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Factors Affecting the Adoption of Estrus Synchronization and Artificial Insemination Service in Selected Areas of Southern Ethiopia

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Authors' contributions

This work was carried out in collaboration between both authors. Author TA designed the study, performed the data collection and analysis using STATA, interpreted the results, drafted the manuscript, and approved the final version. Author MF critically revised the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Ethiopia has the largest livestock population in Africa. To enhance the benefits of cattle, AI technologies have long been introduced into the country to improve the genetic potential of the indigenous cattle population. However, lack of recording scheme, wrong selection procedures, poor management of AI bulls, poor motivation and skills of inseminators are gaps in country and regional level. Therefore, this study was initiated to analyze factors affecting adoption of estrus synchronization and artificial insemination service in selected areas of Southern Ethiopia.

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Place and Duration of the Study: Southern Ethiopia from 2024 to 2025.
Methodology: In total, 141 sample households were selected based on a systematic random sampling technique. The bivariate probit regression model was used to analyze the econometric data.
Results: Education level, distance to AI station, heard information on failure of AI, mobile ownership, total family, and extension contact frequency were significant determinants of adoption of artificial insemination and estrous synchronization technology. Delay of AI technicians, shortage of supplementary feed, insufficient on-farm implementation of the services, indiscriminate application of AI, encountered failure, and insufficient equipment are challenges. In addition, inputs for the delivery of service, efficiency and specialization problems, shortage of technicians and limitation of access are constraints for sustainable utilization of AI and ES service.
Conclusion: continuous training for AI technicians and farmers, focusing on on-farm implementation, fulfilling inputs and equipment, helping AITs to specialize on the area are required. In addition, working on improved/supplementary feed, provision of manuals for AITs in local language and raising awareness of farmers are necessary. Smoothening communication of farmers with AI technicians, and making AI centers functional at every time are also recommended.

Keywords: Artificial Insemination; estrous synchronization; adoption; AI technicians; farmers.

ABBREVIATIONS

Acronym	*: Meaning*
AI	*: Artificial Insemination*
AITs	*: Artificial Insemination Technicians*
CSA	*: Central Statistical Agency*
ES	*: Estrus synchronization*

1. INTRODUCTION

Agriculture is the backbone of the Ethiopian economy which accounts for approximately 85% of the total population. Ethiopia holds the largest livestock population in Africa. The estimated cattle population in Ethiopia is about 57.83 million, 28.04 million sheep, 28.61 million goats, 1.23 million camels and 60.51 million poultry. Out of 57.83 million cattle the female cattle constitute about 55.38% (32.0 million) and the remaining 44.55% (25.8 million) are male cattle. From the total cattle in the country 98.59% (57.01 million) are local breeds and the remaining are hybrid and exotic breeds that accounted for about 1.19% (706,793) and 0.14% (109,733), respectively (CSA, 2017).

This number clearly indicates that exotic and hybrid female cattle population remained insignificant due to unsuccessful crossbreeding through AI. Artificial insemination (AI) has been defined as a process by which sperm is collected from the male, processed, stored, and artificially introduced into the female reproductive tract for conception (Webb, 2003). Semen is collected from the bull, deep-frozen and stored in a container with Liquid Nitrogen at a temperature of minus 196 degrees Centigrade and made for use.

Artificial insemination has become one of the most important techniques conducted for genetic improvement of farm animals. It has been widely used for breeding dairy cattle as the most valuable management practice available to the cattle producer and has made bulls of high genetic merit available to all (Webb, 2003; Bearden et al., 2004).

In Ethiopia, AI was introduced in 1938 in Asmara (the current capital city of Eritrea), the then part of Ethiopia, which was interrupted due to the Second World War and restarted in 1952 (Yemane et al., 1993). It was again suspended due to unaffordable expenses of importing semen, liquid nitrogen and other related input requirements.

In 1967, an independent service was started in the then Arsi Region, Chilalo Awraja under the Swedish International Development Agency (SIDA). The present National Artificial Insemination Center (NAIC) was established in 1984 to coordinate the overall AI operation at the national level (GebreMedhin, 2005). The efficiency of the service in the country, however, has remained at a very low level due to infrastructure, managerial, and financial constraints, as well as poor heat detection, improper timing of insemination and embryonic death (Shiferaw et al., 2003).

Reproductive problems related to crossbreed dairy cows under farmers' conditions are immense (Bekele, 2005). It is widely believed that the AI service in the country has not been successful in improving the reproductive performance of dairy industry (Sinishaw, 2005). From the previous little studies, it has been found that AI service is weak and even declining due to inconsistent service in the smallholder livestock production systems of the Ethiopian highlands (Dekeba et al., 2006).

The problem is more aggravated by a lack of recording scheme, wrong selection procedures, and poor management of AI bulls associated with poor motivations and skills of inseminators (Gebre Medhin, 2005). In Southern Ethiopia, despite the effort of government to increase the dissemination of the service, the status of AI is not satisfactory. Also, the whereabouts of the AI service is not studied in a formal manner in the Southern Ethiopia. Therefore, this study analyzed factors affecting adoption of estrus synchronization and artificial insemination service in selected areas of Southern Ethiopia, and identified constraints in AI and Es utilization and came up with recommendations that could attract the attention of decision makers and stakeholders to gear their efforts to the successful AI operation in the study area. Specifically, it was undertaken to identify significant determinants of Artificial Insemination (AI) & estrus synchronization (ES) technologies adoption and assess constraints of AI & ES technologies utilization.

2. METHODOLOGY

2.1 Description of the Study Area

This study was carried out in Wera *woreda* of Halaba zone, Dale *woreda* (Sidama region) and Dilla Zuria woreda (Gedeo zone).

2.2 Sampling and Sample Size Determination

A two-stage sampling technique was used in the study. In the first stage, one *woreda* from each zone (Gedeo, Halaba and Sidama) as the mandate area of Hawassa Agricultural Research Center were selected purposefully based on the level of artificial insemination service coverage. Consequently, Dilla Zuria, Wera and Dale were selected from Gedeo, Halaba and Sidama respectively.

In the second stage, two rural *kebeles* were selected purposively from each *woreda* based on level of artificial insemination service. Finally, using systematic random sampling technique, 141 household heads (from Gedeo/Dillazuria=51, Halaba/Wera=50, Sidama/Dale=40 were selected for the study.

AI professionals at different administrative levels were also contacted to obtain data on the problems they face in delivering the service to the community.

2.3 Type of Data and Method of Data Collection

Both qualitative and quantitative data were collected from primary and secondary sources. Primary data was collected from respondents using a structured interview questionnaire. Focus group discussions were arranged in each of the selected kebeles by organizing farmers into group of eight members to gather qualitative data using checklists. Experts' information was also gathered using checklists. Secondary data was obtained from websites and published materials with regard to the subject matter under study.

2.4 Methods of Data Analysis

Both descriptive and econometric analysis methods were used. Descriptive statistics such as tables, graphs, charts, percentages, etc. were employed. For the econometric analysis part, bivariate probit model was used to analyze factors affecting Estrous Synchronization and Artificial Insemination technology adoption.

The Bivariate Probit Model is used when there are two binary dependent variables that may be jointly determined, with possible correlation between their error terms.

2.4.1 Model structure

According to Greene (2018), Let $Y_1{}^*$ and $Y_2{}^*$ be two latent variables defined as:

$Y_1{}^*=X_1'\beta_1+\varepsilon_1$
$Y_2{}^*=X_2'\beta_2+\varepsilon_2$
$Y_1=1$ if $Y_1{}^*>0$; otherwise $Y_1=0$
$Y_2=1$ if $Y_2{}^*>0$; otherwise $Y_2=0$

Where:

X_1 and X_2 are vectors of explanatory variables (they can be the same or different)
β_1 and β_2 are vectors of coefficients
ε_1 and ε_2 are error terms

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics

As the results in Table 1 indicate, the majority of the sample respondents were males (90.78%). This result indicates a firm access to and control of resources by males as a household head. Males are known to have control of resources required to conduct agricultural activities either by a contract or as a gift from family when they establish the household of their own after marrying loved ones. Those who reported having used only artificial insemination were 14.19%. There are cases where the cows are already at the heat stage and require only insemination with the exotic breed semen. Those who used both artificial insemination and estrous synchronization were 42.55%. This happens when the district launches the dissemination of the technology. The farmers are required to bring their cows to local AI stations to get the service. Those who didn’t use the technology at all were 43.26%. The alternatives for those farmers or cattle herders are local bull services, and to some extent locally available improved bulls which are available on the neighbor farmers’ houses. Those who have heard about the failure of artificial insemination and estrous synchronization technology were 60.99%. Local farmers will inevitably hear about it when their neighbors use the technology and come up with bad news of failure when they meet in the pretext of different social gatherings. Almost half of the sample respondents (55.32%) had access to mobile. Not all development agents can reach every household requiring the delivery of extension services. Even if the development agents want to do so, there are constraints like shortage of vehicles and limitations in number of experts. In this circumstance, extension contacts are enhanced by mobile phones. Those who used improved feed were 61.70%. Improved feeds include elephant and desho grasses, and legumes.

As indicated in Table 2, artificial insemination service had a significant association with information related to failure of the service (Chi^2=7.38) and mobile ownership (Chi^2=65.91) at a one percent significance level. Estrous synchronization service also had a significant association with information on failure of the service (Chi^2=11.23) and mobile ownership (Chi^2=41.52) at at one percent significance level. More intuitive interpretations are indicated at the model result part.

As shown in Table 3, there is a statistically significant mean difference in education (t=-6.99), distance to artificial insemination service stations ((t=5.95), extension contact frequency (t=-3.05), and total family (t=-5.62) between categories of adopters and non-adopters of artificial insemination service at a one percent significance level. Education (t=-3.47), distance to the artificial insemination center (t=3.64) and extension contact frequency (t=-3.66) also showed a significant mean difference between adopters and non-adopters’ categories of estrous synchronization.

3.2 Feeding Practices of Sample Respondents

In cases of Sidama, the majority of feed sources were natural pasture (82.35%), crop residue (65%), and the cut and carry technique of the natural pasture (45%). Concentrate feed (42.5%) and improved forage (17.5%) came at the bottom of the rank. This is because the preparation of the concentrate feed at home requires knowledge, whereas purchasing it requires

Table 1. Summary of discrete variables

Variables		Freq	Percent
Sex	Male	128	90.78
	Female	13	9.22
	Total	141	100
AI only=1, ES=0		20	14.19
Both AI=1 and ES=1		60	42.55
Both AI=0 and ES=0		61	43.26
Use of improved bull services/locally available		16	11.35
Use of local bull services		45	31.91
Heard failure of AI and ES		86	60.99
Mobile ownership		78	55.32
The use of improved feed		87	61.70

Source: survey result, 2024

Table 2. Association between discrete variables

Variable	Value	AI					Ch^2	ES					Ch^2
		Non adopters (61)		Adopters (80)		Total		Non adopters (81)		Adopters (60)		Total	
		N	%	N	%			N	%	N	%		
Heard failure	0	16	26.23	39	48.75	55	7.38***	22	27.16	33	55.00	55	11.23***
	1	45	73.77	41	51.25	86		59	72.84	27	45.00	86	
	Total	61	100	80	100	141		81	100	60	100	141	
Mobile	0	51	83.61	12	15.00	63	65.91***	55	67.90	8	13.33	63	41.52***
	1	10	16.39	68	85.00	78		26	32.10	52	86.67	78	
	Total	61	100	80	100	141		81	100	60	100	141	
Improved feed	0	19	131.15	35	43.75	54	2.33	27	33.33	27	45.00	54	1.99
	1	42	68.85	45	56.25	87		54	67.67	33	55.00	87	
	Total	61	100	80	100	141		81	100	60	100	141	

Source: survey result, 2024

Table 3. Association between AI and ES in relation to continuous variables

Variables	AI					ES					Total mean
	Non adopters (61)		Adopters (80)		Ttest	Non adopters (81)		Adopters (60)		T test	
	Mean	Std.Err.	Mean	Std.Err.		Mean	Std.Err	Mean	Std.Err.		
Education	4.80	0.23	6.7	0.16	-6.99***	5.43	0.23	6.48	0.17	-3.47***	5.88
TLU	1.60	0.07	1.67	0.05	-0.90	1.61	0.06	1.69	0.06	-0.96	1.64
Age	38.59	1.69	40.55	1.25	-0.95	40.40	1.49	38.77	1.31	0.79	39.70
Distance to AI	5.72	0.08	5.22	0.04	5.95***	5.58	0.07	5.24	0.05	3.64***	5.44
Extension contacts freq.	2.51	0.22	3.26	0.14	-3.05***	2.56	0.17	3.45		-3.66***	2.94
Feed per day	1.82	0.05	1.78	0.05	0.65	1.83	0.04	1.75	0.06	1.12	1.79
Total family	6.06	0.19	7.59	0.18	-5.62***	6.47	0.18	7.55	0.22	-3.77***	6.93

Source: survey result, 2024

Table 4. Summary of feeding Practices

Feed type	Sidama (N=40)		Gedeo(N=51)		Halaba(N=50)		Total(N=141)	
	Freq	%	Freq	%	Freq	%	Freq	%
Concentrate	17	42.5	10	19.61	14	28.0	41	29.08
Improved forage	7	17.5	6	11.76	5	10.0	18	12.77
Natural pasture	33	82.5	42	82.35	44	88.0	119	84.40
Crop residue	26	65.0	22	43.14	35	70.0	83	58.87
Cut and carry	18	45.0	25	49.02	21	42.0	64	45.39
Hay	-	-	-	-	46	92.0	46	32.62

Source: survey result, 2024

Table 5. Housing &watering

Housing (N=141)	Freq	%
Main house	88	62.41
Separately	53	37.59
Watering frequency(N=141)		
Once	74	52.48
Twice	50	35.46
Every other day	-	-
Freely available	17	12.06

Source: survey result, 2024

money. Improved forage access is limited. In the same way, natural pasture (82.35%), cut and carry (49.02%) and crop residues (43.14%) take the upper hand as the sources of feed in Gedeo zone. In the Halaba areas, in addition to natural pasture and crop residue, hay making is customary as the area is a cash crop environment.

3.3 Housing and Watering Conditions

The majority (62.41%) of the respondents reported to having housed their cattle in main house together with family. If possible, separate house construction is of paramount importance to keep the health of livestock safe and the dwelling home clean and convenient. The watering frequency of livestock, specifically cattle was once and twice majorly (Table 5).

3.4 Factors Affecting AI and ES Adoption

Before running the model, relevant statistical tests were conducted as a precondition. The mean VIF was 1.15, which was evidence not to worry about multicollinearity (Appendix Table 3). Heteroscedasticity was also not prevalent in the data with the test statistics of chi^2 (1) = 1.49 and Prob > chi^2 = 0.2225 (Appendix Fig. 1). This result is interpreted as we fail to reject the null hypothesis for Constant variance as per the result of the Breusch-Pagan / Cook-Weisberg test for heteroscedasticity. The overall fitness of the model was good with several statistical values. The probability value was highly significant (Prob>chi^2=0.0000) with Wald chi^2 (22) = 60.00. Ten explanatory variables were used in the model, out of which five were significant on the AI side and three were significant on the ES side.

Education level: It was statistically significant at a five percent significance level (*P*=.015) and positively related to AI adoption. Average marginal effects indicate that as education level increases by one grade level, the probability of adopting artificial insemination increases by 5.99%. The probable reasons might have been that education makes farmers aware and adopt agricultural technologies. This result was in line with the findings which indicated direct positive relationship between education and adoption of estrus synchronization and artificial insemination (Gebre et al., 2022; Adem and Abebe, 2022).

Distance to AI station: It was statistically significant at a five percent significance level (*P*=.013) and negatively related to AI adoption. Average marginal effects indicates that as distance to AI station increases by one kilometer, the probability of adopting artificial insemination decreases by 10.55%. The implication is that distance becomes a barrier for farmers and prevents easy access to the technology whenever they need. This finding is in line with studies which implicated negative impact of a greater distance of AI stations from farmers homes (Tefera, 2014).

Heard failure on AI: It was statistically significant in the case of AI at ten percent (*P*=.050) and in the case of ES at one percent (*P*=.002) and was negatively related to the adoption of both AI and ES. Average marginal effects show that for those who heard failure information on AI relative to those who didn't hear, the probability of adopting artificial insemination and estrous synchronization decreases by 12.40% and 19.30% respectively. The probable implication is that farmers may be discouraged from participating in technologies they don't trust their efficiency if they get bad information and misled by their neighbors. A study by Tefera (2014) indicated that access to AI information significantly enhances the adoption likelihood of AI.

Mobile ownership: It was statistically significant at a one percent significance for both the AI and the ES (*P*=.000) and was positively related to the adoption of both the AI and the ES. Average marginal effects show that for those who have mobile phones relative to those who don't have, the probability of adopting artificial insemination and estrous synchronization increases by +25.52% and 31.88% respectively. The implication is that better communication with development agents in all available means of communication helps them to adopt technologies.

Total family: It was statistically significant at ten percent significance level (*P*=.065) and positively related to AI adoption. Average marginal effects show that as total family size increases by one, the probability of adopting artificial insemination increases by 4.59%. The probable reasons might have been that the household with more family members can better afford to take their cattle to AI stations even if some of the family members are assigned for different tasks (Tefera, 2014).

Extension contact frequency: It was statistically significant at one percent significance level (*P*=.005) and positively related to ES adoption. Average marginal effects show that as extension contact frequency in a year increases by one, the probability of adopting estrous synchronization increases by 8.74%. The implication is that extension contact in frequent sequence helps to better adopt agricultural technologies (Adem and Abebe, 2022).

Table 6. Model results for determinants of AI and ES adoption

	Coefficient	Standard error	Z	P>Z
AI				
Education level**	.4190592	.1729024	2.42	0.015
TLU	.5138085	.5101419	1.01	0.314
Age	.0371479	.128222	0.29	0.772
Age2	-.0004925	.0014289	-0.34	0.730
Distance to AI station**	-.7380225	.2978158	-2.48	0.013
Heard failure on AI*	-.8678716	.4431766	-1.96	0.050
Extension contact frequency	.272517	.216883	1.26	0.209
Mobile ownership***	1.785664	.4235055	4.22	0.000
Feed per day	-.4264517	.5365805	-0.79	0.427
Total family size*	.3215362	.1740078	1.85	0.065
Improved feed use	-.5404535	.3712164	-1.46	0.145
_cons	-2.024185	3.397803	-0.60	0.551
ES				
Education level	.0909314	.0944739	0.96	0.336
TLU	.4414554	.3385956	1.30	0.192
Age	.0887229	.0978356	0.91	0.364
Age2	-.001323	.0011238	-1.18	0.239
Distance to AI station	-.5926788	.3742401	-1.58	0.113
Heard failure on AI***	-.9179505	.2968202	-3.09	0.002
Extension contact frequency***	.4157865	.1479243	2.81	0.005
Mobile ownership***	1.516663	.3240382	4.68	0.000
Feed per day	-.6049717	.3862417	-1.57	0.117
Total family size	.094197	.103569	0.91	0.363
Improved feed use	-.3695884	.2963995	-1.25	0.212
_cons	-.6188812	3.202917	-0.19	0.847
/athrho	13.81741	1171.21	0.01	0.991
rho	1	4.67e-09	CI -1	1

Source: survey result, 2024

Table 7. Average marginal effects

Varable	Average marginal effects			
	Expression: Pr(AI=1), predict(pmarg1) dy/dx w.r.t. : Xs		Expression: Pr(ES=1), predict(pmarg2) dy/dx w.r.t. : Xs	
Educ	0.0598798	+5.99%		
DistAI	-0.1054567	-10.55%		
Herdfailure	-0.124011	-12.40%	-0.1929607	- 19.30%
Mobile	0.2551552	+25.52%	0.3188148	+31.88%
Totfam	0.0459446	+4.59%		
Extcont			0.0874017	+8.74%

Source: survey result, 2024

Table 8. Summary of Ranked Constraints in ES & AI Utilization

Constraints in ES and AI utilization	Freq	%	Rank
Delay of AI technicians after farmers had detected heat	84	59.57	5
Shortage of supplementary feed	72	51.06	7
Insufficient on farm implementation of the services	75	53.19	6
Indiscriminate application of AI on every available cows without considering body condition	66	46.80	8
Tendency of farmers not to repeat the service once encountered failure	57	40.43	9
Insufficient equipment and inputs for the delivery of service	94	66.67	2
Efficiency and specialization problems on AITs side	89	63.12	4
Shortage of AITs	91	64.53	3
Limitation of access which is confined to annual launching	101	71.63	1

Source: survey result, 2024

3.5 Ranked Constraints in ES & AI Utilization

As Table 8 indicates, limitations of access confined to casual launching (71.63%), insufficient equipment and inputs for running the services of AI and ES (66.67%) and shortages of AI technicians (64.53%) take the upper hand in one to three in rank. It is important to prioritize and work on each of the ranked constraints to ensure the continuous utilization and sustainability of the service.

4. CONCLUSION AND RECOMMENDATIONS

Education level, distance to AI station, heard information on failure of AI, mobile ownership, total family, and extension contact frequency were significant determinants of adoption of artificial insemination and estrous synchronization technology. Delay of AI technicians after farmers had detected heat , shortage of supplementary feed insufficient on farm implementation of the services , indiscriminate application of ai on every available cows ,tendency of farmers not to repeat the service once encountered failure ,insufficient equipment and inputs for the delivery of service , efficiency and specialization problems on technicians of AI side, shortage of technicians and limitation of access which is confined to annual launching are constraints for sustainable utilization of AI and ES service.

As per the result, AI technicians and farm owners need continuous training to improve their heat detection skills, increase their knowledge, and implement a successful program. Focusing on-farm implementation in place of annual launching to increase accessibility of the technology and to minimize distance barriers is required. Also working to fulfill inputs and equipment with stakeholders is required to increase the efficiency of the service. Expanding professional schemes of opportunity for AITs to specialize in the area either in short-term training/ long-term education opportunities are necessary measure to fill the gap of knowledge. Working on development of improved/supplementary feed is also required as feed goes hand in hand with better body condition for the efficiency of the technology. The provision of printed guidelines for AITs in the local language is important as it helps to ease barriers. Raising awareness of farmers who discontinued usage in frustration with using the technologies after failures is necessary for the continuation of the service. Where possible, AITs need to provide their phone number to those who can afford to call development agents. The number of AITs needs to be availed at kebele level as many are delivering service by touring from urban seats of offices to rural areas in inconvenient conditions. Local AI stations should be functional at every time-of-service requirement.

CONSENT

Study participants were informed that their personal identity would not be disclosed in any form in this study and the information they provided was used solely for the purpose of the study. Ahead of the study, their willingness to participate was asked and the objectives of the study were clearly indicated.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Appendix Table 1. coefficients of model results

	Coeff.	Std. Err.	Z	P>Z	CI	
AI						
Educ	.4190592	.1729024	2.42	0.015	.0801767	.7579417
TLU	.5138085	.5101419	1.01	0.314	-.4860512	1.513668
Age	.0371479	.128222	0.29	0.772	-.2141627	.2884585
Age2	-.0004925	.0014289	-0.34	0.730	-.0032931	.0023082
DistAI	-.7380225	.2978158	-2.48	0.013	-1.321731	-.1543143
Herdfailure	-.8678716	.4431766	-1.96	0.050	-1.736482	.0007385
Extcont	.272517	.216883	1.26	0.209	-.1525659	.6975999
Mobile	1.785664	.4235055	4.22	0.000	.9556085	2.61572
Feedperday	-.4264517	.5365805	-0.79	0.427	-1.47813	.6252268
Totfam	.3215362	.1740078	1.85	0.065	-.0195129	.6625854
Impfeed	-.5404535	.3712164	-1.46	0.145	-1.268024	.1871173
_cons	-2.024185	3.397803	-0.60	0.551	-8.683757	4.635387
ES						
Educ	.0909314	.0944739	0.96	0.336	-.094234	.2760968
TLU	.4414554	.3385956	1.30	0.192	-.2221798	1.105091
Age	.0887229	.0978356	0.91	0.364	-.1030313	.2804772
Age2	-.001323	.0011238	-1.18	0.239	-.0035256	.0008797
DistAI	-.5926788	.3742401	-1.58	0.113	-1.326176	.1408183
Herdfailure	-.9179505	.2968202	-3.09	0.002	-1.499707	-.3361936
Extcont	.4157865	.1479243	2.81	0.005	.1258601	.7057129
Mobile	1.516663	.3240382	4.68	0.000	.8815594	2.151766
Feedperday	-.6049717	.3862417	-1.57	0.117	-1.361991	.152048
Totfam	.094197	.103569	0.91	0.363	-.1087945	.2971885
Impfeed	-.3695884	.2963995	-1.25	0.212	-.9505207	.211344
_cons	-.6188812	3.202917	-0.19	0.847	-6.896483	5.658721
/athrho	13.81741	1171.21	0.01	0.991	-2281.713	2309.348
rho	1	4.67e-09		-1	1	

Appendix Table 2. mfx results

Variable dy/dx	Std. Err.	z	P>z	[95%	C.I.]	X
Educ .0320747	.03295	0.97	0.330	-.032514	.096664	5.87943
TLU .155717	.11768	1.32	0.186	-.074941	.386375	1.64219
Age .0312957	.03419	0.92	0.360	-.03571	.098301	39.7021
Age2 -.0004667	.00039	-1.19	0.233	-.001234	.0003	1721.26
DistAI -.2090589	.12814	-1.63	0.103	-.460201	.042083	5.43506
Herdfa~e* -.3289128	.10563	-3.11	0.002	-.535945	-.121881	.609929
Extcont .1466627	.0488	3.01	0.003	.051011	.242314	2.93617
Mobile* .4810954	.08532	5.64	0.000	.313864	.648327	.553191
Feedpe~y -.2133951	.13452	-1.59	0.113	-.47704	.05025	1.79433
Totfam .0332266	.03628	0.92	0.360	-.037877	.10433	6.92908
Impfeed* -.1324707	.10728	-1.23	0.217	-.342745	.077803	.617021

Appendix Table 3. Tests of multicollinearity

Variable	VIF	1/VIF
Mobile	1.35	0.738337
Educ	1.29	0.777129
DistAI	1.24	0.803398
Totfam	1.18	0.850078

Variable	VIF	1/VIF
Impfeed	1.10	0.909422
Extcont	1.10	0.911575
TLU	1.09	0.921490
Age	1.07	0.934513
Feedperday	1.05	0.954330
Herdfailure	1.03	0.970818
Mean VIF	1.15	

```
. estat hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of AI

         chi2(1)      =     1.49
         Prob > chi2  =   0.2225
```

Appendix Fig. 1. Tests of heteroskedasticity

Peer-review history:
The peer review history for this paper can be accessed here:
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