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## Research Article

### SIMULATION ANALYSIS OF LIVESTOCK PRODUCTION EFFICIENCY AND ITS IMPACT ON WOMEN'S EMPOWERMENT IN BANGLADESH

Rajib Kumar Roy<sup>1</sup>, Paresh Kumar Sarma<sup>2</sup>, Jahangir Alam Khan<sup>3</sup>,  
Sadika Haque<sup>4</sup> and Jasim Uddin Ahmed<sup>1\*</sup>

<sup>1</sup>Department of Agricultural Economics and Policy, Sylhet Agricultural University, Sylhet

<sup>2</sup>Senior Scientific Officer (SSO), BAURES, BAU, Mymensingh

<sup>3</sup>Director, School of Economics, University of Dhaka

<sup>4</sup>Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh

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### \*Corresponding author

Dr. Jasim Uddin Ahmed

E-mail:

[jahmed.aep@sau.ac.bd](mailto:jahmed.aep@sau.ac.bd)

## Abstract

Livestock production plays a vital role in rural livelihoods and household security in Bangladesh, yet gender disparities often limit women's participation and decision making in this sector. This study investigates the relationship between livestock production efficiency and women's empowerment among beneficiaries of the Livestock Development and Dairy Production (LDDP) project in Bangladesh. The main objective was to examine how women's empowerment influence by technical efficiency in livestock production. Primary data were collected from 450 livestock-farming household across six upazilas in the LDDP coverage three southern divisions. Descriptive and inferential statistics, the Alkire–Foster methodology, stochastic frontier analysis (SFA), and ordered probit regression were applied to analyze the data. Results showed that the overall WELI score was 0.735, with 26.65% of women (WELI  $\geq$  0.80) classified as empowered. The mean TE scores were 0.941 for male-headed and 0.940 for female-headed households, respectively. A positive and statistically significant ( $p < 0.05$ ) relationship between TE and WELI was observed, indicating that households with greater gender parity exhibit higher production efficiency. The study concludes that enhancing livestock production not only women empowers them but also improve overall productivity, supporting Sustainable Development Goals (SDGs) on gender equality and inclusive economic growth. Future research should explore longitudinal impacts and the role of institutional support in sustaining women's empowerment in livestock farming.

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## Introduction

Livestock production plays a vital role in the rural economy by contributing a substantial share to household income, enhancing food security, and promoting women's empowerment (FAO, 2011). It improves household welfare by increasing income and enhancing the nutritional status of women and other household members. Moreover, livestock possesses significant economic value, providing both business opportunities for rural development and raw materials for industrial animal production enterprises (Sakarya & Uysal, 2000). Beyond economic benefits, livestock production also has great potential to mitigate greenhouse gas (GHG) emissions, as effective strategies can reduce emissions from livestock systems by up to 30% (Padmakuma et al., 2019). In developing countries like Bangladesh, understanding the livestock production efficiency is crucial for both productivity improvement and sustainable

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development. From a policy perspective, assessing a producer's performance is often essential, and the concept of technical efficiency (TE) provides a theoretical basis for such evaluation. According to Farrell (1957), efficiency refers to a farm's ability to produce the maximum possible output from a given set of inputs. The concept of TE, as defined by O'Neill et al. (1999), Minviel and Latruffe (2017), and Manevska-Tasevska et al. (2014), captures the extent to which a farm approaches this production frontier. TE was measures how closely a farm approaches this production frontier (O'Neill et al. 1999; Minviel and Latruffe 2017; Manevska-Tasevska et al. 2014) and can be estimated by dividing actual output by maximum achievable output (Shih et al. 2004; Lambarraa et al. 2007)

Women play a crucial role in agricultural development in many developing nations; however, they face persistent gender-based barriers and socio-economic constraints that limit their full participation (Sraboni et al., 2014). Reducing the gender disparities has therefore become a global development priority. Livestock production offers pathways to empower women by expanding decision-making power, access to resources, and participation in value chains (FAO, 2011). Empowered women who can make decision regarding livestock management such as feed, breeding or input selection tend to achieve higher productivity levels. Similarly, access to and ownership of agricultural technologies positively influence performance, as documented by Asfaw et al. (2012), Gitonga et al. (2013), Mendola (2007), and Tefera et al. (2011). These studies show that technology adoption enhance improves empowerment and livelihood outcomes among rural farmers through mechanisms such as input vouchers and training.

Given the importance of women's empowerment in narrowing gender disparities and promoting agricultural sustainability, it is critical to explore the relationship between women's empowerment and technical efficiency. Specifically, this study addresses the following research questions

- What are the levels and key determinants of WELI and TE among livestock-farming households in Bangladesh
- How does women's empowerment influence TE in livestock production.

This study thus aims to assess how aggregate empowerment derived from WELI influences the technical efficiency of livestock-farming households in Bangladesh.

The findings provided valuable policy insights, highlighting the need for government and institutional interventions to strengthen linkages between producers and stakeholders, as well as to enhance the capacity of agricultural extension agents through targeted training. The subsequent sections of the paper described the methodology—including the conceptual framework, estimation techniques, study area, and sampling methods followed by the results, discussion, and concluding policy recommendations.

## **Materials and Methods**

### ***Study area***

The study was conducted in the LDDP intervention areas located in the Southern Delta region of Bangladesh, a region characterized by its diverse agroecological conditions, high dependence on livestock-based livelihoods, and vulnerability to climate-induced challenges. The Southern Delta region was selected because it represents one of the most livestock-intensive areas of the country, where smallholder farmers rely heavily on cattle, goats, and poultry for income generation, nutrition, and household food security. A total of six upazilas from six districts across the three southern divisions, Khulna, Barishal, and Dhaka, were purposively selected to capture regional variation in livestock production systems and women's participation in livestock-related activities. The selected upazilas are Madhukhali (Faridpur District), Rajbari Sadar (Rajbari

District), Hizla (Barishal District), Bauphal (Patuakhali District), Monirampur (Jashore District), and Satkhira Sadar (Satkhira District).

These upazilas were chosen based on several criteria:

- a) **LDDP Project Implementation:** All selected locations fall under the LDDP intervention area, where project activities such as livestock technology dissemination, capacity building, and women's participation initiatives are actively ongoing.
- b) **High Livestock Density and Smallholder Dependence:** The selected upazilas have a high concentration of smallholder livestock farmers, which provides an ideal context for examining the relationship between technical efficiency and women's empowerment.
- c) **Socioeconomic and Gender Relevance:** Women in these areas are significantly engaged in livestock rearing, yet often face barriers to decision-making, resource access, and market participation—making them suitable for assessing empowerment levels using the Women's Empowerment in Livestock Index (WELI).
- d) **Agroecological and Institutional Variation:** The sites represent diverse ecological and institutional settings, from flood-prone lowlands (e.g., Hizla and Bauphal) to saline-prone coastal zones (e.g., Satkhira and Monirampur), which allows comparative analysis of how environmental and institutional contexts influence livestock production efficiency and women's empowerment outcomes.

The Southern Delta region's combination of economic potential, livelihood vulnerability, and strong relevance to the LDDP's objectives makes it an appropriate and representative setting for this research. The selection of these six upazilas ensured that the findings provided context-specific policy insights for promoting women's empowerment and enhancing livestock productivity in similar agroecological zones across Bangladesh.

#### ***Sampling frame and sample size determination***

The sampling frame comprised all households residing in the six selected upazilas—Madhukhali, Rajbari Sadar, Hizla, Bauphal, Monirampur, and Satkhira Sadar—representing the project's target population. Each household constituted a sampling unit. Household lists were obtained from local government offices or census records to develop a complete sampling frame. Where official lists were unavailable, village-level enumeration was conducted to ensure comprehensive coverage. This frame enabled random selection of households, ensuring representativeness across geographical and socio-economic variations. Education level of the household head was also recorded as an important variable to understand its association with livelihood outcomes, adoption behavior, and household welfare.

$$n = \frac{z^2 \cdot p \cdot q \cdot N}{z^2 \cdot p \cdot q + (N - 1)e^2}$$

The total sample size was determined to be 450 households, based on resource constraints while maintaining statistical reliability. Using a 95% confidence level ( $z = 1.96$ ) and assuming  $p = 0.5$ , the sample provided a margin of error of approximately  $\pm 4.6\%$ , which was acceptable for household-level socio-economic research. A multi-stage stratified random sampling approach was applied—first stratifying by upazila and then selecting households randomly within each stratum. Proportional allocation across upazilas was used to ensure that the number of samples corresponds to their respective household populations, thereby enhancing both precision and representativeness.

**Data collection**

Data were collected using a structured household survey as the primary method. A pre-tested interview schedule captured information on household demographics, socio-economic status, livestock ownership, production practices, food security, women’s empowerment, and educational background. Trained enumerators conducted face-to-face interviews with the household head or an adult member knowledgeable about household activities. To ensure data quality, pilot testing of the interview schedule was conducted in a similar area prior to the main survey. Enumerators received training on question interpretation, ethical considerations, and obtaining informed consent. Direct observations of livestock and farm practices supplemented survey responses, providing objective verification of reported information. For sensitive topics such as women’s decision-making, privacy was maintained by interviewing respondents separately. All data were recorded electronically using tablets or smartphones, minimizing entry errors and allowing real-time monitoring by supervisors. This mixed approach ensured reliability, validity, and completeness of collected data.

**Household Dietary Diversity Score (HDDS):** The HDDS is a snapshot of a family's capacity to access a range of foods based on their financial situation (Kennedy et al., 2013; Headey and Ecker 2014). It was once employed as a proxy for food access in the home which was developed by FANTA (Swindale and Bilinsky 2006). The score was calculated by aggregating the number of days that households consumed at least one item from each of the 12 food groups in the previous seven days (Sibhatu and Qaim 2018). The range of HDDS’s is zero to twelve.

The HDDS indicator is expressed as

$$HDDS (0 - 12) = \sum (A + B + C + D + E + F + G + H + I + J + K + L) \dots \dots (v)$$

The HDDS indicator is calculated using 12 food groups over a recall period of 7 days: A. cereals; B. Pulses; C. Fruits D. Edible oil; E. Vegetables F. Meat, eggs and milk; G. Fruits; H. Fish (large); I. Fish (small); J. Spices; K. Drinks and beverages; L. Other foods prepared outside home. The values for A to L can be “0” or “1”.

**Household Wealth Index (HWI):** It is a composite variable produced by principal component analysis (PCA). The PCA model included variables for household land, assets, and productive assets, as well as home amenity ownership indicators. A car, motorcycle, bicycle, radio, gas cooker, sewing machine, bed, and mobile phone, as well as cattle, are among the important goods (Mutisya et al., 2016). Formally, the wealth index for household i is the linear combination;

$$Y_i = \alpha_1 \left( \frac{X_1 - \bar{X}_1}{S_1} \right) + \alpha_2 \left( \frac{X_2 - \bar{X}_2}{S_2} \right) + \dots + \alpha_k \left( \frac{X_k - \bar{X}_k}{S_k} \right) \dots \dots (vi)$$

Where,  $\bar{X}_k$  and  $S_k$  are the mean and standard deviation of asset  $X_k$ , and  $\alpha$  represents the weight for each variable for the first principal component.

**Technical efficiency (TE):** TE is linked to the ability to produce on the frontier isoquant. The TE scale runs from 0 to 1, with 1 signifying a completely efficient farm (Farrell, 1957). Technical efficiency is described as a set of factors measured in a specific method in connection to a set of firms, and any change in these specifications will have an impact on the measure (Farrell, 1957). It evaluates a company's capacity to get the most out of a set of inputs. This is unavoidable in any such metric. However, with these qualifications, it serves as a measure of efficiency in a natural and satisfactory manner (Farrell, 1957). Three quantitative approaches have been developed for the measuring of technical efficiency parametric non-parametric based on Data Envelopment Analysis (DEA), and productivity indices based on growth accounting and index

theory principle (Coelli et al, 1988). The most widely utilized approaches are stochastic Frontier Analysis (SFA) and differential equation analysis (DEA). Both methods calculate the firm's technical efficiency in relation to the efficient frontier. The SFA method necessitates the specification of a functional form for the frontier production function. The DEA method use linear programming to create a piece-wise frontier that encircles a set of observations. The efficient frontier is the one that displays the best performance among the farmers. The DEA approach has the advantage of allowing various inputs and outputs to be examined at the same time, as well as different units of measurement for inputs and outputs. In addition, DEA allows for the calculation of scale efficiency; however, SFA has a distinct advantage over DEA in that it allows for the calculation of scale efficiency. The stochastic frontier model was simultaneously proposed by Aigner et al., (1977) and by Meeusen and ven den Broeck (1977). In contrast to a deterministic model it includes a random term representing the noise.

The model for the  $i^{th}$  farm is written as follows;

$$\ln(Y_i) = \int (X_i, \beta) + v_i - U_i \dots \dots \dots (1)$$

Where

- $Y_i$  is the observed output quantity of the  $i^{th}$  farm
- $\int$  is the production function
- $X_i$  is a vector of the input quantities used by the farm
- $\beta$  is a vector of parameters to be estimated
- $v_i$  is an error term, independent and identically distributed (iid) with  $N(0, \sigma_v^2)$   $u_i$  is a non-negative random error, accounting for efficiency, iid, with  $N(0, \sigma_u^2)$  truncated to zero to ensure non-negativeness.

Following Battese and Corra (1977) and Battese and Coelli (1995), the variance are parameterized by replacing  $\sigma^2_{vu}$  and  $\sigma^2_{\mu}$  with

$$\delta^2 = \sigma_u^2 + \sigma_{vu}^2 \text{ and } \lambda = \frac{\sigma_u^2}{(\sigma_{uv}^2 - \sigma_u^2)} \dots \dots \dots (2)$$

Where,  $0 \leq \lambda \leq 1$  with the value equal to 1 indicating that all the deviations from the frontier are due entirely to technical inefficiency (Coelli, Rao, and Battese, 1998). The technical efficiency of the household can be defined as:

$$TE = \frac{E\left(\frac{Y_i}{U_i}, X_i\right)}{E(Y/u_i = 0, X_i)} = e^{-u_i}$$

Where;

E is the expectation of a Rice farmer. Thus, the measure of technical efficiency is based on a conditional expectation given by Equation (8), given the value of  $V_i - U_i$  evaluated at the maximum likelihood estimates of the parameter in the model, where the expected maximum value of Y is conditional on  $u_i = 0$  (Battese and Coelli, 1988). The measure  $TE_i$  takes the value between zero and 1 and the overall mean technical efficiency of households is estimated as:

$$TE = \left\{ \frac{1 - \Phi\left(\frac{u}{\sigma_u}\right)}{1 - \Phi\left(\frac{u}{\sigma_u}\right)} \right\} e^{-u + (0.05)\sigma_u^2}$$

Where; represents the density function of the standard normal variable

$$\text{Technical inefficiency} = 1 - TE_i$$

**Key variables measurement**

The dependent and independent variables are presented Table 1. A brief description of how the major variables were constructed for the analysis is provided below the table.

**Table 1.** Description of empowerment variables

Code	Level of variable	Variable Types	Expected sign	Reference
<b>Dependent variables for intensity of use</b>				
WELI	Women empowerment in livestock index	Composite continuous		Abebe et al., 2016; Galiè et al., 2019; USAID, 2012; WEAI et al., 2015; Alkire et al., 2012;
HDDS	Household Dietary Diversity Score (HDDS): The HDDS is a qualitative measure of food consumption that indicates access to a variety of foods in the home.	Continuous		Tambo and Wünschler 2017; Deaton 1997; Kassie et al., 2015, Shiferaw et al., 2014; Sinyolo et al., 2014; Bocoum et al., 2014; Wossen et al., 2019;
<b>Key explanatory variables</b>				
TA	Percentage of technology adoption of i <sup>th</sup> household	Continuous	+	Wossen et al., 2017; s Anderson and Feder, 2007; Wossen et al., 201
Lincome	Last month household income in TK	Continuous	+	Hansen and Duveskog (2012); Maltitz et al., 2021; Babatunde et al., 2007
ICT	1 if farmers access any service like mobile, internet/computer/radio/TV and zero otherwise.	Dummy	+/-	Nwafor 2020; Meena and Singh (2013)
HWF	Household welfare measuring adult per head expenditure in TK	Continuous	+/-	Mekbib · 2017; Gebregziabher 2015
HWI	Household wealth index	continuous	+/-	Mutisya et al., 2016
TE	Technical efficiency of livestock production of farmers households using the stochastic frontier method	Composite continuous	+	Adeyeye et al., · 2019 ; Achandi and Kidane 2019
Herd Size	The number of livestock (cattle, cow, bulk, goat and lamb)	Continuous	+	Jago and Berry (2011)
HAge	Households' head age in a complete year	Continuous	+/-	Langyintuo and Mulugetta 2005; Arene and Anyaeji 2010
Hedu	Level of head education in year	Continuous	+/-	Abay and Assefa, 2004; Salasya et al. 2007, Alene and Manyong, 2007
Main occupation	Main occupation is a dummy variable referring 1 (one) if farmers are engaging in livestock farming and 0 (zero) otherwise	Dummy	+/-	Hameed et al., · 2019; Neethi and Sailaja 2018
Hsize	Number of family member	Continuous	+/-	Liberio 2012, Idrisa 2012, Jayne et al., 2005; Deininger, 2003

**Women empowerment in livestock index (WELI):** In this study empowerment of women was measured by empowerment in the livestock index (WELI). WELI is the latest index developed in 2012 by OPHI as a direct indicator of economic empowerment and gender parity at the household and individual level (Alkire et al., 2013; and Yang and Stanley, 2012). Since empowerment is a dynamic and complex concept hence one indicator alone is not adequate to measure, in this research the (Alkire et al., 2013) multidimensional measure of empowerment was adopted. The Alkire-Foster multidimensional measure of empowerment helps to show women’s achievement in 10 indicators and five domains of empowerment. This paper presents the WELI and the dimensions of empowerment it includes: (1) decisions about agricultural production; (2) decisions related to nutrition; (3) access to and control over resources; (4) control and use of income; (5) access to and control of opportunities; and (6) workload and control over own time. WELI helps to measure empowerment in a multidimensional way by using the weighted five domains and 10 indicators, which allows decomposition and comparison across different domains. WELI combines two sub-indexes such as five domains of empowerment (3DE) and gender parity index (GPI) with the arbitrary weights of 90 and 10% respectively.

Hence, in each indicator, the adequacy situation of an individual is determined through the multiplication of the variable with their defined weight and compare with the inadequacy cutoff. Once, adequacy score of an individual and inadequacy cutoff is determined, the overall disempowerment index ( $M_0$ ) is constructed using the weighted indicators (Alkire *et al.*, 2012; and Alkire et al., 2013). The disempowerment of women is decomposed by indicators and domains to show the contribution of each indicator and domain for disempowerment. Empowerment in five domains is a counterpart of disempowerment which is computed as

$$3DE = 1 - M_0 \text{ -----(1)}$$

Where, 3DE is measured using 10 indicators with their corresponding weights and  $M_0$  is the overall disempowerment index. Each indicator shows whether each individual has adequate achievement in that area or not. Another innovative feature of WEAI is Gender Party Index (GPI), which reflects gender differentials in the empowerment women with men across the 3DEs in the same household

Mathematically

$$WELI = 0.90 (3DE) + 0.10 (GPI) \text{ ----- (2)}$$

Where,

WELI index of gender empowerment in agricultural index, 3DEs is the degree of empowered women and GPI is the relative empowerment of women in the household. 0.9, 0.1 are the weight given to the indexes. The WELI interpreted as the percentage of the domains, of women empowerment in livestock index, in which women enjoy adequacy. All indexes were generating by STATA with respective sub-indexes.

**Ordered probit regression on technical efficiency**

Simultaneous equation modeling provides a new approach to the economic analysis. It analyses the impact of technical efficiency of livestock production on novel empowerment tools of women’s empowerment in livestock index using ordered probit regression model. The functional form of the ordered probit regression expressed the following ways;

$$Y_1 = \beta_0 + \beta_1 Y_2 + \beta_2 X_1 + \beta_3 X_2 + \beta_4 X_3 + \beta_5 X_4 + \beta_6 X_5 + \beta_7 X_6 + U_1 \text{ .....(x)}$$

Where,

- $Y_1$  and  $is$  the dependent variables
- $X_1 \dots \dots \dots X_6$  are the vectors of covariance
- $U_1$  is the error terms

## Results and Discussion

### Descriptive Statistic

The average WELI score of livestock farmers who participated in extension services was 0.77, which was higher than the non-participant (0.73). Technical efficiency (TE) (0.94) and percentage of technology adoption (44.85), wealth index (0.07), and average herd size (2.47) were also higher than the non-participant (0.73). The Wilcoxon Rank-Sum Test is a nonparametric test of the null hypothesis (H0) that a randomly picked value from one population will be equally likely to be less or greater than a randomly selected value from another community. The non-parametric variant of the two-sample t-test is a common description. The Women's Empowerment in Livestock Index (WELI) showed a statistically significant difference (P0.01) between participants and non-participants in agricultural extension activities. In agricultural extension efforts, there was a significant (P<0.01) difference in the percentage of technology adoption between participants and non-participants.

**Table 2.** Descriptive Statistic of targets variables

Variables	Non-participants			Participants			Wilcoxon rank-sum test
	Mean	CV	SD	Mean	CV	SD	
Women's empowerment in livestock index (WELI)	0.7350	0.1704	0.0044	0.7720	0.1272	0.0106	0.0019
Technical efficiency (TE)	0.9413	0.0023	0.0001	0.9416	0.0019	0.0002	0.1777
Technology adoption (TA)	37.6829	0.5416	0.7127	44.8505	0.4179	2.0212	0.0010
Household wealth index (HWI)	-0.0073	-137.9604	0.0352	0.0664	14.1380	0.1012	0.0094
Head size of the household	2.2695	0.6188	0.0490	2.4651	0.5555	0.1477	0.1561

### Mean efficiency score of livestock farmers

Below is Table 3 showing the sample size used for the analysis together with the mean, standard deviation, and range of predicted technical efficiency and inefficiency scores. The predicted mean technical efficiency is approximately 94.13 %. This shows that farmers are operating close to the frontier. Mean technical inefficiency is 5.87%, implying that farmers are operating below the frontier at a given technology. This also means farmers have the prospect to improve their performance by improving technology. The technical efficiency scores amongst the farm householders as shown in Table - ranges from a minimum score of 93.11% to a maximum of 95.12%. This disparity shows there is an opportunity for farmers to improve their efficiency.

**Table 3:** Mean efficiency and inefficiency scores of livestock farming households

Variables	Mean	Std. Dev	Min	Max
Technical efficiency	0.9413	0.0021	0.9311	0.9512
Inefficiency	0.0587	0.0021	0.0488	0.0689

### Women's empowerment in livestock index

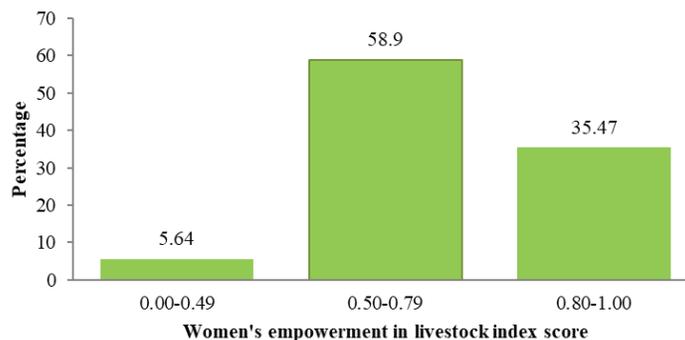
The article advises that qualitative and participative methodologies be employed to provide context-specific insights into the processes of women's empowerment in the livestock sectors. The table 4 below indicates the sub-indices of overall WELI scores for the study site with break down on achievement by men and women.

The 5DE shows that at an 80% achievement threshold, only 37.09 percent of women are empowered and a staggering 62.91 percent of the women not yet empowered. The not yet empowered women have an average inadequate achievement in 29 percent of domains. The women’s disempowerment index ( $M_0$ ) is 0.290 and 5DE is 0.710. The overall WELI for the study area is 0.735 and is a weighted average of the 5DE sub-index value of 0.710 and GPI sub-index of 0.955.

**Table 4.** Women empowerment in Agriculture Index: Scores for the study site

<b>Indicator</b>	<b>Women</b>	<b>Men</b>	<b>Difference</b>
<b>3DE (1-M0)</b>	<b>0.710</b>	<b>0.658</b>	<b>0.052</b>
Disempowerment score (1-3DE)	0.290	0.342	-0.052
N (number of observations)	906	906	
Percent of women achieving empowerment (1-H)	37.09	23.40	-13.69
Percentage of women not achieving empowerment (H)	62.91	76.60	13.69
Mean 3DE score for not yet empowered women (1-A)	0.632	0.604	-0.028
Mean Disempowerment score (1-3DE) for not yet empowered women (A)	0.368	0.396	0.028
<b>GPI Score (1-HGPI*IGPI)</b>	<b>0.955</b>		
N (number of dual adult households)	906		
Percentage of women achieving gender parity (1-HGPI)	71.08		
Percentage of women NOT achieving gender parity (HGPI) percentage	28.92		
Average Empowerment gap (IGPI)	0.045		
<b>WELI Score (0.9*3DE +0.1*GPI)</b>	<b>0.735</b>		

To compare how dimensions and indicators affect WELI score, the respondents were grouped into three quartiles based on their WELI scores. They were first graded based on their WELI scores, and then divided into three groups of 906 families each. Figure-1 depicts the WELI scores for these three groups, as well as their composition. As a result, the first quartile contains 5.64 percent of respondents with the lowest WELI scores (0.50). Because women's empowerment is 0.80 and their position is between 0.80 and 1.00, only 35.47 percent of livestock farming households achieve gender equality. In the livestock business, the WELI is a standardized measure of women's empowerment. Empowering the poorest farmers, particularly rural women, is a proven way to promote gender equality while reducing or eliminating hunger and poverty (UN Women et al., 2012) through technological and institutional advances that increase farm output. (FAO 2011; Galiè 2013a). Goal 5: Gender equality and women's empowerment are critical human rights that are also critical to a sustainable future.



**Figure 1.** Present status of women's empowerment of livestock farmers.

**Association between Technical Efficiency and Women’s Participation**

The empirical findings revealed that while increased rainfall and household size lower technical efficiency, herd size and off-farm income boost inefficiency. The research area's average technical efficiency is 0.837. In the model for all farms, a negative value for the land input parameter corresponds to substantial land use in animal farming in general. The negative influence of organic farming and cattle type of farming to the TE was proved. The technical inefficiency decreases with the growing size of the farm. The TE of conventional farms significantly outstrips the TE of the organic farms. Nonetheless, there is a slight decrease in the TE over the period, opposite to the trend in organic farming in the researched period. It may also be concluded that, to a certain extent, the LFA and AES subsidies had a negative and statistically significant impact on technical efficiency (TE).

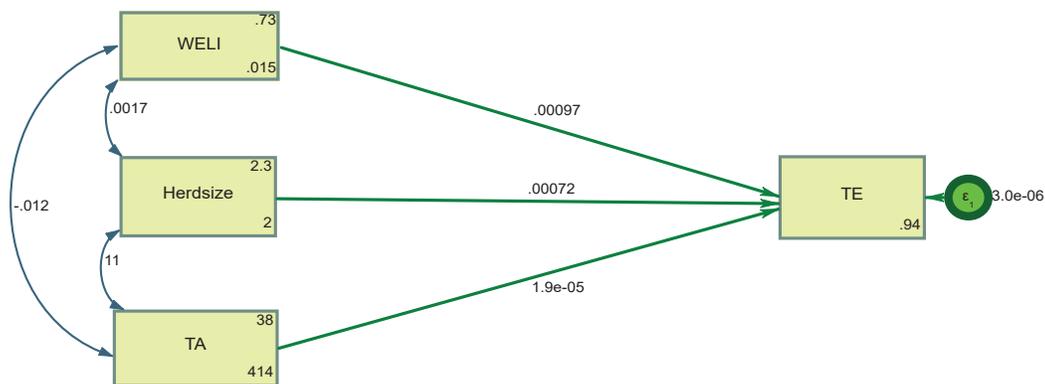
**Table 5.** Ordered probit regression on technical efficiency

Variables	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
WELI	0.7109	0.2760	2.580	<b>0.010</b>	0.1700	1.2518
TA	0.0100	0.0018	5.430	<b>0.000</b>	0.0064	0.0136
ICT	0.2124	0.2401	0.880	0.376	-0.2582	0.6830
HWI	0.0300	0.0347	0.870	0.386	-0.0379	0.0980
Herdsiz	0.4813	0.0289	16.640	<b>0.000</b>	0.4246	0.5380
Lincome	0.0001	0.0001	0.970	0.334	0.0000	0.0000
Age	0.0096	0.0027	3.600	<b>0.000</b>	0.0044	0.0148
Occupation	0.2177	0.0734	2.960	<b>0.003</b>	0.0738	0.3616
Education	0.0115	0.0086	1.340	0.181	-0.0053	0.0284
Hsize	0.0309	0.0217	1.420	0.155	-0.0117	0.0735
HDDS	0.0410	0.0408	1.010	0.314	-0.0389	0.1209
/cut1	-0.2989	0.6193			-1.512653	0.914821
/cut2	-0.0806	0.5898			-1.23661	1.075424
/cut3	0.0725	0.5752			-1.054793	1.199826
Number of observations	= 904					
LR chi <sup>2</sup> (11)	= 490.32					
Prob > chi <sup>2</sup>	= 0.0000					
Pseudo R <sup>2</sup>	= 0.0399					
Log likelihood	= -5893.8256					

$$\bar{TE} = -0.2989 + 0.7109WELI + 0.0100TA + 0.2124ICT + 0.0300HWI + 0.4813Herdsiz + 0.0001Lincome + 0.0096Age + 0.2177occupation + 0.0115Edu + \dots(x) + 0.0309Hsize + 0.0410HDDS$$

**Mechanism of the impact of TE on women’s empowerment in livestock index**

The average technical efficiency scores for the entire period under consideration are presented in Figure 2. This indicates that, on average, each of these regions produced 87% of the output that could potentially have been achieved with the observed input levels. As established earlier, households with women’s participation were associated with improvements in technical efficiency. Evidence suggests that women’s participation enhances both the labor/land ratio and productivity, resulting in increased technological efficiency among rice farmers. Policy levers underlying systemic problems can be identified by examining the causal relationships between the variables within the system. If the occurrence of one event causes the occurrence of another, a causal relationship exists between the two events. The origin of the initial occurrence is referred to as the cause, and the resulting occurrence is the effect. It is important to note that a correlation between two variables does not necessarily imply a causal connection. For a causal relationship to exist between two variables, they must also be correlated.



**Figure 2.** Casual relationship among the target variables.

## Discussion

This study offers solid empirical proof of the connections between women's empowerment, technology adoption, and TE in Bangladeshi livestock production systems. The findings support the claim that gender equity and productive efficiency are mutually reinforcing outcomes rather than conflicting objectives by showing that households with higher WELI scores operate closer to the production frontier. According to the descriptive study, compared to non-participants, cattle producers that use extension services had much higher WELI ratings, TE, technology adoption, and asset ownership. This result is in line with previous research showing that agricultural extension improves women's control over productive resources, decision-making power, and information access, which improves farm performance (FAO, 2011; Sraboni et al., 2014; Galiè et al., 2013a). According to similar data from Ethiopia and Kenya, women's agency and productivity are simultaneously strengthened by extension-mediated technology diffusion (Asfaw et al., 2012; Gitonga et al., 2013). Comparable to efficiency levels observed in dairy and cattle systems in Eastern Europe and South Asia, the high mean technical efficiency (94.13%) suggests that farmers operate along the frontier (Minviel & Latruffe, 2017; Manevska-Tasevska et al., 2014). The remaining inefficiency gap, however, shows potential for increased production through better technology and management. Only 37.09% of women fulfil the empowerment criteria while having a moderate total WELI score, which is consistent with WELI-based research conducted throughout South Asia that show ongoing gender differences in leadership, income control, and asset access (Alkire et al., 2013; Sraboni et al., 2014). The econometric findings reinforce evidence that empowered women adopt better practices and allocate inputs more effectively by confirming a positive and statistically significant link between WELI and TE (Mendola, 2007; Tefera et al., 2011). The detrimental effects of household size and rainfall fluctuation on TE are consistent with research that identifies labour shortages and climatic risk as major issues in livestock systems in underdeveloped nations. Overall, the results confirm that women's empowerment is a social and economic lever for increasing livestock productivity, directly supporting inclusive agricultural growth and Sustainable Development Goal 5 (UN Women et al., 2012).

## Conclusion and policy implication

Higher technological efficiency is favourably and strongly correlated with women's empowerment, according to the study's empirical data. The results show that households operating nearer the production frontier had higher levels of female participation in livestock-related decision-making, resource access, and technology adoption. A significant percentage of women continue to be disempowered despite a comparatively high average TE, underscoring the unrealised potential for productivity improvements through gender-inclusive policies.

Policy recommendations include designing targeted interventions to reduce gender disparities, improve access to technologies, and strengthen women's decision-making in livestock production. Existing programs, such as the LES, could be enhanced through mass media, ICT, and mobile-based advisory services to support women farmers. Future research should focus on identifying context-specific strategies to further enhance empowerment and technical efficiency in livestock systems. Furthermore, efficiency losses brought on by climate variability can be lessened by incorporating climate-smart livestock practices into extension programs. To guarantee equitable service delivery and long-lasting results, institutional cooperation between governmental organisations, non-profits, and private sector players is crucial. All things considered, increasing women's empowerment is not just a social necessity but also a financially feasible approach to raising livestock productivity, ensuring food security, and promoting inclusive growth. In order to evaluate causal pathways and investigate region-specific

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