Supplemental Online Appendix

Food Security in Developing Countries: Gender and Spatial Interactions

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Online Appendix A: Study Sites and Sampling Procedures

Our study examines data from seven countries in three world regions: East Africa (Kenya and Tanzania), West Africa (Ghana and Senegal), and South Asia (India, Nepal, and Bangladesh). The countries located in East and West Africa are characterized by large populations in rural areas, depending on rain-fed, cereal-based subsistence agriculture and pastoralism (Förch et al., 2011). These farm-holders are especially vulnerable to climate variability (i.e., primarily droughts). The increasing frequency of climate shocks have led to significant food crises, with a costly cycle of environmental disasters and the resultant loss of livelihoods.

Apart from these similarities, there are notable differences between the East and West Africa sites. East Africa is characterized by a diversity of climate, topography, agro-ecosystems, and environmental challenges. Elevation and temperature gradients typically dictate whether agriculture is practiced for subsistence use or as commercial plantations and high-value horticulture (Silvestri et al., 2015). The predictability of rainfall is relatively high and provides the opportunity to help manage risk. In contrast, the climate of West Africa is distinguished by heavy rainfall that influences cropping systems (Frelat et al., 2016). Year-to-year rainfall variability causes climate-driven shifts in crops and adaptations to changes in rainfall. The region experiences widespread land degradation, but benefits from policy support for regional drought management and intra-regional trade promoted by a common currency across the francophone countries.

South Asia is characterized by a broadly favorable climate, rich soils, rice-wheat systems, and plentiful surface and groundwater; all of which help to promote food security for the several hundred million people in the region (Förch et al., 2011). Nonetheless, vulnerability to climate change arises from high levels of population paired against a relatively limited and depleted resource base. From a risk management perspective, the region's high dependence on agriculture makes its population especially vulnerable to food insecurity.

With regards to sampling, the IMPACT Lite datasets offer a representative cross-sectional sample of household-level responses to numerous socioeconomic questions, including detailed information about farm resources and production, land allocation, on-farm and off-farm activities, as well as food consumption (i.e., home-grown and purchased) and household assets (Rufino et al., 2012). Within each of the regions and countries, sampling was conducted across districts and villages. Within each district, the objective was to sample 200 households across multiple villages, with 10 households per village. Our sample contains a total of 1496 households for which we have complete data.

The choice regarding which villages to sample within districts was guided by the desire to capture different types of production systems. The IMPACT Lite survey teams, in collaboration with local researchers and development partners, geographically divided the research districts into several production systems according to land use, farming activities, and market characteristics, which could influence the combinations of farming activities available (Rufino et al., 2012). Each village, and its accompanying households, were assigned to one production system. The number of villages to be sampled for a given production system was specified as:

$$V_p = \frac{HS}{P * HV}$$

where V_p is the number of villages to be sampled for a given production system, HS is the target number of households per research district (i.e., 200), P is the number of production systems per district, and HV is the target number of households sampled in each village (i.e., 10). For example, if there are four production systems (P) identified at a research district, then the number of villages sampled for each production system was 5, $V_p = \frac{200}{4*10}$.

Within each production system (P) the survey team aimed at an equal number of villages (V_p) to be randomly selected from a village list constructed for each district. The survey team acquired high-resolution satellite images, generated a series of maps, and geo-referenced lists of all villages within the districts. This information was updated and reviewed for purposes of the survey.

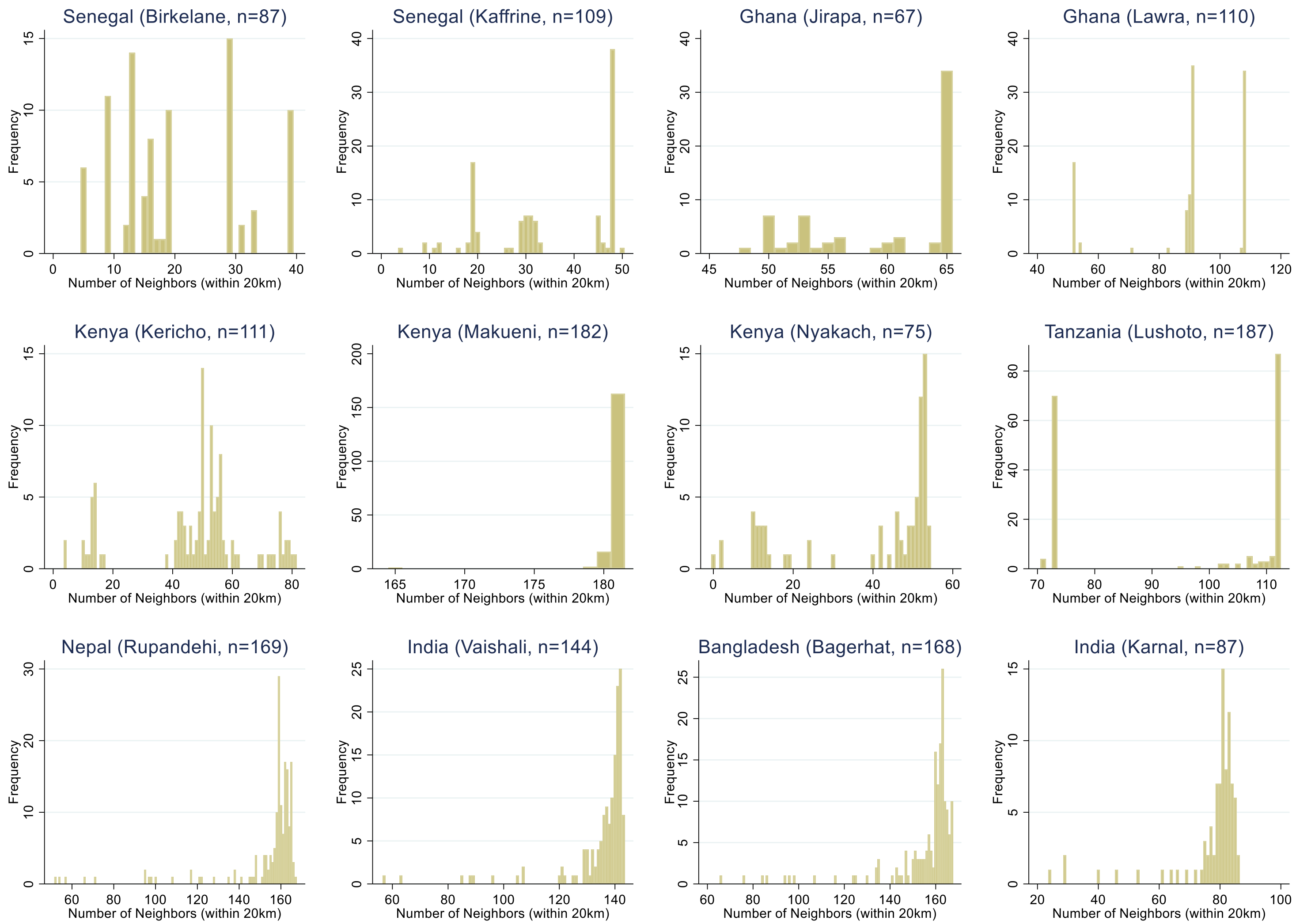
Ten households per village were randomly selected from the compiled list. For purposes of the survey, a household was defined as "a group of people living in the same home and sharing meals and income-generating activities, and acknowledging the authority of the household head" (Rufino et al., 2012). Only households who are "land users" (i.e., households involved in aquaculture or cultivating land and/or keeping livestock) were considered for the survey.

Online Appendix B: Distances between Households

Descriptive Statistics of Distances between Households, by District

Region, country, and district	Average Distance between two households in a district (in kilometers)	The standard deviation of the distance between two households in a district (in kilometers)	Number of households
West Africa			
Senegal (Birkelane)	55.8	42.9	87
Senegal (Kaffrine)	53.8	44.5	109
Ghana (Jirapa)	10.5	8.2	67
Ghana (Lawra)	11.9	7.6	110
East Africa			
Kenya (Kericho)	29.1	22.9	111
Kenya (Makueni)	6.1	3.2	182
Kenya (Nyakach)	24.4	21.2	75
Tanzania (Lushoto)	35.0	28.5	187
South Asia			
Nepal (Rupandehi)	11.3	6.0	169
India (Vaishali)	9.9	5.5	144
Bangladesh (Bagerhat)	10.5	5.8	168
India (Karnal)	10.8	6.4	87
Sample average	24.8	19.114	1496

Online Appendix C: Distribution of Neighbors, by District



Online Appendix D: Spatial Weights

GPS coordinates of the location of each household are used to construct a distance matrix and spatial weights. Households residing in the same geographic region, e.g., a village, are considered "neighbors" who can influence each other's food security (Behrman et al., 2002; Munshi, 2003; Nolin, 2010). The spatial weight matrix W indicates, for each household in the region, which of the other households affect food security at that location (Anselin, 2001). A fundamental assumption in the spatial econometrics' literature is a decline in influence among agents as the distance between two observations increases. That is, neighbors close by may have more influence than ones further away. The declining influence of neighbors with distance is typically captured by weighting spatial connections such that they are inversely proportional to their distance. We adopt a truncated version of W, where an element $w_{ij} = 0$ if households at locations i and j are further than 20 kilometers apart. Truncation allows us to focus on the immediate neighborhood of each household, where spatial effects are stronger and more likely to influence food security.

We follow the convention of row-normalization of the distance matrix (Bramoullé et al., 2009; LeSage & Pace, 2009). Each row i represents a convex combination (or weights) that household i places on the influence of neighbors j within 20 km. That is, every element w_{ij} is between 0 and 1 and $\sum_j w_{ij} = 1$ (the sum of weights of i's neighbors equals to 1). The diagonal of W is zero. Taken together, inverse proportionality to distance, truncation, and row-normalization lead to a spatial matrix of the form:

$$\begin{cases} w_{ij} = \dfrac{\left(1/d_{ij}\right)}{\left[\sum_j \left(1/d_{ij}\right)\right]} & \text{if} \quad i \neq j \text{ and } d_{ij} \leq 20 \\ w_{ij} = 0 & \text{if} \quad i = j \text{ or } d_{ij} > 20 \end{cases}$$

where d_{ij} is the distance between household i and j, measured in km.

Online Appendix E: Interpreting Spatial Effects

To obtain insights regarding spillovers and the source of spatial multipliers, it is useful to isolate Y in model (1) and use a Neumann series to re-write the model as (Meyer, 2000)[1]:

$$\begin{aligned} Y &= (I - \rho W)^{-1} Z\gamma + \mu \\ &= [I + \rho W + (\rho W)^2 + (\rho W)^3 + \cdots] Z\gamma + \mu \end{aligned} \qquad (E1)$$

where $\mu = (I - \rho W)^{-1}\varepsilon$.

The top row of the SAR model (E1) shows that the effect of changes in Z are mediated by the spatial relationships via the term $(I - \rho W)^{-1}$. Since the rows of W sum to 1, the spatial multiplier can be approximated by $\frac{1}{1-\rho}$ (Anselin, 2003; Lim et al., 2021). For $0 < \rho < 1$, a typical regularity assumption, the term $\frac{1}{1-\rho} > 1$ multiplies the parameter γ (the effect of Z on Y).

The second row of (E1) shows how the multiplier is affected by the direct neighborhood, and by the indirect neighborhoods generated from first-order neighbors. The term ρW depends on the spatial connections (and strength, or distance) of immediate neighbors. As we will discuss later in the estimation and instrumental variable section, the following terms depend on high-order spatial effects: $(\rho W)^2$ captures second-order spatial connections, i.e., the influence of neighbors of neighbors on own food security; $(\rho W)^3$ captures third-order spatial connections, effects of neighbors of neighbors of neighbors, and so on. Note that the model predicts a decay of spatial effects as the order of spatial interaction increases, i.e. ρ^s decreases as the order s increases (Anselin, 2003; LeSage & Pace, 2009; Wichmann, 2015). The Neumann formulation (E1) makes it explicit that the entire neighborhood W can influence the food security of a given household, either directly or indirectly.

[1] The Neumann series shows that $(I - \rho W)^{-1} = I + \rho W + (\rho W)^2 + (\rho W)^3 + \cdots$

Online Appendix F: Construction of the Calorie Gap Measure of Food Security

Data from the IMPACT lite survey for Africa and Asia were collected on a household basis.[2] Households reported consumed home-grown food items and food obtained outside the farm for different seasons throughout the year. Households reported quantity consumed, measured in kilograms (kg) or liters (L), and the length of time used to finish consumption of each of the items. To convert the quantities that a household consumes into daily amounts, the amounts were divided into the length of time used to consume each product. For instance, if the household reported that 5kg of millet were consumed in 5 days, then the daily quantity consumed was 1kg of millet. This amount was then transformed into the equivalent number of calories using the FAO's food composition tables for Africa[3] and Asia.[4]

As food availability can vary significantly depending on the agricultural season, the elicitation of food consumption considered seasonality. To accommodate local practices, the survey depicted seasonality differently across regions. For Africa, seasonal differences were indicated by the households as "good periods" and "bad periods" in a year. For Asia, seasonal differences were designated by the households as rainy, summer, and winter seasons. Households were surveyed once and were asked to recall their consumption for a typical week within each season.

We therefore construct calorie gap measures for each household, for each season. The variable that measures the actual daily calorie intake is a weighted aggregation (from seasonal level to yearly level) of households' caloric intake. The survey also elicited food consumption by source,

[2] Our data does not contain information on individual specific food consumption. Hence, our calorie intake measures are per household.

[3] Available online at http://www.fao.org/infoods/infoods/tables-and-databases/africa/en/.

[4] Available online at http://www.fao.org/infoods/infoods/tables-and-databases/asia/en/.

i.e. on-farm (Q) or purchased (P). These sources are also aggregated to obtain overall food consumption. For example, for an African household, we calculate the actual daily calorie intake as:

$$ACI_i = \sum_{j=1}^{J} \left[\left\{ \left(Q_{Gj} \times E_j\right) + \left(P_{Gj} \times E_j\right) \right\} \times \frac{G_i}{12} + \left\{ \left(Q_{Bj} \times E_j\right) + \left(P_{Bj} \times E_j\right) \right\} \times \frac{B_i}{12} \right]$$

where ACI_i is the actual daily calorie intake for household i in Africa; Q_{Gj} is the daily quantity of food item j (kg or L) produced on-farm and consumed in "good" periods; E_j is the calorie content of food item j (Megajoules kg^{-1} or L); P_{Gj} is the daily quantity of food item j purchased and consumed in "good" periods; Q_{Bj} is the daily quantity of food item j produced on-farm and consumed in "bad" periods; P_{Bj} is the daily quantity of food item j (kg or L) purchased and consumed in "bad" periods. ACI_i is weighted seasonally with $\frac{G_i}{12}$ and $\frac{B_i}{12}$, where G_i is the number of "good" months in the last year as indicated by household i; and B_i is the number of "bad" months as indicated by household i. For Asia, all the variables are the same as for Africa, except for seasonal differences, where each season is 4 months long.

Although we do not have individual specific calorie intake, we do have age and gender information for each household member. This allows us to use recommended calorie intakes by age and gender from WHO/FAO (Table F.1) to construct a household level recommended caloric intake. To calculate the WHO/FAO recommended daily calorie intake for every household (RCI_i), recommended calories for each household member (considering age and gender) are summed:

$$RCI_i = \sum_{n=1}^{m} K_{nga} \,,$$

where K_{nga} is the calorie requirement in Megajoules for member n of gender g, and age a; and m is the number of members in household i. The *calorie gap* is $GAP_i = ACI_i - RCI_i$. When the gap is positive, household i is food secure.

Table F.1: Daily Calorie Requirements by Age and Sex

Age (years)	Female Energy Requirements (Kcal/day)	Male Energy Requirements (Kcal/day)
1 to 2	865	948
2 to 3	1047	1129
3 to 4	1156	1252
4 to 5	1241	1360
5 to 6	1330	1467
6 to 7	1428	1573
7 to 8	1554	1692
8 to 9	1698	1830
9 to 10	1854	1978
10 to 11	2006	2150
11 to 12	2149	2341
12 to 13	2276	2548
13 to 14	2379	2770
14 to 15	2449	2990
15 to 16	2591	3178
16 to 17	2503	3322
17 to 18	2503	3410
18 to 30	2400	3300
30 to 40	2350	2950
40 to 50	2350	2950
50 to 60	2350	2700
60 to 70	2100	2250
70 to 80	1950	2250
80 to 90	1600	2050
>90	1600	2050

Source: Based on FAO/WHO (2008).
Refer to Ncube et al. (2016), Appendix Table 7.

Online Appendix G: Construction of the Household Asset Index

For each of three categories of assets (domestic, transport, and productive), and for each household, we construct:

$$Asset\ Index = \sum_{k=1}^{K} \left\{ \sum_{n=1}^{N} (\omega_{gn} * a) \right\}, n = 1,2,\ldots,N;\ k = 1,2,\ldots,K$$

where, k is an identifier of a type of asset (e.g., radio, bicycle, hoes), n is the number of assets of type k owned by a household, ω_{jn} is the weight of asset k based on economic value, and a is the age adjusted value for asset k. We follow Njuki et al. who calculate weight (ω) based on the value of the asset compared across countries, which ensures that assets of the same value are accorded the same weight, despite country differences in prices (Njuki et al., 2011). Age adjustments are based on weights of the aged asset. The adjustment occurs according to three categories of the asset's age. If the asset is i) less than 3 years old, the adjustment is 1; ii) between 3 and 7 years old, the adjustment is 0.8; iii) more than 7 years old, the adjustment is 0.5. Table G.1 contains lists of which asset types, (k), belong to which categories, with weights (ω), and age adjustments (a) for each asset type.

Table G.1 Household Assets used in constructing the Household Index

Asset (g)	Weight of asset (ω_g)	Age (Adjustment for age) (a)		
		< 3 yrs. old	3-7 yrs. old	>7 yrs. old
<u>Domestic assets</u>				
Stove	2			
Refrigerator	4			
Radio	2			
Television	4			
DVD player	4	x 1	x 0.8	x 0.5
Cellphone	3			
Sofa	1			
Mosquito nets	1			
<u>Transport assets</u>		< 3 yrs. old	3-7 yrs. old	>7 yrs. old
Car/truck	160			
Motorcycle	48	x 1	x 0.8	x 0.5
Bicycle	6			
Cart (animal drawn)	12			
<u>Productive assets</u>		< 3 yrs. old	3-7 yrs. Old	>7 yrs. old
Hoes	1			
Spades/shovels	1			
Ploughs	4	x 1	x 0.8	x 0.5
Water pump	6			
Panga/machete	1			
Sewing machine	4			

Source: Adapted from Njuki et al. (2011).

Online Appendix H: Descriptive Statistics, by Gender

Category / Variable	Definition	Females (n=198)		Males (n=1298)	
		mean	st. dev.	mean	st. dev.
Dependent Variable[a]					
Calorie Gap	Household caloric intake minus WHO recommended caloric intake (per day)	-2,611.9	6,851.7	-7,692.4	9,762.3
Household Characteristics					
Age of Household Head	Household head's age in years	54.48	15.75	49.29	14.39
Household Size	Number of people living in a household	4.35	1.96	6.72	3.49
Household Assets[b]					
Domestic Assets	Index of domestic assets	6.88	5.82	10.23	7.34
Transport Assets	Index of transport assets	4.35	11.56	11.59	19.44
Productive Assets	Index of productive assets	3.87	3.00	4.69	3.78
Household Livelihood strategies					
Off-farm Income	Dummy: 1 if the household earns off-farm income	0.83	0.38	0.85	0.36
Ruminants per Unit of Land	Number of ruminants (cattle, buffaloes, goats, sheep) per acre	2.26	4.08	2.32	5.99
District Fixed Effects					
Birkelane (Senegal)		0.01	0.10	0.07	0.25
Kaffrine (Senegal)				0.08	0.28
Jirapa (Ghana)		0.01	0.10	0.05	0.22
Lawra (Ghana)		0.01	0.07	0.08	0.28
Makueni (Kenya)		0.28	0.45	0.10	0.30
Nyakach (Kenya)		0.15	0.35	0.04	0.18
Kericho (Kenya)		0.11	0.32	0.07	0.25
Lushoto (Tanzania)		0.22	0.41	0.11	0.31
Bagerhat (Bangladesh)		0.06	0.23	0.12	0.33
Karnal (India)		0.02	0.14	0.06	0.24
Vaishali (India)		0.03	0.17	0.11	0.31
Rupandehi (Nepal)		0.12	0.32	0.11	0.32
Crop Fixed Effects					
Aquaculture fish		0.05	0.21	0.07	0.26
Beans		0.05	0.22	0.02	0.13
Groundnuts		0.02	0.12	0.14	0.34
Lentils		0.04	0.19	0.04	0.20
Maize		0.40	0.49	0.24	0.43
Mangoes		0.06	0.24	0.03	0.18
Millets		0.01	0.10	0.08	0.28
Mustard Seed		0.07	0.25	0.10	0.30
Rice Paddy		0.17	0.37	0.35	0.48
Potato		0.06	0.23	0.07	0.25
Sorghum		0.06	0.23	0.02	0.14
Sugarcane		0.03	0.16	0.02	0.14
Vegetables		0.02	0.12	0.04	0.19
Wheat		0.13	0.34	0.26	0.44
Technological Fixed Effects					
Intercropping		0.69	0.46	0.58	0.49
Fragmentation		0.16	0.37	0.24	0.43

Online Appendix I: Sensitivity Analysis

Estimates of the SAR model using spatial weights with different truncation thresholds

	SAR Model	
	15km	25km
Food Security of Neighbors	0.140**	0.163***
	(0.056)	(0.052)
<u>Households Characteristics</u>		
Female-Headed Household	-995.604**	-986.669**
	(495.039)	(496.978)
Age of Household Head	-42.440***	-42.285***
	(9.735)	(9.701)
Household size	-1559.336***	-1559.059***
	(125.927)	(125.340)
<u>Household Assets</u>		
Domestic Assets	-23.317	-22.398
	(29.734)	(29.803)
Transport Assets	5.228	5.007
	(9.700)	(9.639)
Productive Assets	-12.745	-12.209
	(32.546)	(32.391)
<u>Household Livelihood Strategies</u>		
Off-farm Income	603.659	599.532
	(561.068)	(561.218)
Ruminants per Unit of Land	152.131**	152.107**
	(60.386)	(60.567)
Ruminants per Unit of Land squared	-2.482***	-2.480***
	(0.819)	(0.824)
N	1496	1496

*. Significant at the 10% level. **. Significant at the 5% level. ***. Significant at the 1% level. Standard errors are clustered at the site level. All regressions include crop, site, and technology fixed effects.

Online Appendix J: Heterogeneous Spatial Effects

Dependent Variable: Calorie Gap Measure[+]	SAR Model	Ego-Gender Models		Gender Homophily Models	
Model	(1)	(2)	(3)	(4)	(5)
Description 1 – Gender of Ego	All	Females	Males	Females	Males
Description 2 – Gender of Neighbors	All	All	All	Females	Males
Food Security of Neighbors	0.187***	0.489***	0.161***	0.600*	0.174***
	(0.044)	(0.142)	(0.040)	(0.319)	(0.038)
Food Security of Neighbors × Asia	-0.039	-0.710	-0.043	-0.087	-0.082
	(0.229)	(0.802)	(0.211)	(0.431)	(0.209)
Household Characteristics					
Female-Headed Household	-989.101**				
	(495.954)				
Age of Household Head	-42.183***	-1.458	-47.507***	4.049	-47.608***
	(9.673)	(24.219)	(10.825)	(25.249)	(10.765)
Household Size	-1557.590***	-1430.933***	-1565.428***	-1516.705***	-1565.253***
	(125.748)	(250.803)	(134.829)	(238.481)	(134.512)
Household Assets					
Domestic Assets	-21.811	-51.668	-27.378	-56.286	-26.749
	(29.963)	(74.651)	(31.891)	(86.755)	(31.716)
Transport Assets	5.109	106.260***	0.988	108.383***	0.770
	(9.555)	(22.766)	(9.224)	(25.363)	(9.195)
Productive Assets	-12.701	24.321	-24.959	67.273	-25.297
	(34.313)	(116.601)	(36.670)	(122.255)	(36.679)
Household Livelihood Strategies					
Off-farm Income	600.936	1776.482**	466.810	2214.481**	464.552
	(558.886)	(734.931)	(491.150)	(884.651)	(491.302)
Ruminants per Unit of Land	151.945**	165.319	153.740**	159.670	153.732**
	(60.251)	(156.433)	(62.150)	(164.648)	(61.610)
Ruminants per Unit of Land Squared	-2.479***	-6.129	-2.364***	-5.886	-2.376***
	(0.836)	(6.488)	(0.880)	(7.339)	(0.879)
N	1496	198	1298	198	1298
R-squared	0.811	0.540	0.829	0.553	0.829
First Stage F statistic	140.6	24.23	2525.2	26.91	963.23

* Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level. Standard errors are clustered at the site level. All regressions include crop, district, and technology fixed effects. First stage F statistic is based on Kleibergen-Paap cluster-robust statistic (Kleibergen & Paap, 2006). [+] The Calorie Gap Measure is the difference between the actual daily calorie intake of a household and the calorie intake recommended by the WHO.

Online Appendix K: OLS estimates

Dependent Variable: Calorie Gap Measure[+]	SAR Model	Ego-Gender Models		Gender Homophily Models	
Model	(1)	(2)	(3)	(4)	(5)
Description 1 – Gender of Ego	All	Females	Males	Females	Males
Description 2 – Gender of Neighbors	All	All	All	Females	Males
Food Security of Neighbors	0.148**	0.157	0.138**	0.225	0.135**
	(0.049)	(0.268)	(0.047)	(0.174)	(0.054)
Household Characteristics					
Female-Headed Household	-987.865*				
	(525.006)				
Age of Household Head	-42.339***	-0.881	-47.622***	2.256	-47.784***
	(10.325)	(28.193)	(11.517)	(30.184)	(11.486)
Household Size	-1558.647***	-1423.785***	-1566.274***	-1463.221***	-1566.741***
	(132.261)	(283.634)	(141.800)	(273.064)	(141.503)
Household Assets					
Domestic Assets	-22.719	-60.347	-27.929	-58.314	-27.690
	(31.878)	(92.592)	(33.741)	(97.942)	(33.641)
Transport Assets	4.966	107.818***	0.927	109.893***	0.752
	(10.080)	(27.601)	(9.777)	(28.843)	(9.825)
Productive Assets	-12.186	11.994	-24.302	29.390	-24.322
	(34.374)	(142.205)	(36.988)	(146.509)	(37.465)
Household Livelihood Strategies					
Off-farm Income	601.104	1841.497*	465.579	2070.248*	463.129
	(593.413)	(869.494)	(520.661)	(990.907)	(522.077)
Ruminants per Unit of Land	152.172**	164.114	153.825**	171.144	153.759**
	(63.852)	(172.158)	(66.001)	(188.166)	(65.373)
Ruminants per Unit of Land Squared	-2.482**	-5.625	-2.362**	-6.028	-2.369**
	(0.869)	(6.956)	(0.918)	(8.274)	(0.912)
N	1496	198	1298	198	1298
R-squared	0.710	0.478	0.723	0.495	0.723

* Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level. Standard errors are clustered at the site level. All regressions include crop, district, and technology fixed effects.[+] The Calorie Gap Measure is the difference between the actual daily calorie intake of a household and the calorie intake recommended by the WHO.

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