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Abstract

During the last 10-15 years, mobile phone technologies have been widely adopted in most developing countries, including adoption by rural households that never had access to landline phones before. Existing research shows that use of mobile phones has improved market access for smallholder farmers and thus household income. Beyond income, mobile phones can possibly also affect other dimensions of social welfare, such as gender equality and nutrition. Such broader social welfare effects have hardly been analyzed up till now. Here, we address this research gap, using panel data from smallholder farm households in Uganda. Regression results show that mobile phones have significantly contributed to household income gains and women empowerment. Mobile phone use has also improved household food security and dietary quality. Simultaneous equation models are estimated to show that the positive nutrition effects are primarily channeled through the influence of mobile phones on household income and gender equality. Gender disaggregation reveals that female mobile phone use has stronger positive welfare effects than if males alone use mobile phones. We conclude that equal access to mobile phones cannot only foster economic development, but can also contribute to gender equality, food security, and broader social development.

1. Introduction

During the last 10-15 years, mobile phone technologies have been widely adopted in developing countries. Mobile phones have significantly improved people's access to information, especially for the rural poor who were never connected to landline phones before. Mobile phones have also reduced other types of transaction costs, thus improving the functioning of markets in various sectors, including agriculture, health, education, financial services, and many more (Fozdar and Kumar, 2007; Jensen, 2007; Duncombe and Boateng, 2009; Aker and Mbiti, 2010; Aker, 2011; Boulos et al., 2011; Aker and Ksoll, 2016; Blauw and Franses, 2016, Nakasone and Torero, 2016). Currently, about 4 billion people globally are using mobile phones. More than two-thirds of these people live in developing countries; with 89% the highest penetration of mobile phones being recorded in sub-Saharan Africa (PRC, 2015). People in Africa use their mobile phones for a large number of activities and services, including communication with business partners and friends via calls and text messages, access to news and various other types of information, financial transactions, and entertainment (PRC, 2015; UCC, 2015).

A growing body of literature has used micro-level data to analyze the effects of mobile phone use on market access, input and output prices, agricultural production patterns, and household income (Donner, 2007; Jensen, 2007; Aker, 2010; Aker and Mbiti, 2010; Aker, 2011; Kikulwe et al., 2014; Aker and Ksoll, 2016; Nakasone and Torero, 2016; Sekabira and Qaim, 2017). However, mobile phones can possibly also affect various other dimensions of social welfare, such as gender equality and nutrition. Understanding such broader effects is important especially against the background of the United Nations' Sustainable Development Goals, which go far beyond a narrow set of economic development indicators. While a few recent studies have conceptually discussed how mobile phones could influence food security and other welfare dimensions (e.g.,

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Aker and Mbiti, 2010; Nakasone et al., 2014; Nakasone and Torero, 2016), empirical data that actually measure such broader social outcomes are scarce.

Here, we address this research gap by using panel data from a farm household survey carried out in Uganda. In particular, beyond looking at income effects, we analyze impacts of mobile phone use on gender equality and nutrition. As in other African countries, mobile phones were adopted very rapidly in Uganda during the last 10 years and are now widely used even by very poor households in remote rural locations (Muto and Yamano, 2009; UCC, 2015; Munyegera and Matsumoto, 2016).

How can mobile phone use influence gender equality and nutrition? A few early studies discussed possible effects on gender roles (Bayes, 2001; Nath, 2001), yet without really evaluating them empirically. For farming households, improved market access through mobile phones will likely increase the degree of commercialization, which could reduce the decision-making power of women. Agricultural commercialization is often associated with men taking stronger control of agricultural production and income (Udry, 1996; Fischer and Qaim, 2012). On the other hand, women are often particularly constrained in their access to markets and information. Hence, if women themselves were able to use mobile phones, they could possibly benefit even more than men (Aker and Ksoll, 2016). This could contribute to women empowerment and improved gender equality within the household. Some of our data in Uganda were collected in gender-disaggregated form, so we are able to examine such aspects.

Nutrition effects of mobile phone use can occur through various pathways. Better market access and related income gains are typically associated with improved food security and dietary quality (Sibhatu et al., 2015). Changing gender roles within the household can also influence nutrition

(Fischer and Qaim, 2012). As women tend to spend more on healthcare and dietary quality than men, women empowerment can improve nutrition even in the absence of income gains (Quisumbing and Maluccio, 2003; Hoddinott, 2012). Furthermore, easier access to all sorts of news services and information through mobile phones may raise people's nutrition knowledge and awareness, which could also contribute to improved dietary practices.

2. Materials and Methods

2.1. Farm household survey

We use panel data collected in two survey rounds from randomly selected farm households in Masaka and Luwero Districts, Central Uganda. Farmers in these districts grow coffee as their major cash crop, in addition to banana, maize, sweet potato and various other food crops. Within the two districts, we used a two-stage sampling procedure, first selecting three locations and then randomly selecting farmers in each of these locations. The first survey round was conducted in 2012 and covered 419 farm households (Chiputwa et al., 2015). The second survey round was conducted in 2015, targeting the same households. Due to sample attrition, we had to replace 25 households. In addition, we increased the sample size to a total of 455 households in 2015. Additional households and replacements were randomly selected in the same locations. For the analysis, we use the unbalanced panel with 874 observations from 480 households.

In both survey rounds, we used a structured questionnaire for face-to-face interviews with the household head. Certain sections of the questionnaire were also answered separately by the spouse of the household head. The questionnaire focused on agricultural production and marketing, non-farm economic activities and income sources, household consumption, as well as

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other socio-demographic and contextual details. Household diets were assessed through a 7-day food consumption recall covering more than 100 different food items. We also asked for mobile phone ownership and use at the household level, as well as separately for different household members. In this study, we are particularly interested in the mobile phone use by male and female adults in each household. Similarly, ownership of assets was captured in a gender-disaggregated way.

2.2. Measurement of key variables

The main explanatory variable of interest in our analysis is mobile phone (MP) use. We consider a household to be a MP user if at least one adult household member owned a mobile phone during a particular survey year. Furthermore, we differentiate between households where only male adults own a mobile phone (MMP) and households where at least one female adult owns a mobile phone (FMP).

In terms of outcomes, we are particularly interested in household income, gender equality within households, and nutrition. Household income is measured as the total income of the household from all sources over a period of 12 months. For farm income, this also includes the value of production not sold in the market. The cost of production was subtracted for all income derived from self-employed activities. Annual household income is expressed in Ugandan shillings (UGX) (1 US\$ = 2,690 UGX). To be able to compare incomes between the two survey rounds, income in 2012 was adjusted to 2015 values using the official consumer price index (UBOS, 2015).

Gender equality within the household is measured in terms of the proportion of productive assets owned by women or jointly by male and female household members. The proportion refers to the

monetary value of the assets. Looking at asset ownership is common in the literature when assessing the economic situation of women within households (Quisumbing and Maluccio, 2003; Alsop et al. 2006; Doss et al., 2014). We are interested in how mobile phone use may influence asset ownership. In order to reduce possible issues of reverse causality, we do not consider very durable assets such as land or buildings. We only include short- and medium-term productive assets such as agricultural equipment (hoes, saws, wheelbarrow, sprayers etc.) and vehicles (bike, motorbikes, trucks etc.). In male-dominated households, such assets are predominantly owned by the male household head or other male members. A larger proportion of such assets being owned by females or jointly owned by male and female household members can be interpreted as a higher degree of women empowerment.

Nutrition outcomes can be measured in different ways, including anthropometric indicators, food consumption based measures, and households' subjective assessments of food access (Ruel, 2003; Masset et al., 2012; Shiferaw et al. 2014; Kabunga et al., 2014; Chiputwa and Qaim, 2016). Here, we are particularly interested in how mobile phones affect household food consumption and dietary practices, which we measure through household dietary diversity scores. Dietary diversity scores count the number of different food groups consumed over a specified period of time and are a common tool to assess food security and dietary quality (Ruel, 2003; Jones et al., 2014; Koppmair et al., 2017). Dietary diversity was also shown to be a good proxy of child nutritional status in many situations (Arimond, 2004).

We use the data from the 7-day food consumption recall to calculate two types of dietary diversity scores (DDS) at the household level. First, we use a DDS with 12 food groups, as is common in the literature to calculate household dietary diversity scores for food security assessment (Kennedy et al., 2011). The 12 food groups considered are: cereals; white roots and

tubers; vegetables; fruits; meat and poultry; eggs; fish; pulses, legumes and nuts; milk and milk products; oils and fats; sugar and honey; and spices, condiments, and beverages. Second, we use a DDS with only 9 food groups, excluding the following three: oils and fats; sugar and honey; and spices, condiments, and beverages. These three food groups are calorie-dense but contribute little to micronutrient consumption. Hence, the DDS with only 9 food groups included is generally considered a better indicator of dietary quality (Sibhatu et al., 2015).

2.3. Econometric strategy

We aim to estimate the impact of mobile phone use on household income, gender equality, and nutrition, using the two-round panel data from farm households in Uganda. We start by looking at the three outcomes separately and estimate the following reduced-form panel data models:

$$Y_{it} = \beta_0 + \beta_1 MP_{it} + \beta_2' \mathbf{X}_{it} + \beta_3 T_t + \varepsilon_{it} \tag{1}$$

$$GE_{it} = \beta_0 + \beta_1 MP_{it} + \beta_2' \mathbf{X}_{it} + \beta_3 T_t + \varepsilon_{it} \tag{2}$$

$$N_{it} = \beta_0 + \beta_1 MP_{it} + \beta_2' \mathbf{X}_{it} + \beta_3 T_t + \varepsilon_{it} \tag{3}$$

where Y_{it}, GE_{it}, and N_{it} are the indicators of income, gender equality, and nutrition, as explained above, referring to household i in year t. MP_{it} is a dummy variable that takes a value of one if any adult in the household owned and used a mobile phone in year t, and zero otherwise. $\mathbf{X}_{it}$ is a vector of farm, household, and contextual characteristics, T_t is a year dummy for 2015, and ε_{it} is a normally distributed random error term. Equations (1) to (3) are estimated separately. We are particularly interested in the estimates for β_1. Positive and significant estimates would imply that mobile phone use increases household income, gender equality, and nutrition after controlling for

other factors.

In a second set of estimates, we use the same reduced-form equations (1) to (3) but replace the aggregate mobile phone use dummy with gender-disaggregated dummies. As explained above, we use FMP_{it} for households where at least one female adult owns a mobile phone and MMP_{it} for households where only male adults own and use mobile phones. To avoid collinearity problems, we estimate separate models with each gender-specific mobile phone dummy.

All models are estimated with random effects (RE) panel estimator. However, mobile phone use is not a completely random variable. In our sample, households deliberately chose whether or not to adopt mobile phone technology based on preferences and constraints, some of which may be unobserved. If mobile phone use is correlated with unobserved factors that also influence the outcome variables directly, the RE estimator can lead to biased estimates of β_1. To test for unobserved heterogeneity and reduce potential bias, we also use a fixed effects (FE) estimator, which employs differencing techniques within households over time and therefore eliminates any bias from time-invariant unobserved heterogeneity. RE and FE estimates are compared with a Hausman test (Cameron and Trivedi, 2005). An insignificant Hausman test statistic suggests that the RE estimator leads to consistent results and is preferable due to its higher efficiency. A significant test statistic, on the other hand, points at problems with unobserved heterogeneity, so that the FE estimator is preferred.

One drawback of the FE estimator is that for each variable of interest it requires sufficient variation within households over time to produce efficient estimates. Completely time-invariant variables drop out during estimation, and for variables with little time variation the estimates are often unreliable. One alternative is the Mundlak approach that produces more efficient estimates

for variables with little time variation (Mundlak, 1978). The Mundlak approach builds on the FE estimator but adds variable group means to reduce issues of unobserved heterogeneity. As the time variation in our mobile phone dummies is limited, we use the Mundlak estimator in addition to the standard RE and FE models.

2.4. Modelling impact pathways

As discussed above, the impact of mobile phone use on household nutrition will likely be channeled through the effects of mobile phones on income and gender equality. To model these causal pathways more explicitly, we develop and estimate a system of simultaneous equations as follows:

$$N_{it} = \alpha_0 + \alpha_1 Y_{it} + \alpha_2 GE_{it} + \alpha_3' \mathbf{X}_{it} + \alpha_4 T_t + \mu_{it1} \tag{4}$$

$$Y_{it} = \beta_0 + \beta_1 MP_{it} + \beta_2' \mathbf{Z}_{it} + \beta_3 T_t + \mu_{it2} \tag{5}$$

$$GE_{it} = \gamma_0 + \gamma_1 MP_{it} + \gamma_3' \mathbf{L}_{it} + \gamma_4 T_t + \mu_{it3} \tag{6}$$

$$MP_{it} = \theta_0 + \theta_1' \mathbf{M}_{it} + \theta_2 T_t + \mu_{it4} \tag{7}$$

In equation (4), nutrition (N_{it}) is modeled as a function of household income (Y_{it}), gender equality (GE_{it}), and other socioeconomic factors ($\mathbf{X}_{it}$). In equations (5) and (6), household income and gender equality are modeled as functions of mobile phone use (MP_{it}) and other socioeconomic characteristics ($\mathbf{Z}_{it}$ and $\mathbf{L}_{it}$). In equation (7), mobile phone use is itself considered endogenous and explained by a vector of socioeconomic variables ($\mathbf{M}_{it}$). Equations (4) to (7) are estimated simultaneously using three-stage least squares (Zellner and Theil, 1962).

The vectors $\mathbf{X}_{it}$, $\mathbf{Z}_{it}$, $\mathbf{L}_{it}$, and $\mathbf{M}_{it}$ include farm, household, and contextual characteristics that may overlap across the different equations. For instance, in all equations we include age, education, and gender of the household head, household size (measured in terms of adult equivalents), land owned, distance to road, and a district dummy that can all influence mobile phone adoption and the different welfare outcomes. For $\mathbf{M}_{it}$ in equation (7) we additionally include two instruments that are correlated with mobile phone adoption but have no effect on household welfare through other pathways. These instruments are the strengths of the mobile network coverage in the location of household i and the number of households using mobile phones out of the 10 closest neighbors. Valid instruments control for unobserved heterogeneity and also for possible reverse causality. For instance, it could be possible that the links between mobile phone use, household income, and gender equality work in several directions. Since the FE and Mundlak estimators cannot control for reverse causality, estimates from this simultaneous equation model with instruments for mobile phone use can also serve as a robustness check for the reduced-form results from equations (1) to (3).

3. Results and Discussion

3.1. Descriptive statistics

Table 1 shows the patterns of mobile phone use by households in our sample and how these patterns developed between the two survey rounds. In 2012, 76% of the households used mobile phones. By 2015, this proportion had increased to 89%. Table 1 also shows who within the households actually used mobile phones. While the number of male mobile phone users did not change much, the number of households in which females also use mobile phones increased substantially between 2012 and 2015.

Table 1: Number of households in the sample using and not using mobile phones

	2012		2015		Pooled sample	
	Non-users	Users	Non-users	Users	Non-users	Users
Mobile phone use (MP)	99	320	49	406	148	726
	(23.63)	(76.37)	(10.77)	(89.23)	(16.93)	(83.07)
Mobile phone used by female adults (FMP)	217	202	160	295	377	497
	(51.79)	(48.21)	(35.16)	(64.84)	(43.14)	(56.86)
Mobile phone used only by male adults (MMP)	314	105	343	112	657	217
	(74.94)	(25.06)	(75.38)	(24.62)	(75.17)	(24.83)

Note: Percentage shares are shown in parentheses.

Table 2 shows descriptive statistics for the socioeconomic characteristics that we use as explanatory variables in the econometric models, differentiating between mobile phone users and non-users. Some significant differences can be observed. Mobile phone users have larger farms, more family members, as well as younger and better educated household heads than non-users. Tables, S1 and S2 in the supplementary online material show the same variables, differentiating between female and male only mobile phone users.

Table 2: Socioeconomic characteristics by mobile phone use

	2012		2015		Pooled sample	
	Non-users (N=99)	Users (N=320)	Non-users (N=49)	Users (N=406)	Non-users (N=148)	Users (N=726)
Age of household head (years)	58.051	50.897***	62.551	53.867***	59.541	52.558***
	(16.776)	(13.031)	(13.637)	(13.556)	(15.902)	(13.399)
Education of household head (years)	4.727	7.141***	4.939	7.003***	4.797	7.063***
	(3.454)	(3.490)	(3.369)	(3.646)	(3.416)	(3.577)
Male household head (dummy)	0.646	0.791***	0.592	0.800***	0.628	0.796***
Migrant household (dummy)	0.273	0.200	0.061	0.158*	0.203	0.176
Household size (AE)	4.176	5.489***	3.436	5.369***	3.931	5.422***
	(2.197)	(2.869)	(2.323)	(2.539)	(2.258)	(2.688)
Land owned (ha)	1.827	2.415***	1.759	2.423	1.804	2.419***
	(1.216)	(1.867)	(1.039)	(3.218)	(1.157)	(2.705)
Distance to tarmac road (km)	15.697	16.537	16.235	15.346	15.875	15.871
	(11.103)	(11.575)	(10.724)	(10.062)	(10.946)	(10.763)
Residence in Masaka	0.242	0.575***	0.245	0.483***	0.243	0.523***
Neighbors using mobile phone	3.581	6.156***	1.541	9.145***	2.905	7.828***
	(3.395)	(3.379)	(1.903)	(1.871)	(3.130)	(3.031)
Network coverage	0.384	0.806***	0.041	0.958***	0.270	0.891***

Notes: Mean values are shown with standard deviations in parentheses. AE, adult equivalents. Differences in means between users and non-users are tested for statistical significance. *** p<0.01, ** p<0.05, * p<0.1

Table 3 shows descriptive statistics for the outcome variables of interest in this study. Households using mobile phones have higher incomes and higher levels of gender equality than households without mobile phones. In households without mobile phones, women own less than 50% of the productive assets alone or together with male household members. In mobile phone-using households, 63% of the assets are owned by women or jointly by male and female household members. Dietary diversity is also higher in households with mobile phones. Differences are statistically significant for both dietary diversity scores, with 12 and 9 food groups.

Table 3: Household income, gender equality, and nutrition by mobile phone use

	2012		2015		Pooled sample	
	Non-users	Users	Non-users	Users	Non-users	Users
Mobile phone use (MP)						
Income (million UGX)	1.482	3.576***	1.972	3.549***	1.644	3.561***
	(1.979)	(3.505)	(3.016)	(3.481)	(2.374)	(3.489)
Proportion of assets owned by women or jointly	0.466	0.549**	0.489	0.689***	0.474	0.627***
DDS 12 food groups	8.808	9.544***	8.489	9.246***	8.703	9.377***
	(1.979)	(1.150)	(1.488)	(1.431)	(1.831)	(1.473)
DDS 9 food groups	6.444	6.981***	6.000	6.534***	6.297	6.731***
	(0.161)	(0.074)	(0.152)	(0.061)	(0.119)	(0.048)
Female use (FMP)						
Income (million UGX)	2.636	3.559***	2.655	3.773***	2.644	3.686***
	(2.888)	(3.695)	(2.878)	(3.692)	(2.879)	(3.691)
Proportion of assets owned by women or jointly	0.498	0.563**	0.612	0.698***	0.546	0.643***
DDS 12 food groups	9.147	9.609***	8.831	9.356***	9.013	9.453***
	(1.707)	(1.577)	(1.579)	(1.351)	(1.659)	(1.452)
DDS 9 food groups	6.673	7.049***	6.219	6.617***	6.480	6.793***
	(1.449)	(1.345)	(1.302)	(1.157)	(1.405)	(1.254)
Male use (MMP)						
Income (million UGX)	3.097	3.034	3.493	3.033	3.304	3.033
	(3.511)	(2.730)	(3.636)	(2.869)	(3.579)	(2.796)
Proportion of assets owned by women or jointly	0.532	0.519	0.668	0.667	0.603	0.596
DDS 12 food groups	9.363	9.390	9.227	8.973	9.292	9.175
	(1.662)	(1.661)	(1.402)	(1.597)	(1.532)	(1.638)
DDS 9 food groups	6.847	6.876	6.531	6.313	6.682	6.585
	(1.419)	(1.392)	(1.167)	(1.376)	(1.302)	(1.409)

Notes: Mean values are shown with standard deviations in parentheses. DDS, dietary diversity score. Differences in means between users and non-users are tested for statistical significance. *** p<0.01, ** p<0.05, * p<0.1

The middle and lower parts of Table 3 show the same outcome variables differentiated by female and male mobile phone use. While male-only use of mobile phones is not associated with significant differences in any of the outcome variables, female use of mobile phones is. Households in which females use mobile phones have higher incomes, more equal gender relations, and higher levels of dietary diversity than households in which females do not use mobile phones. The results in Table 3 lend support to the hypothesis that mobile phone use by females has stronger positive social welfare effects than mobile phone use by males alone, although these simple comparisons should not be over-interpreted in a causal sense. Causal relationships are analyzed more formally below.

3.2. Aggregate effects of mobile phone use

Table 4 shows the estimation results of equations (1) and (2), using random effects (RE), fixed effects (FE), and Mundlak (MK) estimators, as explained above. For the income model, the RE estimator produces a positive and significant coefficient for the mobile phone use dummy. However, the Hausman test is statistically significant, so that the RE estimate may be biased. With the FE estimator, the effect of mobile phones is insignificant, due to a relatively large standard error. But the MK estimator produces a positive and significant coefficient, which we use here for interpretation. The results in column (3) of Table 4 suggest that mobile phone use has increased household income by 0.43 million UGX, which is equivalent to a 26% gain compared to the mean income of households without mobile phones. This is a substantial effect that can be explained through mobile phones improving households' access to information and markets, lower transaction costs, and hence higher returns in agricultural and non-agricultural activities. That mobile phones can have sizeable economic effects at the micro level was also shown in number of previous studies (Donner, 2007; Jensen, 2007; Muto and Yamano, 2009;

Aker, 2010; Blauw and Franses, 2016).

Table 4: Effects of mobile phone use on household income and gender equality

	Income (million UGX)			Gender equality (proportion of assets)		
	(1) RE	(2) FE	(3) MK	(4) RE	(5) FE	(6) MK
MP use (dummy)	0.561***	0.410	0.433**	0.090***	0.075	0.088***
	(0.182)	(0.279)	(0.181)	(0.031)	(0.047)	(0.031)
Education of head	0.094***	0.020	-0.013	0.005	-0.005	-0.004
(years)	(0.022)	(0.051)	(0.052)	(0.004)	(0.009)	(0.009)
Male head (dummy)	0.704***		1.528***	-0.082***		-0.067
	(0.164)		(0.518)	(0.028)		(0.089)
Household size (AE)	0.054*	-0.061	-0.072	0.021***	0.019**	0.019**
	(0.028)	(0.053)	(0.052)	(0.005)	(0.009)	(0.009)
Land owned (ha)	0.518***		0.209**	-0.020**		-0.021
	(0.051)		(0.092)	(0.009)		(0.016)
Age of head (years)	-0.018***	-0.005	-0.019	-0.0004	0.001	0.001
	(0.005)	(0.016)	(0.016)	(0.001)	(0.003)	(0.003)
Distance to tarmac road	-0.007		-0.005	-0.0002		-0.002
(km)	(0.007)		(0.017)	(0.001)		(0.003)
Year 2015 (dummy)	0.151	0.128	0.154	0.123***	0.125***	0.120***
	(0.116)	(0.130)	(0.122)	(0.019)	(0.022)	(0.021)
Migrant (dummy)	0.107	0.164	0.220	-0.047*	-0.026	-0.031
	(0.159)	(0.229)	(0.227)	(0.027)	(0.039)	(0.039)
Masaka (dummy)	0.999***		1.016***	0.029		0.023
	(0.145)		(0.147)	(0.025)		(0.026)
Constant	7.261***	9.094***	7.395***	0.418***	0.356**	0.419***
	(0.404)	(0.996)	(0.443)	(0.069)	(0.169)	(0.077)
Observations	874	874	874	874	874	874
No. of households	480	480	480	480	480	480
Wald χ2 / *F*-value	354.12***	1.06	393.48***	103.21***	9.44***	105.82***
Hausman χ2		11.77*			3.05	

Notes: Coefficient estimates are shown with standard errors in parentheses. RE, random effects estimator; FE, fixed effects estimator; MK, Mundlak estimator; MP, mobile phone; UGX, Ugandan shillings; AE, adult equivalents. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Columns (4) to (6) of Table 4 show that mobile phone use also improves gender equality. As the

Hausman test statistic in this model is insignificant, we rely on the RE estimate for interpretation.

Mobile phone use increases the proportion of productive assets owned by women or jointly by

women and men by 0.09, which is equivalent to a 19% increase over the mean female asset

ownership in households without mobile phone. Such effects on gender equality were not

analyzed before, but they are plausible given that women are often particularly constrained in

their access to information and markets and may therefore benefit over-proportionally from the

use of mobile phone technologies.

Results of the effects of mobile phones on household nutrition are shown in Table 5. As explained we use a dietary diversity score (DDS) with 12 food groups to assess household food security and a DDS with 9 food groups to proxy dietary quality. For both outcome variables, the Hausman test is insignificant, so we use the RE estimates for interpretation. Mobile phone use significantly improves access to food and dietary quality. This is consistent with what was hypothesized in the literature (Nakasone and Torero, 2016), even though this hypothesis had not been tested before empirically.

Table 5: Effects of mobile phone use on household nutrition

	DDS 12 food groups			DDS 9 food groups		
	(1) RE	(2) FE	(3) MK	(4) RE	(5) FE	(6) MK
MP use (dummy)	0.336**	0.202	0.300**	0.236*	0.173	0.210
	(0.150)	(0.233)	(0.150)	(0.128)	(0.202)	(0.129)
Education of household head (years)	0.059***	0.079*	0.042	0.043***	0.058	0.027
	(0.018)	(0.043)	(0.044)	(0.016)	(0.037)	(0.038)
Male head (dummy)	0.155		1.495***	0.144		1.297***
	(0.135)		(0.434)	(0.114)		(0.376)
Household size (AE)	0.116***	0.078*	0.068	0.082***	0.056	0.048
	(0.023)	(0.044)	(0.044)	(0.019)	(0.039)	(0.038)
Land owned (ha)	0.029		0.102	0.065*		0.132**
	(0.042)		(0.077)	(0.036)		(0.067)
Age of head (years)	-0.009**	0.012	-0.004	-0.006*	0.004	-0.010
	(0.004)	(0.013)	(0.014)	(0.003)	(0.011)	(0.012)
Distance to tarmac road (km)	0.002		0.006	0.004		0.008
	(0.006)		(0.014)	(0.005)		(0.012)
Year 2015	-0.264***	-0.325***	-0.270***	-0.416***	-0.458***	-0.404***
	(0.097)	(0.109)	(0.102)	(0.083)	(0.095)	(0.089)
Migrant (dummy)	-0.252*	-0.478**	-0.414**	-0.221**	-0.410**	-0.351**
	(0.131)	(0.191)	(0.190)	(0.112)	(0.166)	(0.165)
Masaka (dummy)	-0.119		-0.088	-0.123		-0.097
	(0.119)		(0.121)	(0.101)		(0.103)
Constant	8.581***	7.822***	8.730***	6.212***	5.996***	6.278***
	(0.332)	(0.832)	(0.366)	(0.283)	(0.722)	(0.310)
Observations	874	874	874	874	874	874
No. of households	480	480	480	480	480	480
Wald χ2 / *F*-value	92.73***	3.45***	111.63***	94.49***	5.61***	110.75***
Hausman χ2		6.56			3.98	

Notes: Coefficient estimates are shown with standard errors in parentheses. DDS, dietary diversity score; RE, random effects estimator; FE, fixed effects estimator; MK, Mundlak estimator; MP, mobile phone; AE, adult equivalents. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

A few other explanatory variables in Table 5 also have significant effects. Education of the household head and household size tend to increase dietary diversity at the household level, while age decreases dietary diversity, as one would expect. The 2015 dummy has a negative effect, which can be explained by lower rainfall in the 2014 season and thus poorer agricultural harvests than in the 2011 season that was captured in the 2012 survey round.

3.3. Gender-disaggregated effects of mobile phone use

So far, we have used household-level mobile phone use as the main explanatory variable in the models, regardless of who in the household actually used mobile phones. We now differentiate between female and male mobile phone use to gain further insights into gendered effects. Table 6 shows the estimation results for household income and gender equality. Female mobile phone use has significantly positive effects on both outcome variables, while male mobile phone use has not. The same pattern is also observed for the effects of female and male mobile phone use on household diets, which are shown in Table 7.

The insignificant coefficients of male mobile phone use should not be over-interpreted. As explained, the MMP dummy only captures households in which males alone use mobile phones. In many cases, both male and female household members use mobile phones, and these cases are captured by the FMP dummy. Nevertheless, that female mobile phone use seems to be more important for positive social welfare effects than male mobile phone use is remarkable and in line with our hypothesis on gendered implications. Women benefit over-proportionally from the use of mobile phone technologies, and larger economic benefits are also reflected in enhanced gender equality within the household and better household nutrition.

Table 6: Effects of female and male mobile phone use on household income and gender equality

	Income (million UGX)						Gender equality (proportion of assets owned)					
	(1) RE	(2) FE	(3) MK	(4) RE	(5) FE	(6) MK	(7) RE	(8) FE	(9) MK	(10)RE	(11)FE	(12)MK
FMP use (dummy)	0.320**	-0.259	0.241*				0.047**	0.063	0.047*			
	(0.137)	(0.295)	(0.138)				(0.024)	(0.050)	(0.024)			
MMP use (dummy)				-0.227	0.091	-0.237				0.006	-0.011	0.006
				(0.152)	(0.294)	(0.151)				(0.026)	(0.049)	(0.026)
Education of head (years)	0.094***	0.024	-0.009	0.099***	0.024	-0.009	0.005	-0.004	-0.003	0.006*	-0.004	-0.003
	(0.022)	(0.051)	(0.052)	(0.022)	(0.051)	(0.052)	(0.004)	(0.009)	(0.009)	(0.004)	(0.009)	(0.009)
Male head (dummy)	0.788***		1.623***	0.773***		1.647***	-0.069**		-0.047	-0.082***		-0.047
	(0.168)		(0.517)	(0.170)		(0.518)	(0.028)		(0.089)	(0.029)		(0.089)
Household size (AE)	0.061**	-0.057	-0.066	0.069**	-0.054	-0.070	0.022***	0.021**	0.021**	0.024***	0.020**	0.021**
	(0.028)	(0.053)	(0.052)	(0.027)	(0.053)	(0.052)	(0.005)	(0.009)	(0.009)	(0.005)	(0.009)	(0.009)
Land owned (ha)	0.529***		0.204**	0.533***		0.201**	-0.018**		-0.022	-0.018**		-0.022
	(0.051)		(0.092)	(0.051)		(0.092)	(0.009)		(0.016)	(0.009)		(0.016)
Age of head (years)	-0.020***	-0.007	-0.021	-0.021***	-0.006	-0.023	-0.001	0.001	0.001	-0.001	0.000	0.001
	(0.005)	(0.016)	(0.016)	(0.005)	(0.016)	(0.016)	(0.001)	(0.003)	(0.003)	(0.001)	(0.003)	(0.003)
Distance to tarmac road (km)	-0.007		-0.008	-0.008		-0.007	-0.000		-0.002	-0.000		-0.002
	(0.007)		(0.017)	(0.007)		(0.017)	(0.001)		(0.003)	(0.001)		(0.003)
Year 2015	0.177	0.226*	0.172	0.231**	0.187	0.213*	0.127***	0.126***	0.124***	0.136***	0.135***	0.133***
	(0.116)	(0.134)	(0.122)	(0.114)	(0.125)	(0.119)	(0.019)	(0.023)	(0.021)	(0.019)	(0.021)	(0.021)
Migrant (dummy)	0.089	0.177	0.228	0.100	0.174	0.234	-0.049*	-0.025	-0.029	-0.046*	-0.024	-0.028
	(0.159)	(0.229)	(0.227)	(0.160)	(0.229)	(0.227)	(0.027)	(0.039)	(0.039)	(0.027)	(0.039)	(0.039)
Masaka (dummy)	1.043***		1.050***	1.093***		1.091***	0.037		0.029	0.043*		0.037
	(0.144)		(0.145)	(0.143)		(0.144)	(0.025)		(0.025)	(0.025)		(0.025)
Constant	7.534***	9.577***	7.633***	7.722***	9.378***	7.773***	0.464***	0.373**	0.468***	0.482***	0.418**	0.484***
	(0.388)	(0.992)	(0.425)	(0.386)	(0.982)	(0.424)	(0.067)	(0.168)	(0.074)	(0.066)	(0.166)	(0.074)
Observations	874	874	874	874	874	874	874	874	874	874	874	874
No. households	480	480	480	480	480	480	480	480	480	480	480	480
Wald χ^2 / F-value	348.38***	0.83	389.61***	343.58***	0.71	388.44***	98.35***	9.27***	101.33***	93.95***	8.97***	97.13***
Hausman χ^2		14.84**			14.82**			3.04			3.50	

Notes: Coefficient estimates are shown with standard errors in parentheses. RE, random effects estimator; FE, fixed effects estimator; MK, Mundlak estimator; FMP, mobile phone used by at least one female; MMP; mobile phone only used by males; AE, adult equivalents. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Effects of female and male mobile phone use on household nutrition

	DDS 12 food groups						DDS 9 food groups					
	(1) RE	(2) FE	(3) MK	(4) RE	(5) FE	(6) MK	(7) RE	(8) FE	(9) MK	(10) RE	(11) FE	(12) MK
FMP use	0.350***	0.034	0.310***				0.307***	0.102	0.277***			
(dummy)	(0.112)	(0.246)	(0.113)				(0.095)	(0.214)	(0.096)			
MMP use				-0.198	0.196	-0.160				-0.173	0.124	-0.143
(dummy)				(0.125)	(0.245)	(0.125)				(0.106)	(0.212)	(0.107)
Education of	0.056***	0.081*	0.044	0.062***	0.078*	0.044	0.039**	0.061	0.029	0.044***	0.059	0.029
head (years)	(0.018)	(0.043)	(0.043)	(0.018)	(0.043)	(0.044)	(0.016)	(0.037)	(0.038)	(0.016)	(0.037)	(0.038)
Male head	0.242*		1.557***	0.214		1.577***	0.220*		1.340***	0.195*		1.357***
(dummy)	(0.137)		(0.432)	(0.139)		(0.433)	(0.116)		(0.375)	(0.118)		(0.375)
Household size	0.115***	0.081*	0.073*	0.125***	0.083*	0.069	0.079***	0.059	0.052	0.088***	0.060	0.049
(AE)	(0.023)	(0.044)	(0.044)	(0.022)	(0.044)	(0.044)	(0.019)	(0.038)	(0.038)	(0.019)	(0.039)	(0.038)
Land owned (ha)	0.035		0.098	0.039		0.096	0.068*		0.129*	0.072**		0.127*
	(0.042)		(0.077)	(0.042)		(0.077)	(0.036)		(0.067)	(0.036)		(0.067)
Age of head	-0.009**	0.011	-0.005	-0.011***	0.012	-0.006	-0.007**	0.003	-0.010	-0.009**	0.003	-0.012
(years)	(0.004)	(0.013)	(0.014)	(0.004)	(0.013)	(0.014)	(0.003)	(0.011)	(0.012)	(0.003)	(0.011)	(0.012)
Distance to	0.003		0.004	0.001		0.005	0.004		0.006	0.003		0.007
tarmac road (km)	(0.006)		(0.014)	(0.006)		(0.014)	(0.005)		(0.012)	(0.005)		(0.012)
Year 2015	-0.276***	-0.302***	-0.285***	-0.217**	-0.292***	-0.229**	-0.436***	-0.450***	-0.425***	-0.383***	-0.431***	-0.375***
	(0.096)	(0.111)	(0.102)	(0.094)	(0.104)	(0.100)	(0.083)	(0.097)	(0.0883)	(0.081)	(0.091)	(0.087)
Migrant (dummy)	-0.271**	-0.473**	-0.412**	-0.259**	-0.473**	-0.404**	-0.238**	-0.407**	-0.351**	-0.227**	-0.406**	-0.344**
	(0.131)	(0.192)	(0.190)	(0.132)	(0.191)	(0.190)	(0.112)	(0.166)	(0.165)	(0.113)	(0.166)	(0.165)
Masaka (dummy)	-0.113		-0.085	-0.061		-0.036	-0.127		-0.104	-0.081		-0.060
	(0.117)		(0.119)	(0.117)		(0.119)	(0.099)		(0.101)	(0.099)		(0.101)
Constant	8.680***	7.957***	8.843***	8.872***	7.904***	8.991***	6.257***	6.065***	6.335***	6.425***	6.083***	6.467***
	(0.317)	(0.828)	(0.349)	(0.317)	(0.817)	(0.350)	(0.269)	(0.718)	(0.295)	(0.269)	(0.709)	(0.296)
Observations	874	874	874	874	874	874	874	874	874	874	874	874
No. households	480	480	480	480	480	480	480	480	480	480	480	480
Wald χ2 / *F*-val.	98.07***	3.33***	115.66***	89.83***	3.43***	108.90***	102.28***	5.52***	117.06***	93.66***	5.54***	109.78***
Hausman χ2		7.69			10.06			4.55			6.75	

Notes: Coefficient estimates are shown with standard errors in parentheses. DDS, dietary diversity score; RE, random effects estimator; FE, fixed effects estimator; MK, Mundlak estimator; FMP, mobile phone used by at least one female; MMP; mobile phone only used by males; AE, adult equivalents. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

3.4. Impact pathways

We now turn to estimating the simultaneous equation model explained in equations (4) to (7) in order to test the expected causal pathways more explicitly. The system of equations can be estimated with aggregate mobile phone use (MP) or also with female mobile phone use (FMP) and male mobile phone use (MMP) separately. The previous sections showed that FMP is more important for the economic and social effects analyzed here; hence we only show the results using the FMP dummy. The main effects are summarized in Table 8. Full effects are shown in Table S3 (supplementary online material).

Table 8: Effects of female mobile phone use (summary of causal pathways)

	(1) DDS 12 food groups	(2) DDS 9 food groups
Effect on DDS		
Household income (million UGX)	0.335[*]	0.333[**]
	(0.174)	(0.150)
Gender equality (proportion of assets)	2.451[**]	1.473
	(1.067)	(0.915)
Effect on household income (million UGX)		
FMP use (dummy)	0.455[**]	0.466[**]
	(0.222)	(0.220)
Effect on gender equality (proportion of asset)		
FMP use (dummy)	0.065[***]	0.065[***]
	(0.022)	(0.022)
Effect on FMP use (dummy)		
Neighbors using mobile phone	0.025[***]	0.025[***]
	(0.006)	(0.006)
Network coverage	0.391[***]	0.391[***]
	(0.048)	(0.048)

Notes: Estimates from two separate simultaneous equation systems are summarized in columns (1) and (2). Coefficient estimates are shown with standard errors in parentheses. Full model results are shown in Table S3 (supplementary online material). DDS, dietary diversity score; FMP, mobile phone used by at least one female, [***] $p<0.01$, [**] $p<0.05$, [*] $p<0.1$

Column (1) of Table 8 shows results of the model with the 12 food group DDS as the final outcome variable. As can be seen, household income and gender equality both have positive and significant effects, meaning that they increase DDS and thus food security. A one million UGX (372 US$) increase in annual household income will lead to an increase in dietary diversity by

0.34 food groups. The coefficient of gender equality is larger, which is also due to the fact that this variable is measured as the proportion of assets owned. When all productive assets are owned by females or jointly by males and females in the household (as opposed to ownership by males only), the number of food groups consumed in the household will increase by 2.45. This is a very substantial effect, clearly underlining the importance of women empowerment for food security.

The middle part in column (1) of Table 8 shows that both variables – household income and gender equality – are positively affected by female mobile phone use. Thus, the simultaneous equation model confirms that the effects of mobile phones on nutrition are channeled through household income and gender equality. We can also use the coefficient estimates in Table 8 to calculate the relative contribution of each of these two pathways. The effect of female mobile phone use on DDS through the income pathway is $0.455 \times 0.335 = 0.152$, whereas the effect through the gender equality pathway is $0.065 \times 2.451 = 0.159$. Hence, female mobile phone use contributes to improved nutrition almost equally through both pathways. And the combined effect of $0.152 + 0.159 = 0.311$ is similar in magnitude to the directly estimated effect of female mobile phone use on DDS of 0.350 in the reduced-form model in Table 7. In other words, the two pathways modeled here seem to explain most of the effects of mobile phones on household food security.

The lowest part of column (1) in Table 8 shows that the two instruments employed for female mobile phone use – number of neighbors using mobile phones and network coverage – are highly significant. The consistency of this instrumental variable approach with the earlier results confirms the robustness of the findings and also suggests that reverse causality is not an issue.

Column (2) of Table 8 shows estimates for the same simultaneous equation model but now using the 9 food group DDS as the final outcome variable. The results are very similar to those in

column (1), only that the gender equality effect on DDS is smaller and statistically insignificant. This model suggests that income is more important for dietary quality than women empowerment. However, concluding that gender equality would not matter at all would be wrong. When excluding income from this model, the coefficient of gender equality increases and turns significant, meaning that income and gender equality are positively correlated.

4. Conclusion

Mobile phone technologies have spread very rapidly in rural Africa and other parts of the developing world. While previous studies had analyzed effects of mobile phone use on economic indicators – such as input and output prices, profits, and income – research on implications for broader social development is scarce. Better understanding social welfare effects is of particular importance against the background of the United Nations' Sustainable Development Goals. In this paper, we have used data from farm households in Uganda to analyze effects of mobile phone use on household income, gender equality, and nutrition. Gender equality was measured in terms of the proportion of household productive assets owned by females or jointly by female and male household members, as opposed to ownership by male members alone. Nutrition was measured in terms of two dietary diversity scores that portray food security and dietary quality.

Results from reduced-form panel regressions showed that mobile phone use has positive and significant effects on income and gender equality. After controlling for other factors, mobile phone use has increased household income by 26% and gender equality by 19%. Likewise, mobile phone use has enhanced household food security and dietary quality. Gender disaggregation further revealed that female mobile phone use has stronger positive effects than

male mobile phone use alone. Women seem to benefit over-proportionally from mobile phone technologies, which is plausible given that women are often particularly constrained in their access to markets and information. Hence, a new technology that helps reduce transaction costs and allows new forms of communication can be particularly advantageous for women. Higher incomes and better access to information for women influence their bargaining position within the household, thus also improving gender equality.

Simultaneous equation models were used to analyze causal pathways of these effects more explicitly. Estimation results showed that the effects of mobile phones on household diets are primarily channeled through the income and gender equality pathways. Both variables significantly affect dietary diversity, and both variables are positively affected by mobile phone use. In terms of relative magnitudes, both channels play almost equal roles for the nutrition effects of mobile phone technologies. In the simultaneous equation models, we also used instrumental variables to explain mobile phone adoption, thus controlling for reverse causality and other possible endogeneity issues. The similarity of the results between the reduced-form and the simultaneous equation models underlines the robustness of the findings.

Nevertheless, a few limitations are worth highlighting. First, our results refer to the specific setting in Uganda and cannot be generalized without further analysis in other regions. Second, our panel data only include two survey rounds. While a panel has clear advantages over cross-section data, more survey rounds would be useful for increasing the reliability of the impact estimates and for better capturing possible long-term effects. Third, and related to the previous point, our panel survey covers a time span in which many of the rural households in Uganda had already adopted mobile phones. Adoption rates further increased between the first and the second survey round, but it is possible that an earlier baseline survey with lower adoption rates would

have led to somewhat different results. Unfortunately, such baseline data were not available. In spite of these limitations, we cautiously conclude that mobile phone technologies can improve gender equality and nutrition in rural households, especially when women have access to mobile phones. Gender-sensitive promotion strategies will have to ensure that these potentials are realized at large scale.

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