can decide to forgo cattle savings and instead invest in solar. In conclusion, our results have two important implications. First, livestock keeping has long been hypothesized as a buffer stock but can also be considered non-precautionary assets to be used for large and modern investment. Second, investment in modern goods depends on income sources. Households who keep livestock (wage and livestock income earners) have an apparent more stable income, whereas non-livestock owners (wage and farming income earners) have an unstable income. Thus, our results are consistent with existing studies that have found that when households have unstable income, they are less likely to switch to higher energy sources (Rao and Reddy, 2007; Heltberg, 2004). Furthermore, solar investment financed through livestock will also depend on whether households have enough information on solar technology. In principle, if solar is to spread within a community, households will have to have information on the upfront costs and maintenance costs and the social and economic benefits of solar technology.

4.3 The Prevalence of Solar Home Systems

Indeed, apart from the income effect of solar investment, solar diffusion within a village is another key aspect which can contribute to solar adoption by livestock owners. To gain insight into this we calculate solar prevalence as the proportion of solar usage at village level by subtracting one household in each village who is observed to have a solar home system installed in their home. For the estimation of the model, we use a dummy for solar prevalence. As indicated in Table 2, solar prevalence has the expected sign and has a positively influence on household adoption of solar energy. While most existing studies on energy choice have been in line with the Energy Ladder Theory, showing that income is the most important factor influencing a decision to switch a cleaner fuel source, our result suggests that the solar spillover, as indicated by the average marginal effect of solar prevalence in a village, is highly influential on solar adoption. Holding other factors constant, a village with at least one household connected to solar increases the adoption of solar by other households by 17%. Furthermore, as the predicted margins indicate in figure 5a, the probability of solar adoption increases much higher with the increase of the household expenditure for households who live in a village with at least one household with solar than those households living without solar systems in their village. This implies that households with the same income will have different responses to solar adoption due to differences in solar diffusion in their community. These differences are statistically significant across most household expenditure levels as indicated by the marginal effect in figure 5b.

Moreover, we notice that once the prevalence variable is dropped in the model, the average marginal effect of solar adoption is twice as much for livestock owners, indicating that half of the difference of solar adoption between livestock and non-livestock owners can be explained by solar diffusion in the community when solar prevalence is not controlled for in the model. Furthermore, figure 5c reveals that the probability of adopting solar is much higher for livestock owners who live in villages with solar systems than for those living in villages without solar. Interestingly, the adoption of solar is higher for non-livestock owners living in villages with a presence of solar home systems than livestock owners living in villages without. These differences increase as per capita household expenditure increases. Our results suggest that the technological leap plays an important role in the adoption of solar technology, and therefore income alone is not enough to explain the phenomena of livestock sales on solar investment. Lay et.al (2012) found a similar result when studying the cross-sectional energy ladder in Kenya, confirming that the prevalence of SHS is among the potential pool of factors in choosing a lighting source in Kenyan. Likewise, Batte and Da Silva (2013) identified a lack of awareness as a key factor that challenges the diffusion of solar technology in Africa.

4.4 Influence of Household Characteristics on Solar Adoption

We have shown that income and SHS prevalence are the main variables that explain the adoption of solar technology. With the exception of household size, we find that gender, education and age also have a direct or an indirect influence on solar adoption (Table 2).

Gender- Holding other factors at their mean, the probability of solar panel installation is 4% less for female-headed households, suggesting that a female household head is less likely to adopt solar technology as compared to a male household head. The conditional difference between male and female household heads on solar adoption, increases as per capita expenditure increases (figure 6a). Mekonnen and Kohlin (2009) take a slightly different approach and also find that female-headed households are more likely to use either solid fuels or a mix as their main fuel, indicating that they are less likely to use modern energy because a large share of female-headed households belong to the poorest segments of society, which limits their access to modern fuels. Some authors find the opposite trend, whereby households headed by women are more likely to choose modern fuels over traditional fuels (See, Rao and Reddy, 2007). The main explanation given for this is based on the assumption that within a household, women are often responsible for cooking and collecting firewood. In addition, fire wood and solid fuels energy sources have direct negative effects on the livelihood and productivity of women by requiring a great deal of time collecting firewood instead of engaging in other economic activities. Hence, if a decision is to be made on the choice of fuel, women will choose fuels that require less time and effort and thus improve their standard of living. However, we argue that a large number of women cannot translate their decision making power to more modern energy sources, because they are in principle stricken by their income poverty, which makes it hard for them to finance solar investment. Indeed, in most rural areas women are highly constrained in their ability to accumulate assets and wealth, making it difficult for them to finance solar investment. We can see examples of gender inequality in terms of livestock ownership and solar adoption between male and female-headed households, where female-headed households who own livestock are more likely to have solar panels installed in their homes than female headed household without livestock (figure 6b). Consequently, gender differences in the ownership of assets and investments are noticeable and all of these differences are increasing as per capita household expenditure increases, implying that the poor female groups are more marginalized in their ownership of assets, which eventually translates into less purchasing power for investing in modern energy. Likewise, Covarrubias et al. (2012) analyzed livestock ownership in rural Tanzania and noticed differences in wealth and livestock ownership in gender, where 67% of male-headed households were participating in livestock activities while only 51% of female-headed households do the same. They explain how the difference is mostly attributed to cattle ownership as female-headed households tend to have more small animals than large animals such as cattle.

Age –we find that the presence of older members in the family leads to a decrease of probability of adopting solar, though the degree of influence for the age of a household on solar adoption is very small as indicated by the average marginal effect. There are two conflicting strands of literature on the influence of age on energy switching. As we know from the human capital hypothesis, age is a function of earnings. As household age increases, the wealthier the household becomes and the more likely it will accumulate financial assets allowing them to increase their bargaining power and in turn enable them to invest in modern energy sources. On the other hand, older members of a household may be more conservative, relying on traditional electric sources, such as wood and charcoal, for cooking and lighting than adopting modern energy sources. Ouedraogo (2006) and Mekonnen and Kohlin (2009) also find a positive relationship between age and the use of solid fuels as the main fuel for cooking, meaning that older family members are less likely to shift from traditional to transitional or modern energy sources.

Education- we use a categorical variable in the model to examine the influence of education on solar adoption. A tertiary level of education is the base category. Our results reveal that households with schooling less than the tertiary level are less likely to adopt solar technology compared to those with a tertiary education. There is evidence of a decreasing effect on adoption as the level of education decreases from the tertiary level down to no school attendance, indicating that as years in school increases, the odds of installing solar panels in the home increases. Indeed, education is an important determinant of energy switching because it characterizes aspects of knowledge and skills pertaining to both the economic and health aspects of energy sources. It can contribute to increasing the level of awareness of the adverse effects of solid fuels. Education at a very high level can contribute to the awareness of environmental pollution caused by solid fuel energy and the benefits of green and renewable energy technologies (Figures 7a and 7b). Most studies also find positive effects for education on switching between a low level of energy use to higher levels, such as LPG, kerosene and solar energy, and the effect is even the same in both rural and urban areas (Heltberg, 2005).

Household size- interestingly, we find a positive relationship between household size and solar adoption, though the average marginal effects are statistically insignificant, meaning that the addition of one household member has no effect on solar adoption. Likewise, Heltberg (2004) and Pundo and Fraser (2006) find no significant relationship between fuel switching and family size. In the literature, particularly those studies on energy switching from lower to higher points on the energy ladder, there are two opposing findings. There are those who find a positive and significant effect for household size on solid fuels. They argue that an increasing family size suggests that there is an abundance of labour available for fuel collection, which limits the need to move to modern fuels purchased in markets. In addition, in order to feed a large family, a large amount of fuel is needed, therefore a large family is more likely to rely on cheap fuel sources, such as firewood and charcoal, for cooking and lighting than to shift to modern energy sources. Furthermore, Rao and Reddy (2007) mention that having a large family in developing countries is often related to having a lower income, hence income prohibit their capacity to purchase commercial fuel. On other hand, Hosier and Dowd (1987) find that larger households are more likely to move away from fuel wood towards kerosene, but they are less likely to move to electricity and solar in place of kerosene and fuel wood.

Availability of institutions in the village- We analyze the influence of institutions in the community with the idea that institutions, such as secondary schools, health centres, commercial banks, and financial institutions, are the basis of economic development for a community. The presence of these institutions may be related to infrastructure development in the community. Infrastructure can trigger solar diffusion in the community indirectly through market integration. In theory, we expect that the availability of commercial banks and financial institutions in a village can influence solar adoption through several channels including loans to finance economic activities, such as farming, and directly through financing the initial investment cost of solar. The base category is villages without any institutions. Our results indicate that the availability of institutions in a village has a positive effect on solar adoption. However, when we include only financial institutions in our model, the significance disappears. A possible explanation is that our sampled households financed their initial solar investment costs themselves. Households were asked how they paid for solar investment and none of them responded with loans from a commercial bank or saving group. Moreover, most commercial banks and credit markets rarely finance poor households because most of the rural poor lack collateral, such as a land title, which is necessary in acquiring a loan from the formal credit market.

Treatment- is the planned grid connections where villages that were targeted to be connected to the grid were surveyed alongside with control villages to evaluate the impact of the grid connection. Results indicate that there is no significant difference in solar adoption between the treatment and control villages. But we might have expected a negative effect for the treatment as households in the treatment village expect the grid to be extended to them in the future, but this does not appear to be the case. Nevertheless, the planned electrified villages (treatment) and chosen non-planned electrified villages (control) do not differ in principle because control villages were carefully selected such that they have similar characteristics to the treatment villages. Therefore, there should not be any substantial difference in the predicted probability of solar adoption between the treatment and control villages. Nevertheless, the treatment variable is one of the factors which explains investment in iron roofing. We find that those households who are living in the planned grid connection are more likely to invest in an iron roof. The influence of the treatment is about 7%, holding other factors constant. Indeed, we expect a positive association between villages who are targeted to receive a grid connection and iron roofing investment, for the reason that villagers were aware of the TANESCO grid connection in the near future. In some scenarios during our survey, households were optimistic for an electric grid connection in the near future and therefore showed a level of preparedness by buying some electric appliances and cabling for electric energy well in advance. Furthermore, because one of the prerequisites for TANESCO customers to be connected with the grid is iron roofing, the households that aspired to the electricity connection from TANESCO were more likely to invest in iron roofing.

To summarize, the treatment has a major effect on iron roofing investment for the reasons related to grid connection, but there is no effect of the treatment on solar adoption.

Regional Fixed Effects - In order to control for the effect of location on solar adoption, we include dummies for the respective district. It is important to control for location because farmers, including livestock owners, may face slightly different factors that could affect livestock keeping. However, the four sampled districts have similar economic characteristics and are among the regions with the lowest access to electricity in the country. All regions are non-electrified rural areas that are heavily dependent on diesel generators for electricity. Nevertheless, we find some degree of regional effects on iron roofing investment and mobile phone accessibility. Households who live in Mpanda and Nsimbo are less likely to have mobile phone access and invest in an iron roof than the base region of Biharamulo. With respect to mobile phone access, the difference is statistically insignificant for the Ngara region compared to the base region. These two districts share the same border, are in the same administrative region and are more economically connected than the Nsimbo and Mpanda regions from western Tanzania. Furthermore, we find a certain degree of regional effects on solar adoption among the four locations. All districts show a positive influence of regional effects on solar adoption when compared to the base region of Biharamulo. Similarly, there is no statistically significant difference in regional effects between the Ngara region and the base region of Biharamulo.

5.0 Conclusion

In this paper our goal was to examine whether households in developing countries can self-finance solar home systems through livestock ownership. We carry out our analysis by estimating a binary latent model of livestock ownership on three selected outcomes, namely the adoption of home system, mobile phone access and iron roofing investment. Our analysis is based on off-grid households from four districts in mainland Tanzania. We hypothesized that mobile phone access and iron roofing investment as criterion for a consumption preference for modern goods through livestock sales. The argument follows that if households can invest in iron roof and have access to a mobile phone by financing them through livestock that would also indicate an ability to finance the installation of a solar home system. Indeed, we have shown that livestock assets can be used to finance large household investments, such as solar panels, which is beneficial for the environment compared with using solid fuels and transition energy sources. We have also shown that households who keep livestock and admire modern consumption, such as iron roofing and mobile phones, are more likely to adopt newly introduced solar technology. We have examined the livestock owners' consumption behavior on iron roofing and mobile phone accessibility and found that at low- and middle-expenditure levels, there is a significant difference in the consumption of modern goods between livestock and non-livestock owners. The significance dies out at very extreme expenditure levels. We argue that the two selected goods are both common and important among households. Specifically, mobile phone technology is wide spread in most rural areas and outweighs the penetration and adoption of solar technology as the most desirable product across all income levels and has now become a basic necessity. Access to a mobile phone is dictated by its price and per capita income, therefore at higher expenditure levels, both livestock and non-livestock owners are more likely to have access to a mobile phone. Similarly, the probability of adopting solar technology is higher for livestock owners than non-livestock owners and the differences are increasing significantly with higher levels of expenditure. In contrast, we find no statistically significant differences at lower- and some middle-expenditure levels. We argue that poor families tend to keep small livestock and poultry farming, such as rabbits and chicken, which may not generate enough sales to allow poor families to afford solar panels. On the other hand, at lower- and middle-expenditure levels, livestock owners can decide to accumulate livestock due to a lack of incentives and postpone investing in solar. Furthermore, we have shown that solar diffusion is among the major factors contributing to difference in adoption between livestock and non-livestock owners. Also, the education level of the household head is positively correlated with solar adoption, particularly at higher education levels where households may be aware of the environmental benefits of solar and are therefore more likely to switch from solid fuel sources to green energy sources. In terms of gender, we notice statistically significant differences of solar adoption between female- and male-headed households. Female-headed households are less likely to adopt solar technology than male-headed households. Also, female-headed households that do not own livestock, are less likely to have installed solar panels on their homes than male-headed households that have livestock. The difference tends to increase as the level of expenditure increases, implying that poor female-headed households are more disadvantaged with regards to owning assets and the effect is translated into investment, which could in principle increase productivity and improve their living standard. The difference tends to decline marginally for male-headed households that own livestock in comparison to female-headed households that also own livestock. However, the pattern remains the same as the level of expenditure increases. In conclusion, livestock as a buffer stock to smooth consumption during adverse risks, can also finance large investments, such as solar panels, which in turn would improve the lives of the rural-poor. However, our results should be taken with care because we are constrained by cross-sectional data in an attempt to determine if livestock saving can be used to finance solar. Furthermore, a non-precautionary savings for the solar investment is discussed in terms of ownership of livestock rather than number of livestock and sale income from livestock. In principle, both the sale and purchase of livestock in a dynamic model can better explain saving behavior. We are aware of these short-comings and we encourage future research in this area. Nevertheless, our results provide evidence on the role of livestock assets on solar investment in a credit constrained environment.

5.1 Policy Implications

Despite solar energy having very strong economic and environmental benefits over other energy sources, some poor farmers can hardly afford solar panels because of a lack of financing. On the other hand, the slow spread of technology within national borders constrains those who are endowed with livestock assets as their desire to acquire and utilize such technologies also prevents them from saving and investing, thus maintaining poor living conditions. It is the role of the government to streamline the implementation of the 2015 national energy policy, which aims to facilitate the adoption and use of solar energy technology. Although the policy statement is to "Create awareness on potential opportunities and economic benefits offered by solar energy technologies," the lack of an enforcement provision prevents on implementation of the policy. As such, an enforcement mechanism should be implemented. Furthermore, steps should be taken to ensure awareness solar technologies in the region such as awareness campaigns. Some of the problems relate to the quality of solar products, which come from global companies. To address this issue, awareness campaigns should educate the public on the differences between high- and low-quality products, while also encouraging greater supply of higher quality products by mandating set standards. We have shown that livestock ownership has a role on solar adoption and even on the consumption of modern goods. The government should revisit the livestock sector to ensure that it meets current demand, as there is insufficient supply of the livestock in the country. As a result, farmers will benefit from the available market of meat and meat products due to the increased livestock productivity in the country. Other related issues that are important for pastoral societies are land ownership and tenure security. Although, the government is now incorporating land issues in its development agenda and resolving complex land related problems, the conflicts of pastoral-farmers are not given at same attention as urban related problems. The government should take further steps in resolving pastoral-farmer land conflicts by ensuring that the security of land rights is guaranteed and enforced.

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Appendix

Table 1 summary statistics and variable description

Variable	Definition	N	Mean	Std. Dev.	Expected sign
Solar	Binary variable for the solar installed households	1000	0.163		Outcome
Prevalence	Dummy , at least one household has solar in the village	1000	0.650		+
Expenditure	Annual expenditure in ' 000, 000 Tshs	765	3.14	3.29	
Log per capita expenditure	Logarithm of per capita annual expenditure	759	12.986	0.839	+
Age	Age of household head	975	42.354	13.437	-
Livestock	Binary variable for household own livestock	999	0.681		+/-
Household size	Household size	998	5.655	2.520	+/-
Female	Binary variable for female headed household	994	0.108		+/-
Education of head of the household	Tertiary education	20	0.02		+
	Secondary school education	114	0.114		+
	Primary school completed	629	0.629		-
	Primary school attended	130	0.130		-
	No school	106	0.106		-
*Institution	Binary variable for at least one institution available in a village	1000	0.420		+
Treatment	Binary variable for r the planned national grid	1000	0.540		+/-
Region of residence	Biharamulu	200	0.20		+/-
	Mpanda	170	0.17		+/-
	Ngara	400	0.40		+/-
	Nsimbo	230	0.23		+/-
Phone	Dummy for household members who have access to the mobile phone	1000	0.834		+
Iron roof	Dummy for households with iron roofing	999	0.797		+

Notes: *Institution- consists of available heath centers, secondary schools, financial institutions in the village

Source; Author's computation

Table 2: Factors influencing solar adoption in rural Tanzania

	(1)	(2)	(3)
Variables	Coeff	Odds ratio	Marginal effects
livestock	0.344**	1.411**	0.0299**
	(0.160)	(0.225)	(0.0133)
Solar prevalence	1.940***	6.960***	0.168***
	(0.368)	(2.560)	(0.0200)
Log per capita exp.	0.285***	1.330***	0.0274**
	(0.100)	(0.133)	(0.0117)
Age	-0.0121**	0.988**	-0.00117**
	(0.00509)	(0.00503)	(0.000527)
Sex	-0.953***	0.386***	-0.0504***
	(0.293)	(0.113)	(0.0156)
Household size	0.0499*	1.051*	0.00480
	(0.0299)	(0.0315)	(0.00297)
Institutions	0.333**	1.395**	0.0337**
	(0.142)	(0.199)	(0.0167)
Secondary school	-1.174***	0.309***	-0.311*
	(0.450)	(0.139)	(0.159)
Primary school	-1.499***	0.223***	-0.345**
	(0.436)	(0.0973)	(0.159)
School attendant	-1.501***	0.223***	-0.345**
	(0.470)	(0.105)	(0.160)
No school	-1.098**	0.334**	-0.300*
	(0.486)	(0.162)	(0.161)
Mpanda	0.710***	2.034***	0.0754**
	(0.240)	(0.488)	(0.0332)
Ngara	0.0957	1.100	0.00565
	(0.218)	(0.240)	(0.0126)
Nsimbo	0.795***	2.214***	0.0909***
	(0.227)	(0.502)	(0.0306)
Treatment	0.0456	1.047	0.00438
	(0.141)	(0.148)	(0.0136)
Constant	-5.608***	0.00367***	
	(1.493)	(0.00548)	
Observations	741	741	741

Notes: Robust standard errors in parentheses

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

Base category; Tertiary education

Source; Author's estimation

Table 3: Factors influencing solar adoption in rural Tanzania

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Logit coeff	Odds ratio	Logit coeff	Odds ratio	Logit coeff	Odds ratio
Livestock	0.283*	1.327*	0.336**	1.400**	0.280*	1.323*
	(0.158)	(0.210)	(0.160)	(0.224)	(0.158)	(0.209)
Mobile phone	0.377*	1.457*	0.424*	1.527*		
	(0.223)	(0.326)	(0.221)	(0.338)		
Iron roofing	0.411**	1.509**			0.447**	1.563**
	(0.202)	(0.305)			(0.198)	(0.310)
Solar prevalence	1.929***	6.882***	1.948***	7.018***	1.919***	6.813***
	(0.378)	(2.600)	(0.369)	(2.587)	(0.377)	(2.571)
Log per capita exp.	0.231**	1.260**	0.254**	1.289**	0.254**	1.289**
	(0.104)	(0.131)	(0.102)	(0.132)	(0.103)	(0.132)
Age	-0.0121**	0.988**	-0.0115**	0.989**	-0.0126**	0.987**
	(0.00504)	(0.00498)	(0.00507)	(0.00501)	(0.00506)	(0.00499)
Sex	-0.896***	0.408***	-0.891***	0.410***	-0.946***	0.388***
	(0.294)	(0.120)	(0.297)	(0.122)	(0.291)	(0.113)
Household size	0.0388	1.040	0.0464	1.047	0.0413	1.042
	(0.0306)	(0.0318)	(0.0304)	(0.0318)	(0.0301)	(0.0314)
Institution	0.322**	1.379**	0.299**	1.348**	0.352**	1.422**
	(0.143)	(0.197)	(0.143)	(0.193)	(0.143)	(0.203)
Secondary school	-1.152***	0.316***	-1.152**	0.316**	-1.171***	0.310***
	(0.446)	(0.141)	(0.448)	(0.142)	(0.447)	(0.139)
Primary school	-1.512***	0.220***	-1.474***	0.229***	-1.539***	0.215***
	(0.435)	(0.0958)	(0.434)	(0.0994)	(0.436)	(0.0936)
School attendant	-1.510***	0.221***	-1.517***	0.219***	-1.496***	0.224***
	(0.468)	(0.103)	(0.470)	(0.103)	(0.467)	(0.105)
No school	-1.079**	0.340**	-1.060**	0.346**	-1.119**	0.327**
	(0.487)	(0.166)	(0.488)	(0.169)	(0.485)	(0.159)
Mpanda	0.940***	2.561***	0.758***	2.134***	0.912***	2.490***
	(0.259)	(0.664)	(0.242)	(0.515)	(0.258)	(0.643)
Ngara	0.112	1.118	0.115	1.122	0.0933	1.098
	(0.216)	(0.242)	(0.216)	(0.242)	(0.218)	(0.239)
Nsimbo	0.926***	2.525***	0.833***	2.301***	0.902***	2.464***
	(0.236)	(0.597)	(0.227)	(0.523)	(0.236)	(0.581)
Treatment	0.00858	1.009	0.0301	1.031	0.0198	1.020
	(0.143)	(0.145)	(0.142)	(0.146)	(0.143)	(0.146)
Constant	-5.512***	0.00404***	-5.610***	0.00366***	-5.465***	0.00423***
	(1.517)	(0.00613)	(1.516)	(0.00555)	(1.495)	(0.00633)
Observations	741	741	741	741	741	741

Notes: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Base category; Tertiary education
Source; Author's estimation

Table 4a The effect of livestock on mobile phone access and iron roofing

Variables	(1) Coeff	(2) Odds ratio	(3) Coeff	(4) Odds ratio
	Mobile Phone		Iron roofing Investment	
livestock	0.344***	1.410***	0.378***	1.459***
	(0.126)	(0.178)	(0.135)	(0.197)
Solar prevalence	0.232*	1.262*	0.292**	1.339**
	(0.126)	(0.158)	(0.147)	(0.196)
Log per capita exp.	0.330***	1.392***	0.344***	1.411***
	(0.0882)	(0.123)	(0.0876)	(0.123)
Age	-0.00679	0.993	0.00711	1.007
	(0.00422)	(0.00419)	(0.00489)	(0.00493)
sex	-0.558***	0.572***	0.0556	1.057
	(0.171)	(0.0978)	(0.197)	(0.209)
Household size	0.0425	1.043	0.0767**	1.080**
	(0.0272)	(0.0283)	(0.0300)	(0.0324)
Institution	0.228*	1.256*		
	(0.122)	(0.153)		
Primary school	0.000121	1.000	0.307**	1.359**
	(0.140)	(0.140)	(0.153)	(0.207)
Post primary school	0.271	1.311	0.146	1.158
	(0.231)	(0.303)	(0.220)	(0.255)
Mpanda	-0.773***	0.462***	-1.955***	0.142***
	(0.212)	(0.0979)	(0.231)	(0.0327)
Ngara	-0.480***	0.619***	-0.0208	0.979
	(0.176)	(0.109)	(0.222)	(0.218)
Nsimbo	-0.670***	0.512***	-1.596***	0.203***
	(0.209)	(0.107)	(0.224)	(0.0453)
Treatment			0.356***	1.428***
			(0.130)	(0.185)
Constant	-3.194***	0.0410***	-4.186***	0.0152***
	(1.178)	(0.0483)	(1.221)	(0.0186)
Observations	741	741	741	741

Notes: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Base category; no school attended
Source; Author's estimation

Table 4b Average marginal effect of mobile phone access and iron roof investment

Variables	(1) Marginal effects	(2) Marginal effects
	Mobile Phone	Iron Roofing
livestock	0.0844**	0.0783***
	(0.0330)	(0.0303)
Solar prevalence	0.0551*	0.0580*
	(0.0304)	(0.0305)
Log per capita exp.	0.0760***	0.0654***
	(0.0200)	(0.0162)
Age	-0.00156	0.00135
	(0.000969)	(0.000935)
sex	-0.157***	0.0103
	(0.0563)	(0.0356)
Household size	0.00977	0.0146***
	(0.00625)	(0.00561)
Institution	0.0514*	
	(0.0272)	
Primary school	2.90e-05	0.0624*
	(0.0334)	(0.0339)
Post-secondary	0.0560	0.0325
	(0.0454)	(0.0480)
Mpanda	-0.164***	-0.505***
	(0.0471)	(0.0551)
Ngara	-0.0857***	-0.00149
	(0.0288)	(0.0158)
Nsimbo	-0.135***	-0.363***
	(0.0418)	(0.0480)
Treatment		0.0689***
		(0.0251)
Observations	741	741

Notes: Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Base category; no school attended
Source; Author's estimation

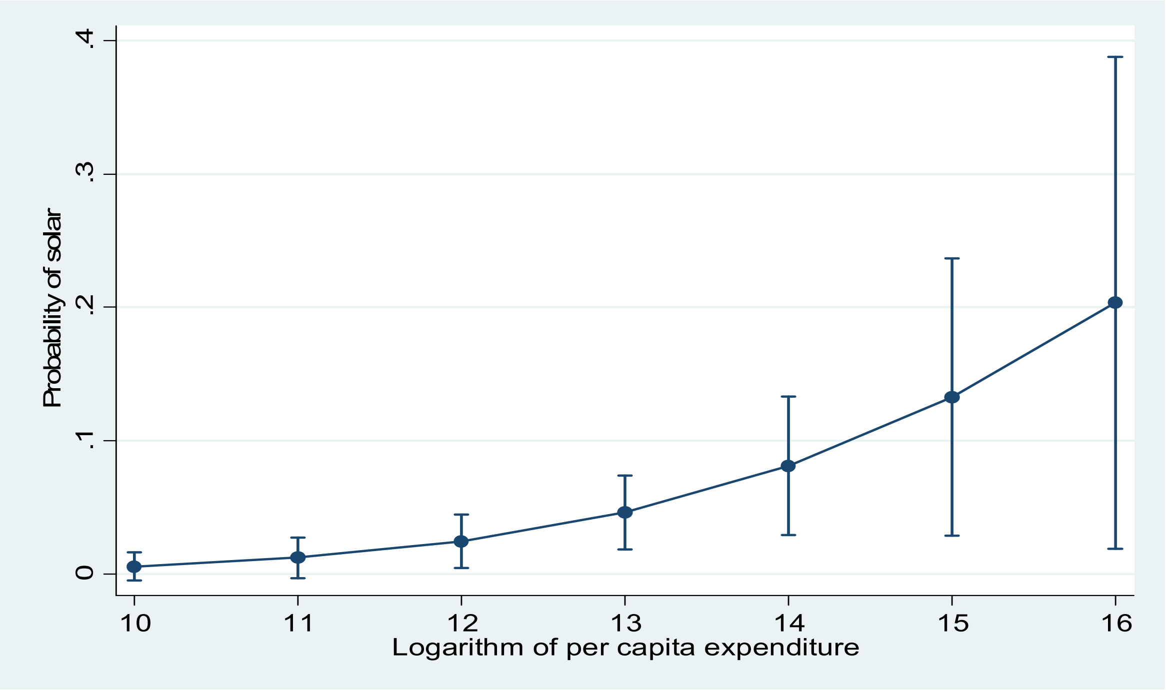

Figure 1a: Predicted probabilities effect of household expenditure on solar

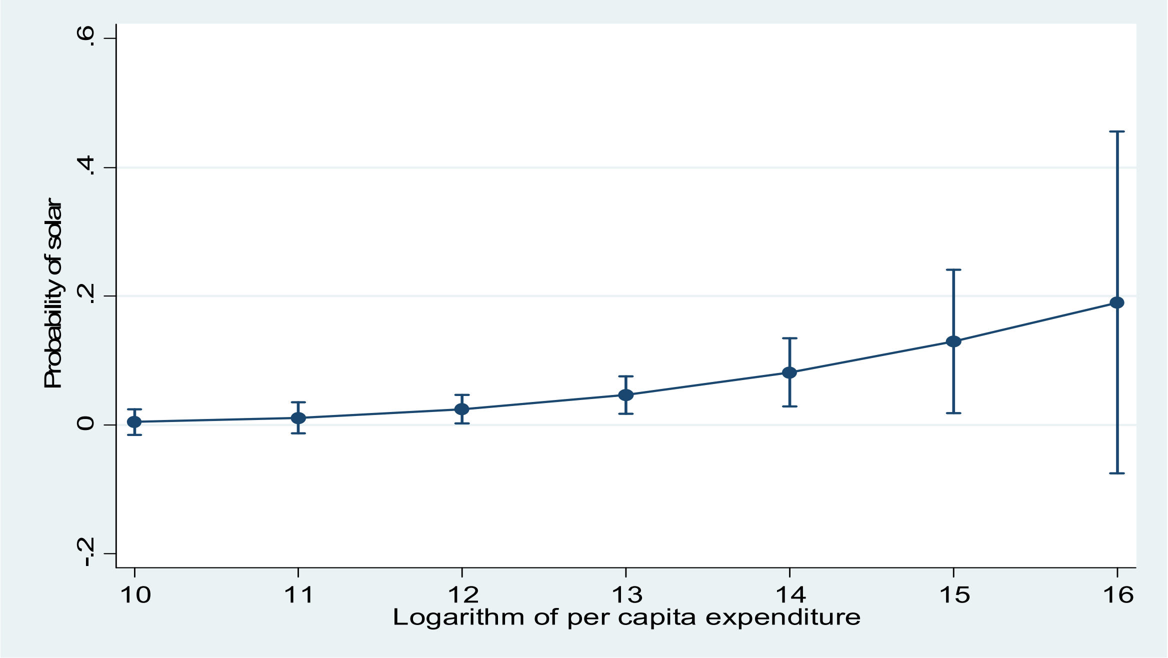

Figure1b: Predicted effect of livestock ownership on solar (Logarithm of expenditure square)

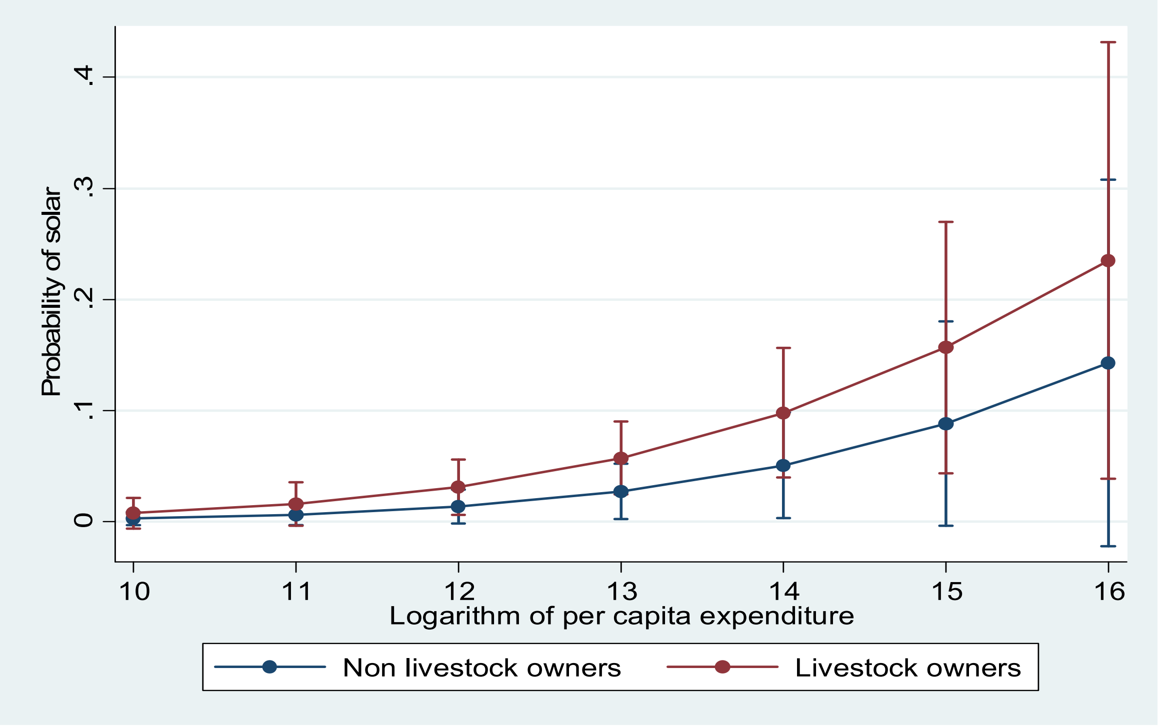

Figure 2a**:** Predicted effect of livestock ownership on solar

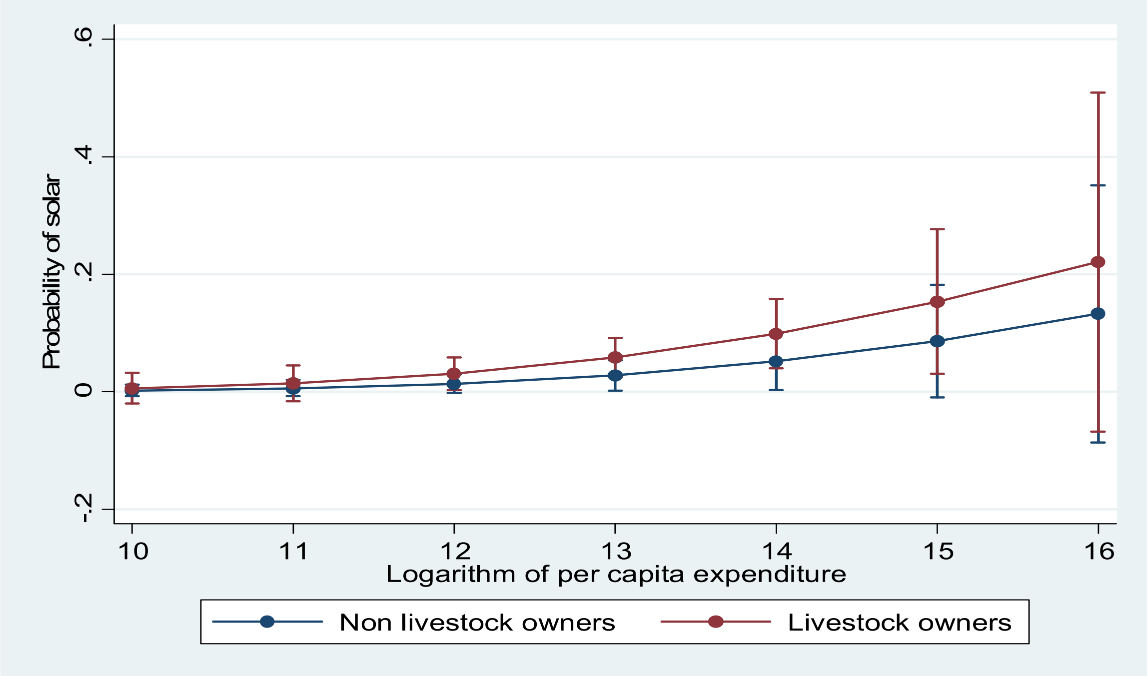

Figure 2b: Predicted probabilities of livestock on solar (Logarithm of expenditure square)

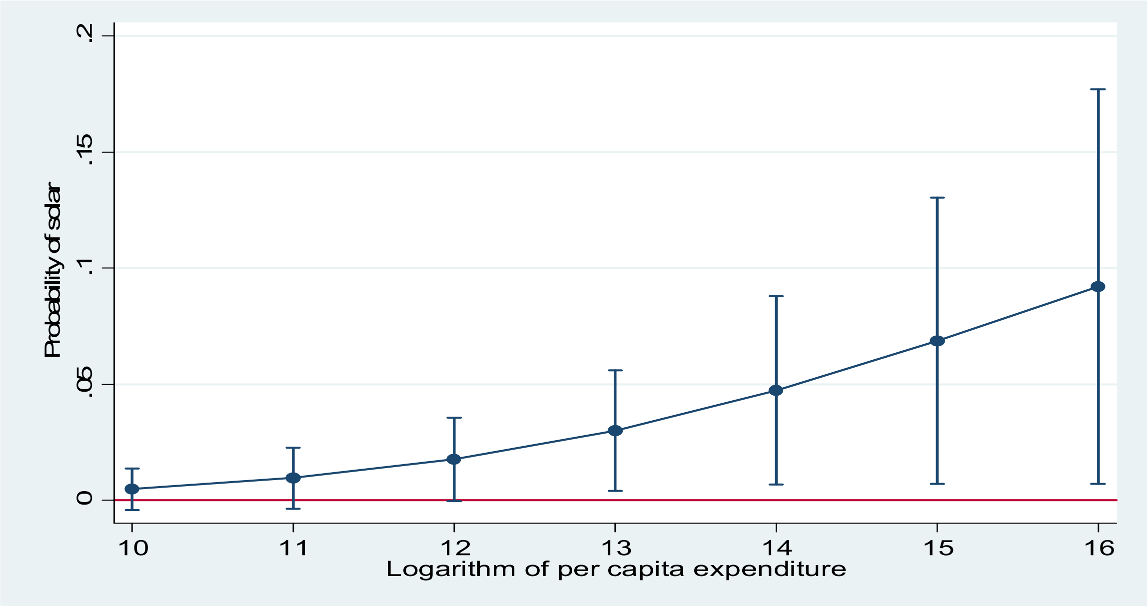

Figure 3: Marginal effects of livestock ownership on solar

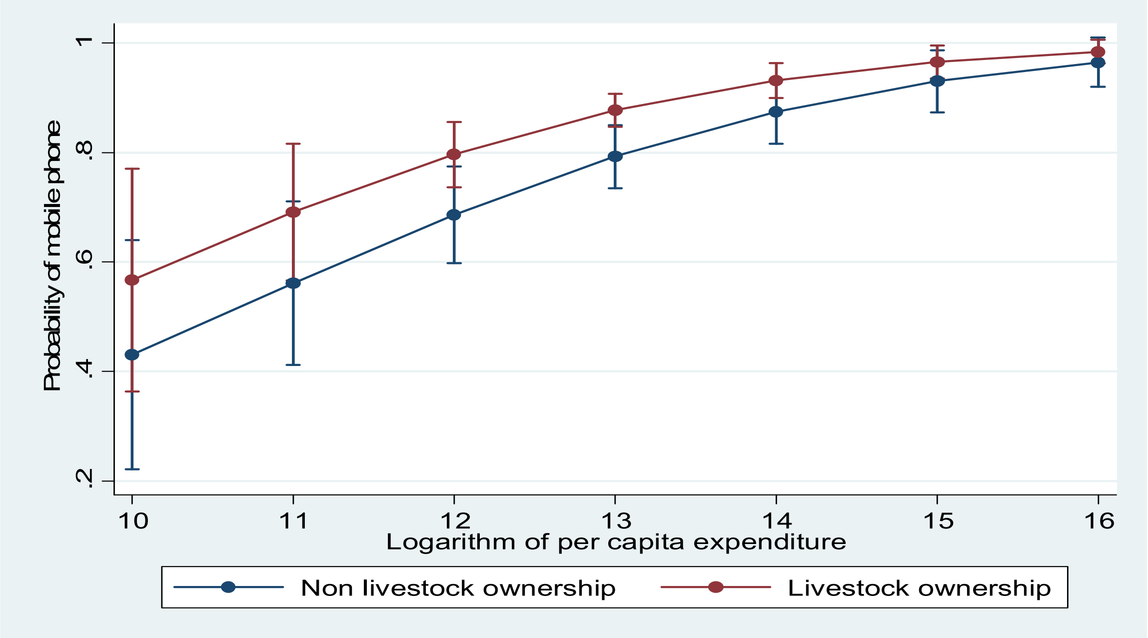

Figure 4a: Predicted effect of livestock ownership on phone

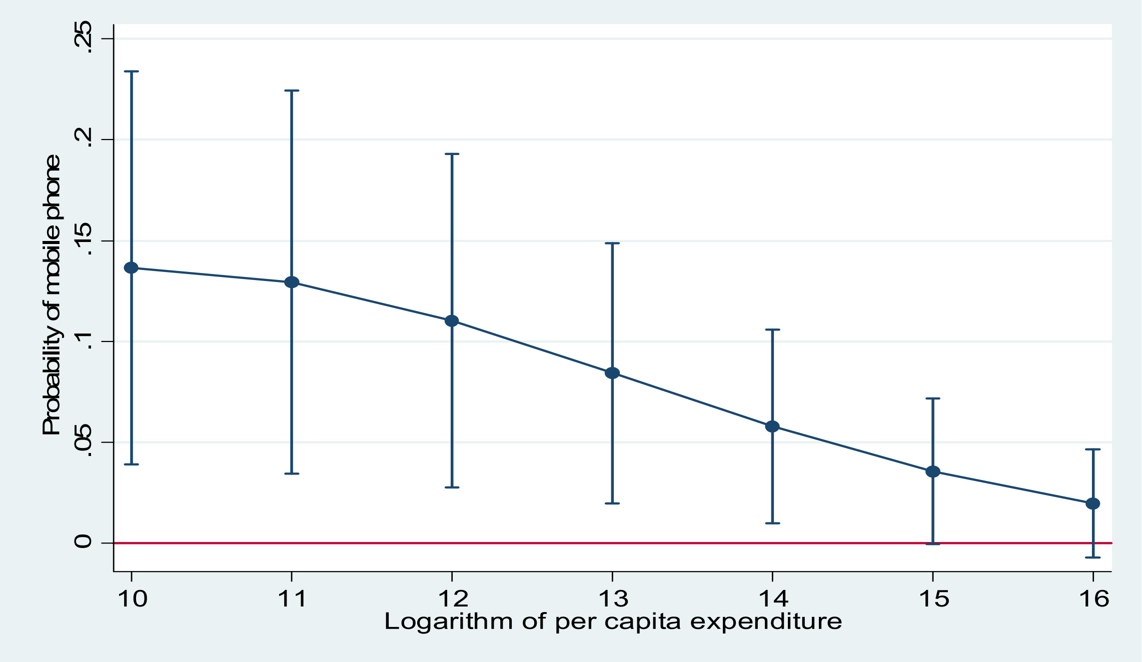

Figure 4b: Marginal effects of livestock ownership on phone

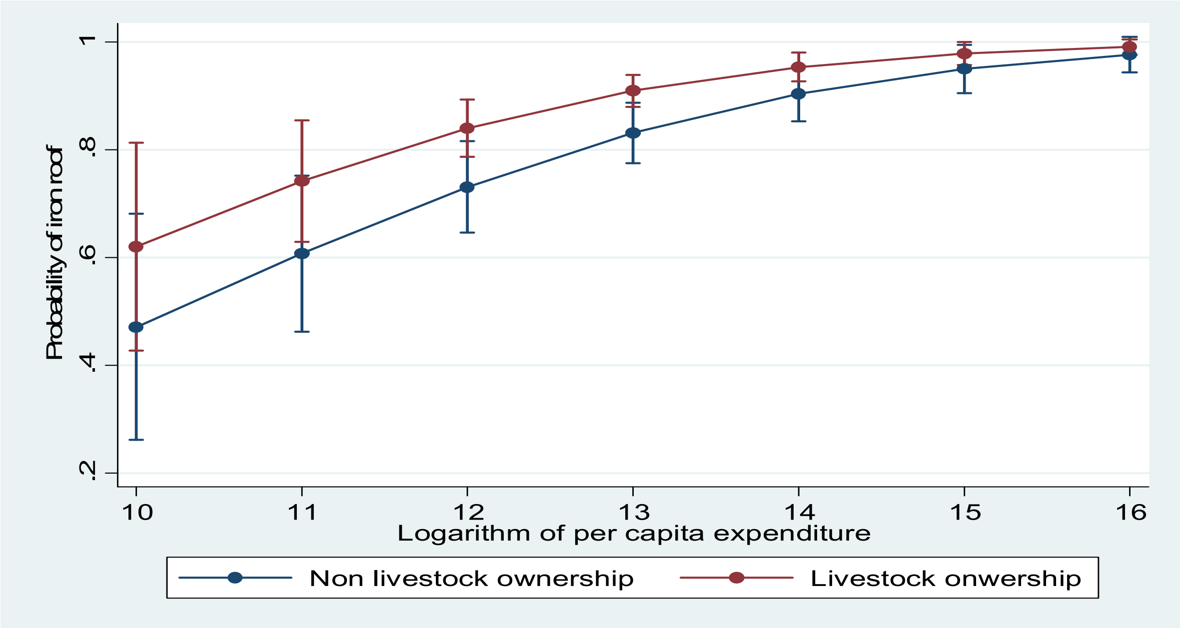

Figure 4c: Predicted effect of livestock ownership on roofing

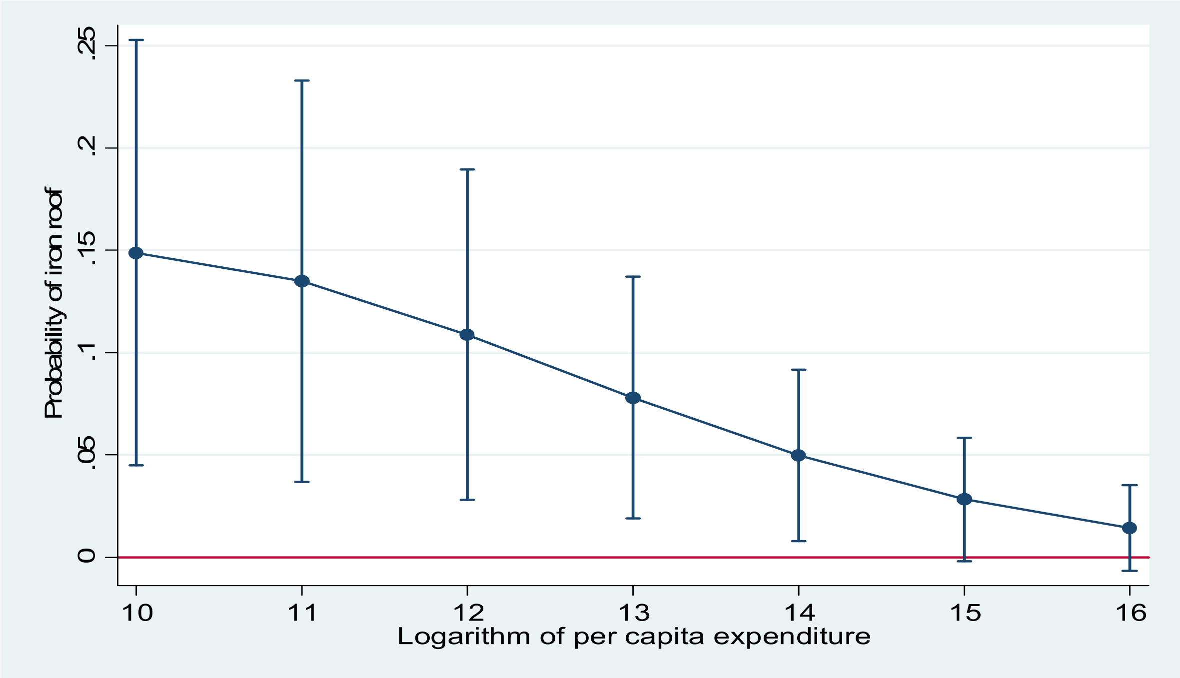

Figure 4d: Marginal effects of livestock ownership on roofing

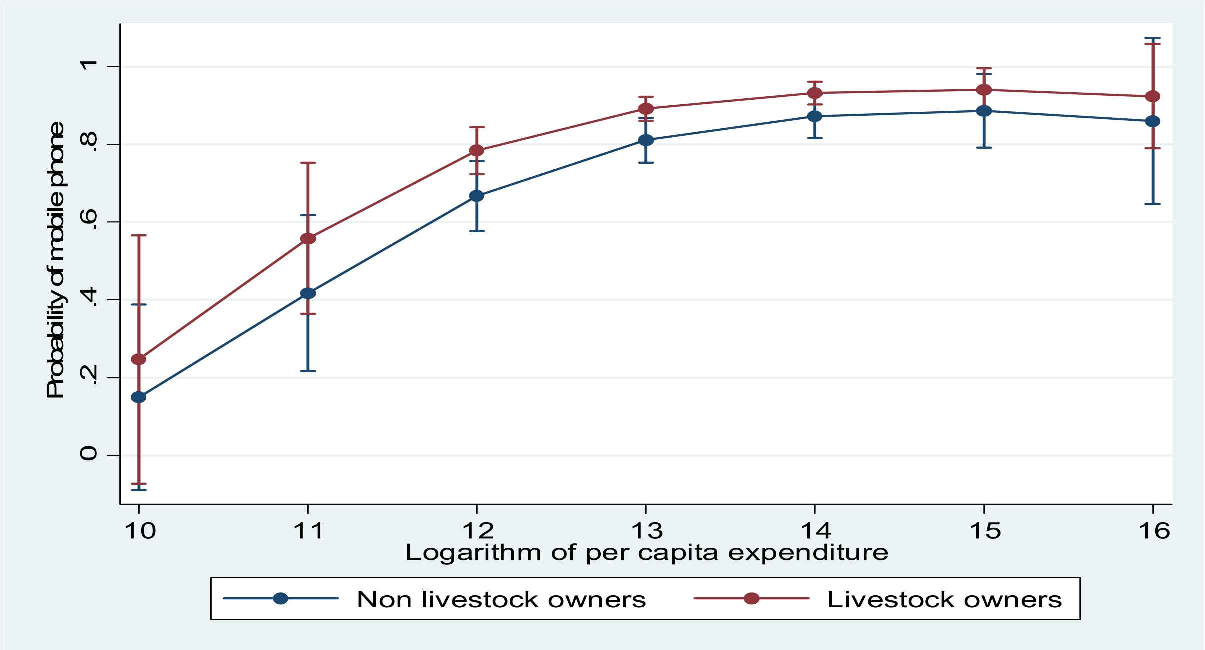

Figure 4e: Predicted margins of livestock on phone (logarithm of expenditure square)

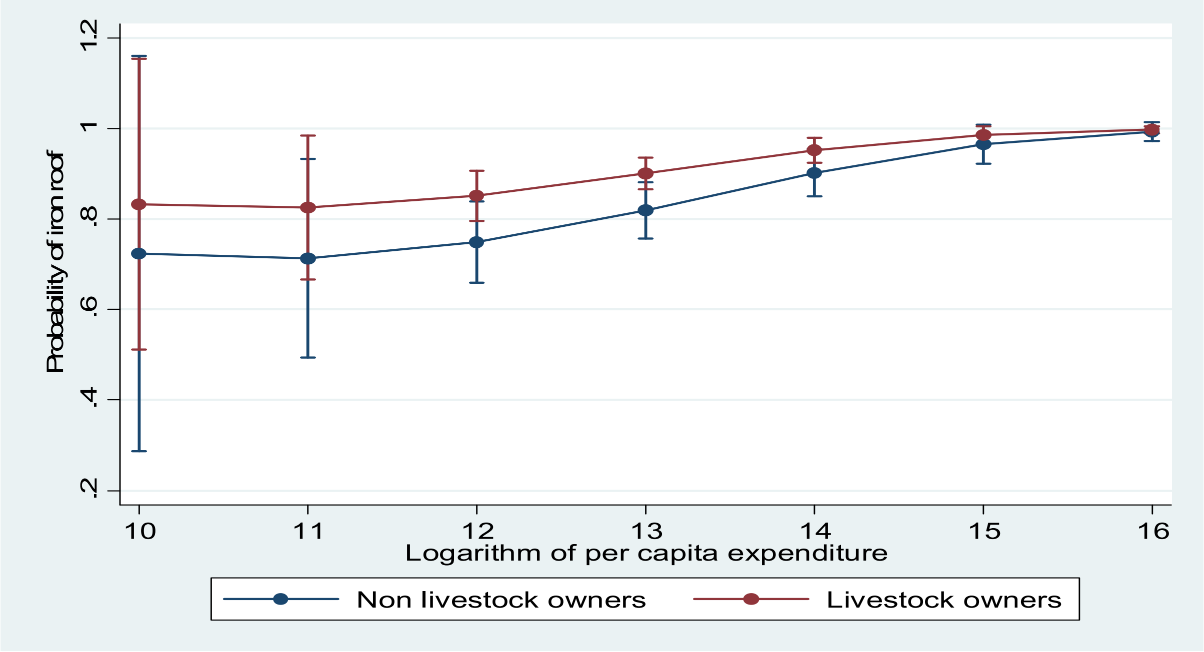

Figure 4f: Predicted margins of livestock on iron roof (logarithm of expenditure square)

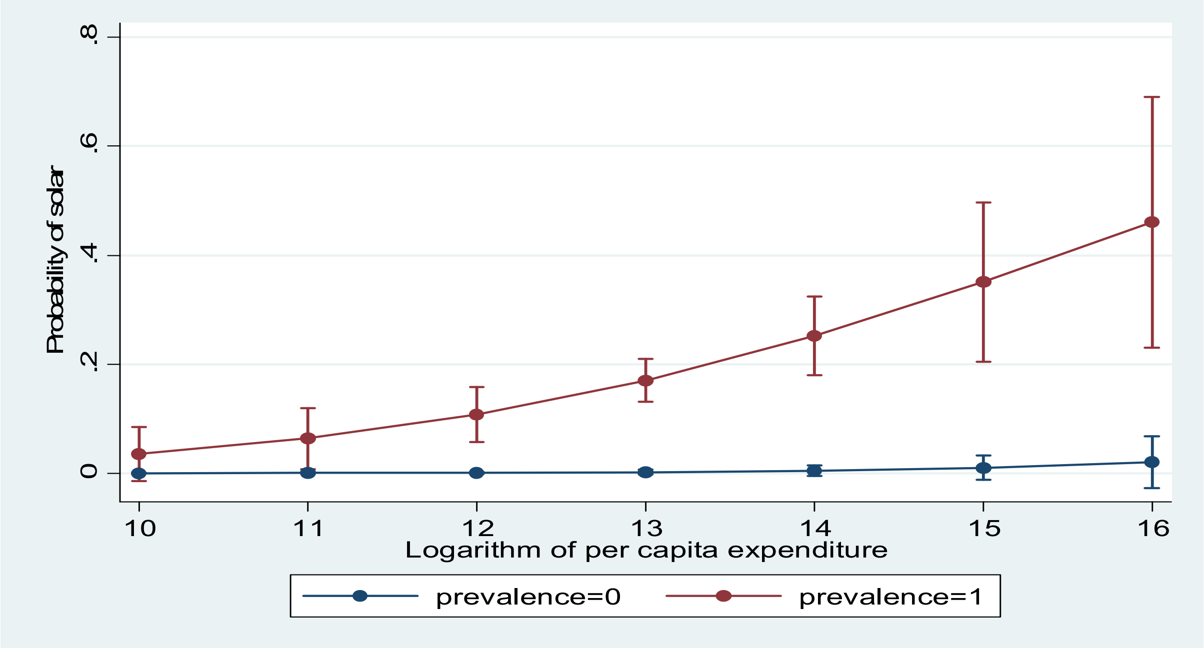

Figure 5a: Predicted effect of solar Prevalence on SHS

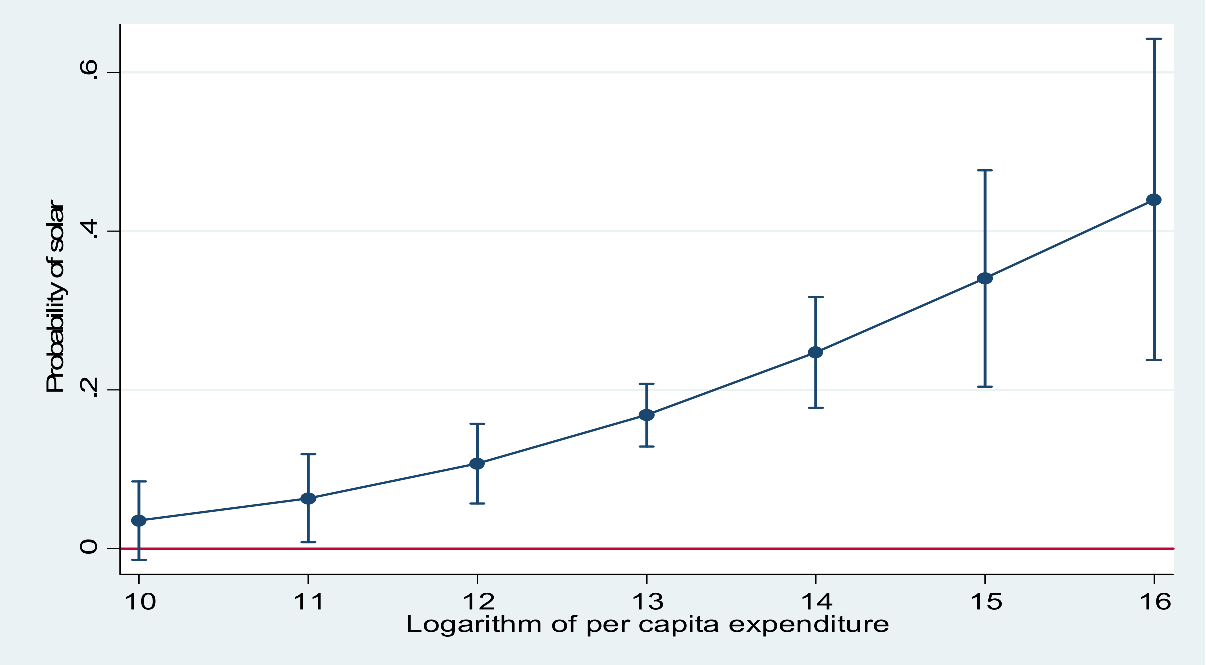

Figure 5b: Marginal effects of solar prevalence

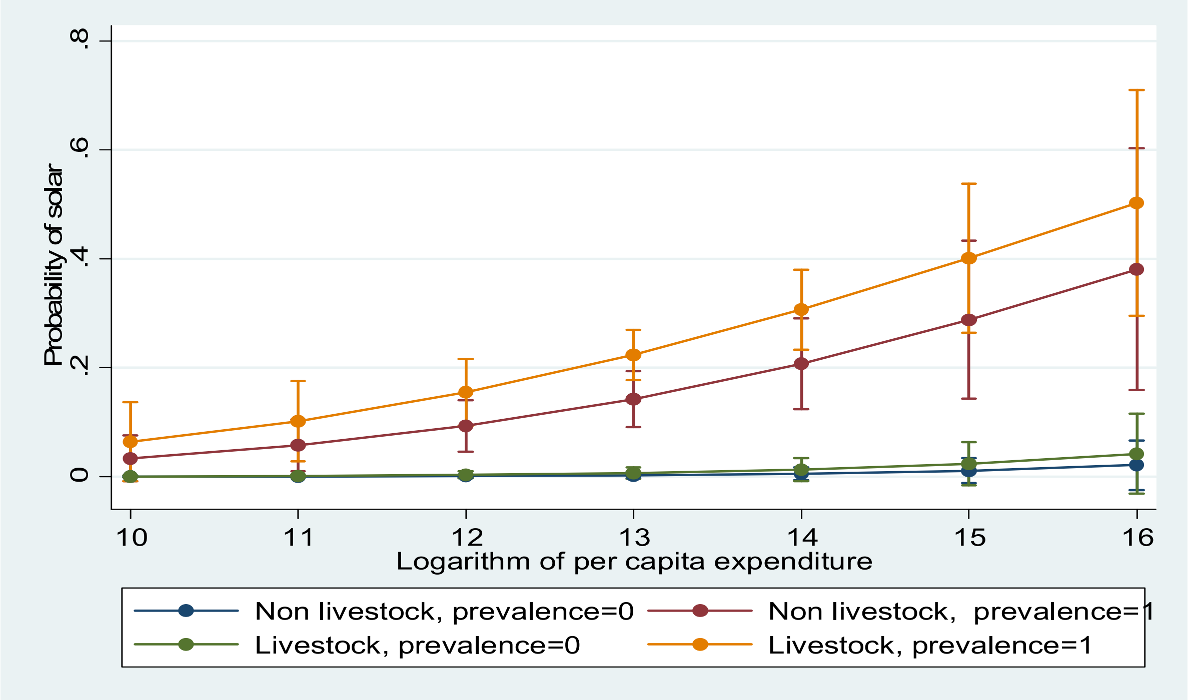

Figure 5c: Predicted effect of solar prevalence and livestock

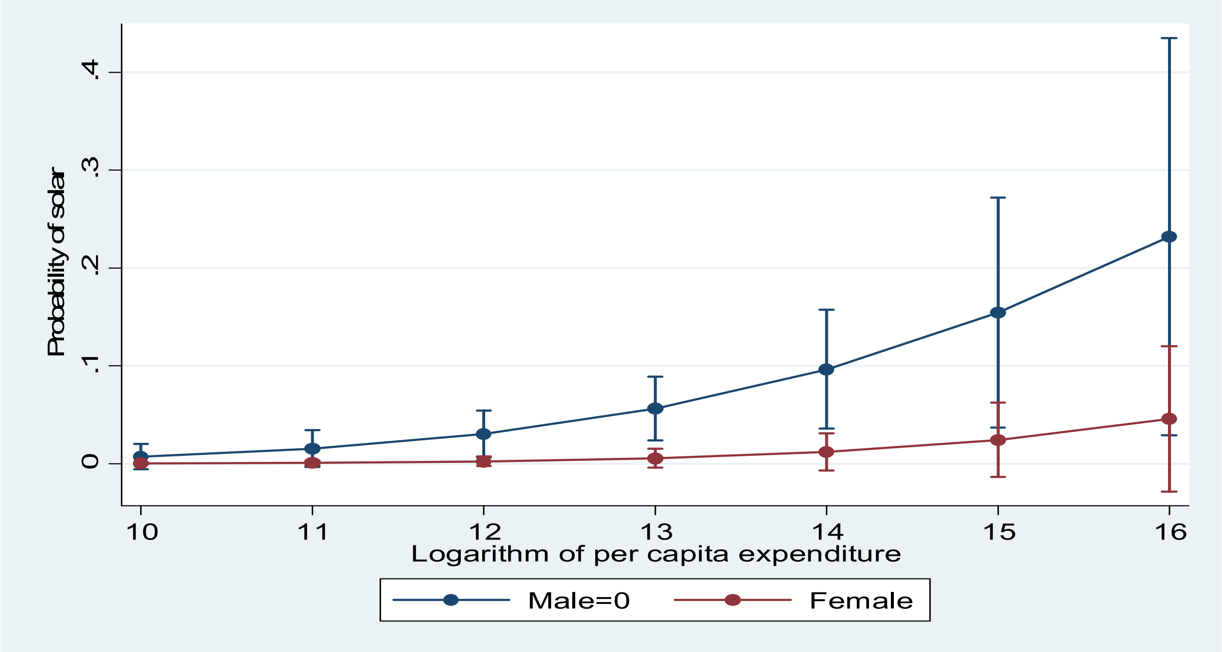

Figure 6a: Predicted effect of gender on solar

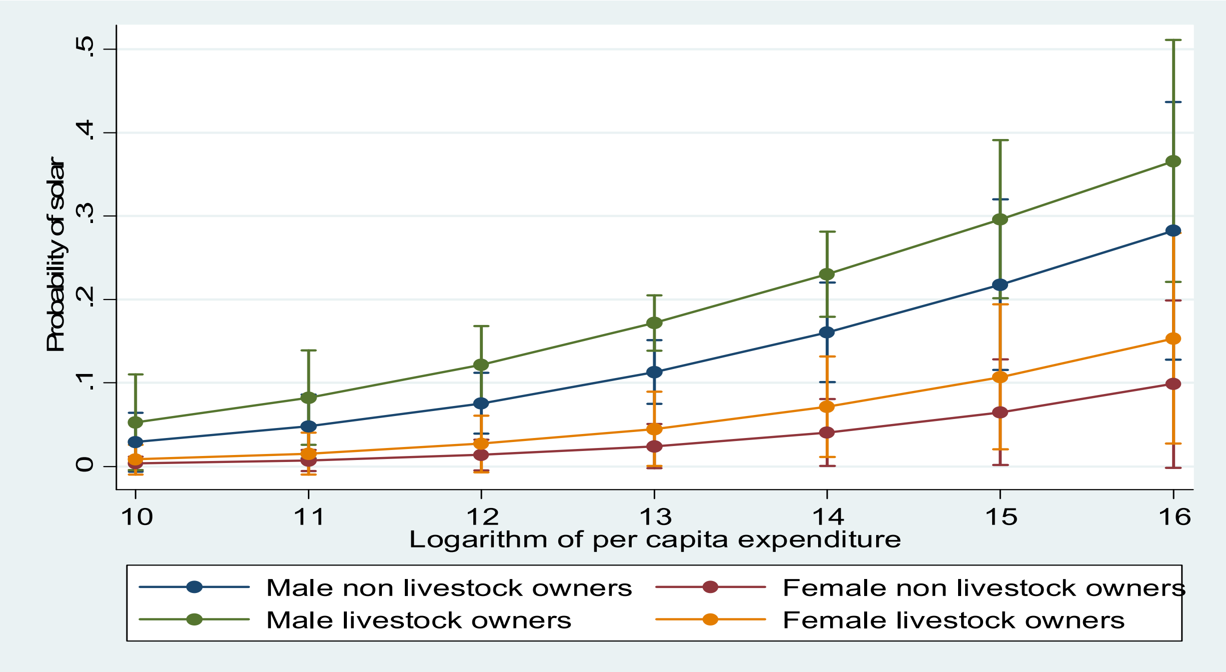

Figure 6b: Predicted effect of livestock and gender on solar

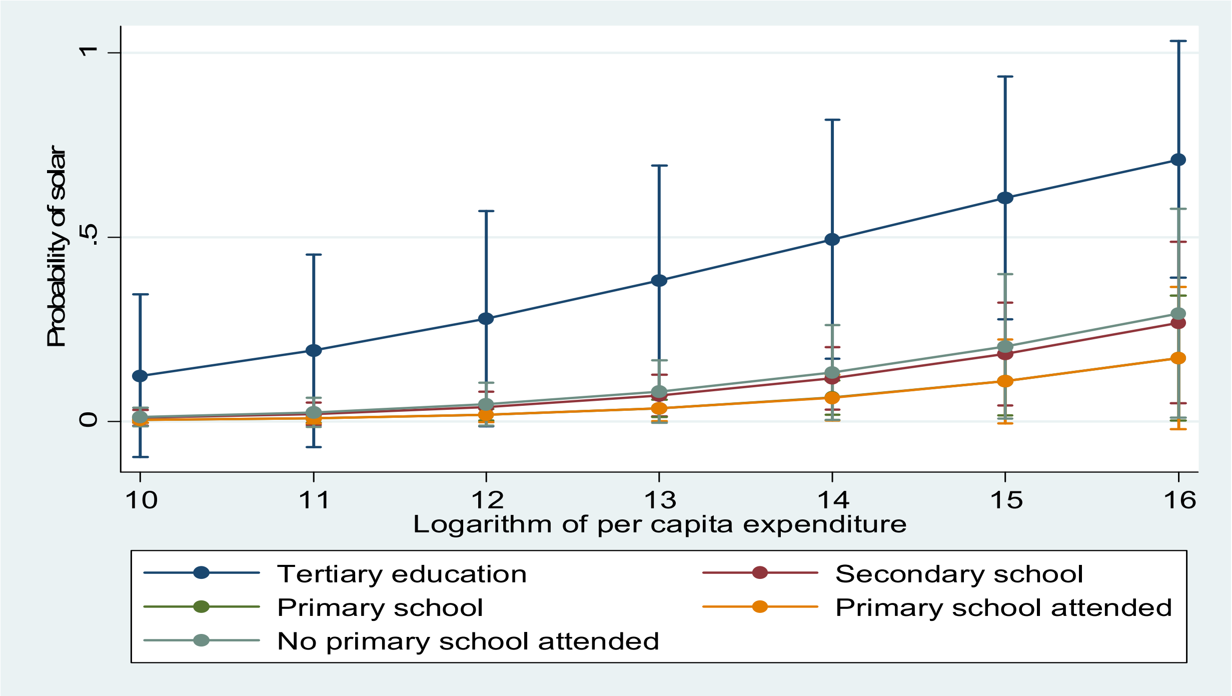

Figure 7a: Predicted effect of education on solar

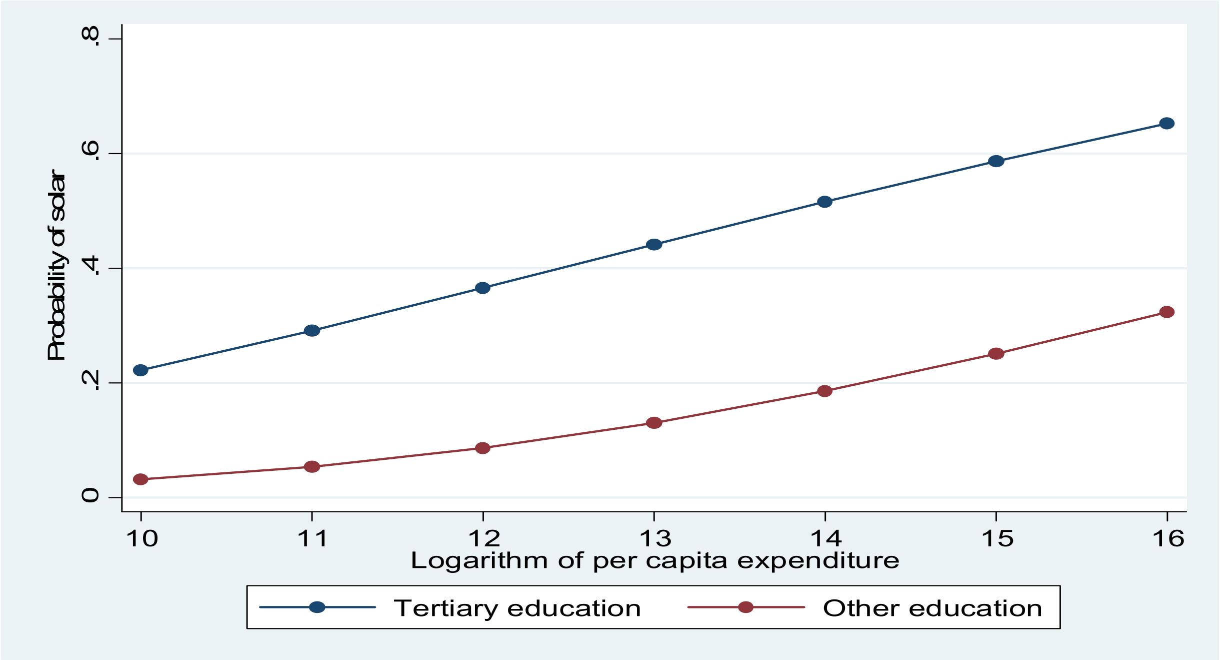

Figure 7b: Predicted effect of education on solar