Agrekon

Agricultural Economics Research, Policy and Practice in Southern Africa

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ragr20

Taking stock of gender gaps in crop production technology adoption and technical efficiency in Ghana

Abigail Ampomah Adaku, Francis Tsiboe & Joseph Clottey

To cite this article: Abigail Ampomah Adaku, Francis Tsiboe & Joseph Clottey (2023) Taking stock of gender gaps in crop production technology adoption and technical efficiency in Ghana, Agrekon, 62:1, 31-48, DOI: 10.1080/03031853.2022.2150664

To link to this article: https://doi.org/10.1080/03031853.2022.2150664

Published online: 27 Jan 2023.

AGREKON
2023, VOL. 62, NO. 1, 31–48
https://doi.org/10.1080/03031853.2022.2150664

Taking stock of gender gaps in crop production technology adoption and technical efficiency in Ghana

Abigail Ampomah Adaku [a], Francis Tsiboe [b] and Joseph Clottey [c]

[a]Department of Agricultural Economics and Agribusiness, University of Ghana, Accra, Ghana; [b]USDA, Economic Research Service, Kansas City, MO, USA; [c]International Centre for Evaluation and Development, Sakumono, Ghana

ABSTRACT
There is a strong linkage between agricultural performance and economic growth in developing countries. However, the gain from agriculture disproportionately trickles down to the poor which can be partly reduced by addressing gender differences in production. Historically, the validity of gender statistics has been questioned as the way researchers and policymakers describe gender differences also affects how they perceive and address them. Amid these antecedents, we apply a meta-stochastic frontier to pooled cross-sectional population-based surveys that represent three decades (1987–2017) of the production history for twelve crops in Ghana to assess the dynamics of gender gaps in technology gaps and technical efficiency (TE). Results indicate that female farmers exhibit technology gap and TE scores of 25 and 76% while their male counterparts exhibit scores of 20 and 73%. The TE gap of 4% against male farmers has remained relatively steady over the three decades while the technology adoption gap against females has reduced from 18% in 1997/98 to 3% in 2016/17. All farmers operate at 60% of the potential possible given the overall crop production technology in Ghana. Over the three decades, the estimated crop production gap of 5.94% against females shifted to a gap estimated at 9.24% against males.

ARTICLE HISTORY
Received 31 October 2022
Accepted 3 November 2022

KEYWORDS
Gender gap; technology; technical inefficiency; Ghana

JEL CODES
D24; Q18; Q12

1. Introduction

The United Nations recognises the role of women in development to be important and therefore advocates for the full and equal participation of women in all areas of sustainable development. One of the sustainable development goals, therefore, is to achieve gender equality. Gender inequality in Agriculture is a longstanding and persistent issue globally that has generated extensive and growing literature (Doss 2001; O'Sullivan et al. 2014; Aguilar et al. 2015). Several studies have identified gender gaps in agriculture along the lines of access/control over productive resources (land, input, technology, and credit), empowerment, and market participation, amongst other things. At the root, these gender gaps are driven by cultural, political, and socioeconomic factors, but they ultimately lead to gender inequality in agricultural production that clusters around 20-30% (Kilic, Winters, and Carletto 2015).

Total factor productivity dictates the performance of agriculture, and agricultural performance is also strongly linked to the growth of developing countries (World Bank 2007). Nonetheless, in the

CONTACT Abigail Ampomah Adaku aaadaku@ug.edu.gh Department of Agricultural Economics and Agribusiness, University of Ghana, P. O. Box 68, Legon, Accra, Ghana
Supplementary material for this article can be accessed online at https://doi.org/10.1080/03031853.2022.2150664.
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

developing world, gains from agricultural growth disproportionately trickle down to the poor (Ligon and Sadoulet 2008). Amongst the many ways of reducing the disproportionate growth between the poor and non-poor is the reduction of gender differences in agriculture. Consequently, two stylised facts that have persisted are (1) female farmers are less productive than their male counterparts, and (2) if given the same resources and opportunities, female farmers can at worst produce at the same level as males and at best outperform males.

Gender roles are dynamic: they respond to changing economic conditions (Doss 2001). Yet, while previous studies have based the two stylised facts on rigorous empirics, they mostly do not account for time trends over a long enough horizon to account for their temporal dynamics. Consequently, within a given socio-economic context, one question that remains largely unanswered is whether there has been any progress in closing the gender gap. While they are effective in mobilising gender action, if stylised facts about gender become "gender myths", they also become less efficient in tackling the underlying issues which can translate into poorly designed, implemented, and monitored interventions (Lambrecht et al. 2018).

Historically, researchers have mobilised to present more objective facts about gender in agriculture (see e.g., special editions of Agricultural Economics in 2015 and Food Policy in 2017).[1,2] Recent work used four rounds of cross-sectional data that reflected 20 years of production history in Ghana to assess five stylised facts about gender in agriculture and to evaluate whether gender patterns have changed over time. The results showed that whilst some stylised facts never existed, others saw their gap closing/widening, and other longstanding beliefs remained largely true (Lambrecht et al. 2018). While the authors provide a modest attempt to contribute to the overall movement to present more objective and recent facts about gender in agriculture in the Ghanaian context, they ultimately do not consider how these dynamisms manifest in production. Consequently, the question of whether the gender inequalities in agricultural production are closing or widening in Ghanaian agriculture is still unknown.

Variation in agricultural output along any dimension can be decomposed into variability due to differences in production technology, resource use efficiency, and idiosyncratic shocks from for example weather. Failure to account for these differences along a given dimension (e.g., gender) can lead to a false measure of the differences in production along that dimension. Gender gaps in production technology and resource use efficiency in Ghana have been well established but they lack the time dimension needed to evaluate whether gender patterns have changed over time (Miriti et al. 2021; Doss and Morris 2001; Danso-Abbeam, Baiyegunhi, and Ojo 2020).

In this regard, this paper examines temporal dynamism in gender inequalities in Ghana by pursuing two related objectives. The first assesses the gender gap in farm output by decomposing it into inequalities due to technology gaps and technical efficiency. The second evaluates whether these gender patterns have changed over time. To achieve these objectives, the study applies a meta-stochastic-frontier analysis along with a gender dimension to data from seven cross-sectional surveys fielded in Ghana that represents about 30 years of production history from 1987 to 2017 that covers all commercially grown crops. This nationally representative dataset covers more farmers across time and space than any previous studies. As such it presents a unique opportunity to empirically assess the temporal dynamics in the differences in agricultural production parameters (elasticities, returns to scale [RTS], and technological gaps) and efficiency along the gender dimension.

Though other studies have shown mixed results concerning male-female technical efficiency (Danso-Abbeam, Baiyegunhi, and Ojo 2020; Koirala, Mishra, and Sitienei 2015; Quisumbing 1996; Sell et al. 2018), they have been for a particular point in time and specific crops. The results from this study with data from three decades and showing the temporal patterns of male-female gaps in technical efficiency provide reasoning for this. The temporal patterns indicate that over the 30 years studied, there has been a technical efficiency gap against female farmers which remained steady and has gradually reduced. The gender gaps are however not robust across all crops and locations. This means that gender gap interventions must be targeted at specific crops and specific locations.

2. Literature review

The gender dimension in agriculture has received considerable attention, particularly in developing countries. Generally, women have been noted to provide about 60-80% of agricultural labour in Africa yet are marginalised in access to factors of production (Burke, Li, and Banda 2018; Due and Gladwin 1991). The gender gap in agricultural productivity is often quoted to be between 20-30% (Aguilar et al. 2015; O'Sullivan et al. 2014) but provides no agreement on the sources of this gap (Karamba and Winters 2015), which has been explained by factors such as inefficient intrahousehold allocation, women's lack of access to cash crop markets, returns to factors of production, and producers' characteristics (Aguilar et al. 2015).

Gender dimensions are characterised by constant change and are responsive to economic incentives. Some studies have shown variations even in the choice of farm enterprise. Generally, men tend to produce cash and export crops while women take to subsistence crop production (Doss 2001). Moreover, specific crop varieties such as the local and improved varieties may be designated for females and males respectively. Doss (2001) however, agrees that these gender roles have become more flexible with overall economic development as women fill in the men's roles and the men seek off-farm opportunities. Men only take interest in the women's role when it appears more lucrative. This could explain more recent findings that there are no clear patterns of distinctive men's or women's crops (Lambrecht et al. 2018).

Over time the validity of gender statistics is being questioned (Doss et al. 2015; Christiaensen 2017) as the way researchers and policymakers describe gender differences also affects how they perceive, and try to address them. Lambrecht et al. (2018) in their study attempt to ascertain the validity and the dynamics of stylised facts about women in agriculture found that men hold more land, cultivate more crops, sell more products, and use more inputs. However, they report that the gender gap is closing over time. Doss et al. (2015), on the other hand, warn that the use of inaccurate statistics could create problems of adverse selection by diverting attention away from areas where the gender gap is the largest.

Technology is particularly important in agricultural development, both in terms of technology adoption and technical efficiency, and gender differentials are equally as important. In Africa, the contribution of women to agricultural production has been recognised, despite their disadvantages in accessing production resources. It has been argued that, if women were to enjoy equal access to production resources, women could be as or even more efficient than male farmers (e.g., Alene et al. 2008; Doss 2001). These studies have however invariably been static. Little is known to predict, a priori, what the temporal pattern of technology adoption and technical efficiency will be among men and women. Furthermore, some scholars have argued that the specific technologies differ according to the gender division of labour within households (Hirshman and Vaughan 1984; Saito 1994). The inference is that, as the value of women's time is lower, farmers are more likely to adopt technology that saves men's time (Doss 2001). In their seminal work, Doss and Morris (2001) found no such gender bias in the adoption of improved maize technology in Ghana, but that female-headed households were less likely to adopt the technology. Their further analysis showed that the differences were linked to differences in access to resources. In their study on the effect of fertiliser subsidy on Ghanaian cereal producing households, Tsiboe, Egyir, and Anaman (2021) indicated that subsidy households significantly had more farmers that were 31% less likely to be females than non-subsidy households.

Alene et al. (2008) show that there have been mixed results from studies conducted to assess the technical efficiency of females compared to males in agricultural production in Africa. For example, Quisumbing (1996) in her study of the gender differences in technical efficiency found that as long as individual characteristics were controlled for, there was no difference between male and female farmers or heads of households. However, a Ghanaian study on cocoa farming has indicated that though both male and female farm managers have the potential to increase output without changing the ratios of input use, women are less technically efficient than men (Danso-Abbeam, Baiyegunhi, and Ojo 2020). Women farmers are also found to be less technically efficient in Uganda (Sell et al. 2018). A study in Malawi on the contrary showed that female-headed households were 15% more technically efficient than male-headed households in maize farming (Koirala, Mishra, and Sitienei 2015).

This paper adds to the literature by providing new evidence from temporal patterns in agricultural production in Ghana.

3. Research data

3.1 Data sources

The study uses data from all seven rounds of the Ghana Living Standards Surveys (GLSS), fielded between 1987-2017. All seven surveys followed a two-stage stratified sampling design, where enumeration areas and households were selected in the first and second stages, respectively. The seven surveys have been harmonised into a farmer-level dataset (Tsiboe 2020). For each GLSS, households are resampled for each round so the sample can be considered a cross-sectional sample of the population of Ghanaian crop farmers at roughly five-year intervals. The final sample was limited to crop farmers originating from households drawn from the various surveys, with yield (kg/ha) above the 2.5th and below the 97.5th percentile by survey, crop, and gender. The final sample, therefore, consisted of 32,317 farmers originating from 29,980 households. The specific crops considered in this study include maize, rice, millet, sorghum, cassava, yam, cocoyam, plantain, dry beans, groundnut, pepper, and cocoa.

3.2 Descriptive statistics

Table 1 describes the household-level characteristics, showing their temporal and gender variation.[3] In assessing the differences in these variables across gender and seasons, we used linear regression for continuous variables and a logit model for dummies. A trend variable, and a fixed effect for gender, as well as their interactions, were included in the estimations.

Table 1 indicates females constituted 28% of the sample of farmers, whose average age was 46 years old, with five years of formal education. The average household size was about five members, with a dependency ratio of 1.40. There are significant gender differences across all the farmer and household variables. Notably, male farmers are older but less educated than their female counterparts. Table 1 indicates that over the three decades under review, the age of both genders has significantly increased annually, by 0.42% for female farmers and 0.26% for male farmers. On the contrary, the rate of change in their years of formal education has evolved at significantly similar rates of 1.28%.

Crop production output was estimated at 532.96 Ghana Cedis (GHS)/ha for female farmers which was significantly higher than that of their male counterparts estimated at 495.65 GHS/ha.[4] This level of output was produced on significantly different farm sizes that averaged 3.35 and 1.91 ha amongst female and male farmers, respectively, with both genders having significantly similar ownership rates over their farmland. The mean usage rate for planting material, hired labour, fertiliser, and pesticide was estimated at 59.66 GHS/ha, 21.88 person-days/ha, 166.55 kg/ha, and 11.68 L/ha, respectively. Except for fertiliser, these mean input use rates varied significantly across gender. Particularly, female farmers used more of all inputs than male farmers. Table 1 also shows that, except for fertiliser and pesticide, all inputs use rates have increased significantly ($p < 0.05$) annually, albeit at different rates along gender lines. Some 7, 1, 16, and 18% of the sample

Table 1. Summary Statistics of Crop-Producing Farmers in Ghana (1987-2017).

Variable	Mean (SD)			Annual trend (%)[a]		
	Pooled (n = 32,317)	Female (n = 9,398)	Male (n = 22,919)	Pooled (n = 32,317)	Female (n = 9,398)	Male (n = 22,919)
Farmer						
Female farmer (dummy)	0.28 (0.447)	–	–	−0.19** [0.092]	-	-
Age (years)	46.21 (15.263)	45.55 (15.227)	47.94 (15.223)	0.31*** [0.020]	0.42*** [0.036]	0.26*** [0.024]
Education (years)	4.03 (4.925)	4.50 (5.127)	2.81 (4.110)	1.28*** [0.076]	1.69*** [0.168] †	1.12*** [0.081] †
Household headship (dummy)						
Member	0.04 (0.193)	0.03 (0.174)	0.06 (0.233)	−0.54* [0.289]	−0.38 [0.430] †	−0.60* [0.361] †
Head	0.07 (0.259)	0.01 (0.071)	0.25 (0.432)	0.04 [0.600]	1.31*** [0.183]	−0.44 [0.828]
Spouse of head	0.89 (0.314)	0.96 (0.187)	0.69 (0.461)	−0.10*** [0.022]	−0.44*** [0.072]	0.02* [0.012]
Marital status (dummy)						
Not married	0.05 (0.223)	0.06 (0.244)	0.02 (0.152)	−0.85*** [0.276]	0.66 [0.729]	−1.43*** [0.259]
Married/In a union	0.77 (0.421)	0.87 (0.335)	0.51 (0.500)	−0.07* [0.037]	−0.65*** [0.112]	0.15*** [0.026]
Divorced/Separated/Widowed	0.18 (0.382)	0.06 (0.246)	0.47 (0.499)	−0.27 [0.189]	0.67*** [0.120]	−0.63** [0.257]
Crop production						
Output (GHC/ha)	522.63 (1034.958)	532.96 (995.973)	495.65 (1130.045)	2.59*** [0.161]	3.85*** [0.286] †	2.07*** [0.187] †
Land (ha)	2.95 (5.304)	3.35 (5.600)	1.91 (4.264)	−7.94*** [0.389]	−12.78*** [1.330]	−6.20*** [0.235]
Land owned (dummy)	0.58 (0.493)	0.59 (0.492) †	0.58 (0.494) †	0.71*** [0.048]	0.72*** [0.090] †	0.71*** [0.055] †
Crop diversification (index)	0.46 (0.269)	0.47 (0.265)	0.43 (0.277)	0.01 [0.037]	−0.04 [0.074] †	0.02 [0.040] †
Seed (GHC/ha)	59.66 (415.369)	70.35 (466.575)	31.74 (231.389)	6.50*** [0.316]	7.15*** [0.698]	6.21*** [0.327]
Household labour (Adult Equivalent)	7.75 (7.170)	8.62 (7.587)	5.49 (5.319)	0.65*** [0.055]	0.36*** [0.115]	0.77*** [0.062]
Hired labour (person-days/ha)	21.88 (115.900)	25.05 (131.550)	13.62 (56.811)	1.20*** [0.179]	0.65 [0.427]	1.42*** [0.183]
Fertiliser (Kg/ha)	166.55 (5404.976)	208.90 (6354.027) †	55.96 (239.413) †	−1.65 [2.798]	−6.77 [5.040]	0.31 [3.382]
Pesticide (Litre/ha)	11.68 (225.988)	14.12 (265.417)	5.33 (20.574)	1.61 [1.086]	1.80*** [0.481]	1.53 [1.507]
Mechanisation (dummy)	0.07 (0.263)	0.08 (0.264)	0.07 (0.258)	−1.99*** [0.185]	−3.39*** [0.313]	−1.46*** [0.205]
Irrigation (dummy)	0.01 (0.113)	0.02 (0.125) †	0.01 (0.073) †	4.32*** [0.761]	3.16* [1.700] †	4.77*** [0.803] †
Credit (dummy)	0.16 (0.363)	0.16 (0.363) †	0.16 (0.364) †	−0.64*** [0.124]	−0.96*** [0.228] †	−0.52*** [0.143] †
Extension (dummy)	0.18 (0.386)	0.18 (0.385) †	0.19 (0.389) †	3.00*** [0.141]	3.05*** [0.241] †	2.99*** [0.166] †
Household						
Size (AE)	5.26 (3.079)	5.50 (3.132)	4.64 (2.846)	0.32*** [0.037]	0.25*** [0.067] †	0.34*** [0.042] †
Dependency (ratio)	1.40 (1.691)	1.50 (1.773)	1.14 (1.422)	0.18** [0.073]	0.38*** [0.134] †	0.10 [0.084] †
Female ratio	0.46 (0.236)	0.40 (0.197)	0.62 (0.250)	0.06** [0.029]	−0.19*** [0.045]	0.15*** [0.036]
Rural locality (dummy)	0.83 (0.372)	0.84 (0.364)	0.81 (0.391)	0.49*** [0.028]	0.65*** [0.056]	0.43*** [0.031]

* Significance levels: * $p < 0.10$, ** $p < 0.05$, ***$p < 0.01$.
† Indicate insignificant ($p < 0.05$) variation across gender.
[a] *The trend was estimated via a linear regression for continuous variables and a logit model for dummies.*
Data Sources: Ghana Living Standards Surveys [wave 1-7]

had access to mechanisation, irrigation, credit, and extension respectively over the three decades under review. The rate of access to irrigation, credit, and extension was similar along gender lines.

4. Methodology

Output and input information from the surveys described above are incompatible because of potential differences in sampling and data collection procedures. Thus, this study follows a two-step research design similar to Tsiboe (2021) where technological gaps and pure farmer technical inefficiency were first estimated separately for each sample and then regressed on gender, location, season, and other social factors to identify any potential heterogeneities along gender lines. Thus, the study essentially relaxes the assumption that the frontier remains unchanged as does the relationship between factors that are associated with technical inefficiency.

The prototypical stochastic-frontier approach assumes that technology is homogeneous. Thus, depending on their input set, all farmers will operate at various points along the production frontier if they use best management practices. However, because of technical inefficiency and/or idiosyncratic shocks, some farmers are found below the stochastic frontier. It is also possible to observe some farmers above the frontier purely due to idiosyncratic shocks. The prototypical stochastic production frontier (SF) is represented as.

$$y_i = f(x_i)e^{v_i - u_i}, \tag{1}$$

where, y_i is the total output by the ith farmer. The function $f(\cdot)$ captures the relationship between the production inputs (x_i) used in producing y_i. In this study $f(\cdot)$ is taken as Translog because the study is interested in farmer-level productivity measures, and it has been shown to best fit Ghanaian crop production under diverse conditions (Asravor et al. 2019). The terms u_i and v_i describe the deviations from the production frontier attributable to technical inefficiency and idiosyncratic shocks, respectively.

The negative skewness assumption of u_i (Farrell 1957) is the key feature of the SFA, where u_i is assumed to follow either an exponential, half-normal, gamma, or a truncated distribution. On the contrary, v_i, is assumed to follow a normal distribution with zero mean and variance σ_v^2 [$v_i \sim N(0, \sigma_v^2)$] (Belotti et al. 2013). Here the study assumes that the distribution of u_i is half-normal. The deviation due to technical inefficiency can further be assumed as heteroscedastic and modelled as $\sigma_{u_i}^2 = exp(\boldsymbol{w}_i\boldsymbol{\alpha})$, where $\boldsymbol{w}_i$ contains covariates that affect technical inefficiency and $\boldsymbol{\alpha}$ is a vector parameter to be estimated (Battese, Rambaldi, and Wan 1997; Tsiboe et al. 2022). Thus, a superior and flexible model can be represented as:

$$y_i = f(x_i)e^{v_i - u_i}, \;\; u_i \sim N^+[0, \exp(\boldsymbol{w}_i\boldsymbol{\alpha})], \;\; v_i \sim N[0, \sigma_v^2], \tag{2}$$

Given the parameters of the model, the technical efficiency score of the ith farmer is calculated as:

$$TE_i = \; y_i[f(x_i)e^{v_i}]^{-1} = e^{-u_i} \tag{3}$$

The main objective of this paper is to ascertain the gender heterogeneity in crop production technology and efficiency in Ghana. Thus, the study formulates the SF in a way that captures how farmers adopt distinct production technologies based on their gender. Miriti et al. (2021) show that technological changes are affected by gender, while Doss and Morris (2001) found that female-headed households were less likely to adopt improved maize technology in Ghana which was linked to differences in resource access. In Ghana, the literature on assessing production inefficiency across gender lines has focused on cross-sectional samples of farmers growing cassava (Missiame, Irungu, and Nyikal 2021), rice (Owusu, Donkor, and Owusu-Sekyere 2018), and cocoa (Danso-Abbeam, Baiyegunhi, and Ojo 2020) for singleton production seasons. The lack of spatiotemporal heterogeneity amongst these studies masks important lessons that could emerge from taking stock of gender gaps in crop production technology adoption and technical efficiency in Ghana.

For example, knowledge on whether gender-driven technology gaps or resource use inefficiencies among farmers contribute most to production shortfalls, and their evolution thereof is not yet clear. This study addresses these limitations by applying a gender-differentiated MSF to most of Ghana's major crops over multiple seasons throughout Ghana.

Since its introduction (Hayami 1969) and further developments (Hayami and Ruttan 1970, 1971), the meta-production-frontier (MSF) has been used to capture the specific production technology adoption behaviour of sub-groups of farmer populations. The literature proposes two approaches to implement MSF. In both cases, the SF is estimated for the different groups in the first step and in the second step, a pooled SF based on predictions from the first is determined using the non-parametric method (Battese, Rao, and O'Donnell 2004; O'Donnell, Rao, and Battese 2008), or estimated using a secondary SF (Huang, Huang, and Liu 2014). This study relies on the approach that uses the secondary SF because the non-parametric method lacks statistical properties which are particularly problematic since it does not fully reflect the decision-making environment of farmers and fails to account for idiosyncratic shocks.

Following the estimation of Equation (2) by gender, the predicted output levels from the gender-specific SFs are used as the observation for a pooled SF that captures both males and females to estimate the MSF. This framework allows for the direct estimation of technology gaps along gender lines by treating them as the conventional one-sided error term (u_i^M). The meta-frontier, enveloping the male and female frontiers [$f^g(x_i)$] is represented as:

$$f^g(x_i) = f^M(x_i)e^{-u_i^M}, \;\; u_i^M \sim N^+(0, \exp(\boldsymbol{w}_i\boldsymbol{\alpha})), \tag{4}$$

where $u_i^M > 0$; therefore $f^g(x_i) \leq f^M(x_i)$, and the ratio of gender g's frontier to the meta-frontier is the technology gap ratio (TGR) represented as

$$TGR_i = \;f^g(x_i)[f^M(x_i)]^{-1} = e^{-u_i^M} \leq 1 \tag{5}$$

The TGR depends on the accessibility and extent of adoption of the available MSF which in turn depends on farmers' specific circumstances. Given an input set, each farmer's output relative to the MSF – i.e., their meta-frontier technical efficiency (MTE) – is represented as:

$$MTE_i = \;f^r(x_i)[f^M(x_i)e^{v_i}]^{-1} = TGR_i \times TE_i \tag{6}$$

The specific stylised empirical model used for both the primary and secondary estimations is

$$\begin{aligned} \ln y_{it} = \beta_{0r} + \sum_j \beta_j \ln x_{jit} + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} + \frac{1}{2}\sum_j \sum_s \beta_{js} \ln x_{jirt}\tilde{x}_{sit} \\ + \sum_j \beta_j \tilde{x}_{jit} + \frac{1}{2}\sum_j \sum_k \beta_{jk}\tilde{x}_{jit}\tilde{x}_{kit} + \frac{1}{2}\sum_j \sum_s \beta_{js}\tilde{x}_{jit} \ln x_{sit} \\ + v_{it} - u_{it}\tilde{x}_{jit} = \text{arcsinh}[x_{jit}], \;\; u_{it} \sim N^+[0, \exp(\boldsymbol{w}_{it}\boldsymbol{\alpha})], \;\; v_i \sim N[0, \sigma_v^2] \end{aligned} \tag{7}$$

where y_{it} is total output for the ith farmer in season t, x_{jit} inputs including total amounts of land, planting material, family and hired labour, fertiliser, and pesticide. Since a handful of farmers report non-zero values for non-land production inputs, the study follows related work (Tsiboe 2021) in order not to lose observations due to zeros, by replacing the log function with an inverse hyperbolic sine function ($\tilde{x}_{jirt} = \text{arcsinh}[x_{jirt}]$) for such inputs.

For each survey wave, parameters of the gender and overall meta-frontier were separately obtained for maize, cassava, plantain, rice, millet, sorghum, yam, cocoyam, dry beans, peanut, pepper, and cocoa via maximum likelihood estimation, utilising the "frontier" command in Stata 16.1. Given the maximum likelihood parameters, farmer-level elasticities for each input were estimated as the first derivative of $f_t(\cdot)$ with respect to that input and evaluated at every observation. The elasticity for the inputs without and with zeroes is given by $\in_{jit}= \beta_j + \sum_k \beta_{jk} \ln x_{kit} + \sum_s \beta_{js}\tilde{x}_{sit}$

and $\in_{jit}= \left(\beta_j + \sum_k \beta_{jk} \ln x_{kit} + \sum_s \beta_{js}\tilde{x}_{sit}\right) \cdot \left(x_{jit}/\sqrt{x_{jit}^2 + 1}\right)$, respectively. Consequently, farmer-level production RTS was estimated as the summation of all the input elasticities. Given the estimated frontiers, each farmer's technical efficiency relative to the gender SF (TE) and MSF (MTE) and their technology gap ratio (TGR) were estimated as outlined in Equations (3), (5), and (6).

For the second step of the two-step research design, the farmer-level scores (TGR, TE, and MTE) and elasticities are pooled across all surveys and crops into one sample since they are all unitless. For farmers that grow multiple crops, their scores and elasticities are aggregated by taking their weighted average by cropped area. Thus, the data used in this second stage is not crop-specific. The study uses this data to model regression of the form.

$$\tau_i = \theta_0 + \boldsymbol{\theta}_s S_i + \boldsymbol{\theta}_x \boldsymbol{X}_i + \vartheta_i \tag{8}$$

In Equation (8), τ_i is the elasticities/score of interest for household i; S_i is a categorical variable with 140 unique values formed from the combination of gender, season, and ecology. The vector $\boldsymbol{X}_i$ contains controls for social factors that contribute to gender gaps including (1) the farmer's age, education, ethnicity, religion, marital status, and relation to household head; and (2) locality (i.e., urban vs rural). Since the range of the scores (TGR, TE, and MTE) is [0,1], a fractional regression model was utilised and for the elasticities and RTS, a linear regression model was used. By omitting the category Male-Sudan Savanah-1987/88, the parameter θ_0 serves as the average elasticity/score for a male farmer in the Sudan Savanah ecology during the 1987/88 growing season, ceteris paribus. The estimates in $\boldsymbol{\theta}_s$ represent the conditional marginal mean difference between the respective category in S_i and the omitted category whose conditional mean estimate is represented by θ_0. Thus, the conditional mean estimates of the remaining un-omitted categories are given by the respective parameters in vectors $\boldsymbol{\theta}_s$ plus θ_0. It is worth noting that the scores (TGR, TE, and MTE) are relative measures that track performance relative to the most efficient observations within a particular sample. Thus, as a caveat, any difference between female and male producers could simply be reflecting differences in heterogeneity across samples.

5. Results and discussions

This study deliberates in detail on the gender dynamics of the production function parameters, technology adoption, and technical efficiency amongst Ghanaian crop farmers to enrich policy debates. Discussion on the covariates in the production inefficiency function is omitted, as they are extensively deliberated in previous studies (Asravor et al. 2019; Danso-Abbeam, Baiyegunhi, and Ojo 2020; Miriti et al. 2021; Onumah et al. 2013; Owusu, Donkor, and Owusu-Sekyere 2018; Tsiboe, Asravor, and Osei 2019, 2021). For the first stage of the research design, 316 Translog stochastic frontier models were estimated across the unique combination of surveys, crops, and gender. The rejection rates of critical model diagnostic tests and sources of variability for the 316 models and production elasticities for the gender – and meta-frontiers are shown in Table 2.[5] Plots of the temporal dynamics of the elasticities, production technology adoption, and technical efficiency by gender are shown in Figures 1 and 4. Specific crop production technology adoption and the technical efficiency gender gap are shown in Figure 2. Finally, the spatial dynamics of the gender gaps in crop production technology adoption and technical efficiency are shown in Figure 3.

5.1 Model specification tests

The Cobb–Douglas restriction (i.e., the cross-terms are jointly equal to zero) was rejected at a rate of 86 and 84% for the female and male frontiers, respectively, which agrees with the existing

Table 2. Input Elasticities, Rejection Rates of Hypothesis Tests, and Sources of Variability for Gender – and Meta-Frontier Models for Crop Production in Ghana (1987-2017).

	Gender production frontier				
	Female (A)	Male (B)	Gender gap (%)[c]	National	Meta-frontier
Elasticity					
Land	0.423*** (0.003)	0.458*** (0.002)	−7.820*** (0.872)	0.456*** (0.001)	0.450*** (0.001)
Planting material	0.181*** (0.004)	0.188*** (0.002)	−3.439 (2.388)	0.187*** (0.001)	0.184*** (0.001)
Family labour	0.067*** (0.004)	0.038*** (0.002)	77.732*** (15.618)	0.079*** (0.001)	0.059*** (0.001)
Hired labour	0.123*** (0.003)	0.125*** (0.001)	−1.441 (2.883)	0.125*** (0.001)	0.131*** (0.001)
Fertiliser	0.116*** (0.005)	0.144*** (0.001)	−19.572*** (4.195)	0.138*** (0.001)	0.113*** (0.001)
Pesticide	0.424*** (0.038)	0.173*** (0.009)	144.827*** (32.195)	0.202*** (0.002)	0.224*** (0.002)
Returns to scale	1.140*** (0.039)	0.929*** (0.009)	22.683*** (5.067)	0.991*** (0.002)	0.983*** (0.002)
Technology					
Technology gap ratio (TGR)	0.752*** (0.003)	0.799*** (0.001)	−5.850*** (0.479)	-	-
Pure farmer technical efficiency (TE)	0.759*** (0.003)	0.731*** (0.002)	3.877*** (0.519)	-	-
Meta-frontier technical efficiency (MTE)	0.600*** (0.003)	0.594*** (0.002)	0.954 (0.718)	-	-
Rejection rates of hypothesis tests (%)					
CD test	85.92	84.06	-	87.32	100.00
Schmidt and Lin (1984) [a]	12.68	17.39	-	25.35	47.89
Coelli (1995) [ab]	19.72	13.04	-	15.49	16.90
Gutierrez, Carter, and Drukker (2001) [a]	12.68	17.39	-	25.35	47.89
Inefficiency function test	39.29	42.62	-	54.69	74.58
Sources of Variability [b]					
Gamma [$\gamma = \sigma_u^2/\sigma^2$]	0.30 [0.05]	0.21 [0.04]	-	0.25 [0.04]	0.44 [0.05]

Significance levels: * $p < 0.10$, ** $p < 0.05$, ***$p < 0.01$

[a]Null hypothesis of no one-sided error (i.e., no inefficiency) was tested. The values show the rate of rejection ($p < 0.10$) across the 316 Translog stochastic frontier models estimated across the unique combination of surveys, crops, and gender.

[b]Inefficiency variance [σ_u], Total variance [$\sigma^2 = \sigma_u^2 + \sigma_v^2$]; values show the mean [standard errors] across the 316 Translog stochastic frontier models estimated across the unique combination of surveys, crops, and gender.

[c]Estimates as [(A-B)/B*100]

Data Sources: Ghana Living Standards Surveys [wave 1-7]

literature on Ghana (Asravor et al. 2019; Onumah et al. 2013; Owusu, Donkor, and Owusu-Sekyere 2018; Tsiboe et al. 2018, 2019, 2021). Three tests were performed to verify the negatively skewed error specification central to the MSF approach, which included the one-sided generalised likelihood-ratio test for technical inefficiency (Gutierrez, Carter, and Drukker 2001) and two skewness tests of the residuals resulting from an OLS estimation (Coelli 1995; Schmidt and Lin 1984). The three tests were rejected at varying rates (13-48%), thus, this study proceeds with the MSF. The null hypothesis that technical inefficiency is not influenced by the variables in the inefficiency function (i.e., H_o:$\boldsymbol{\alpha} = 0$) also had varying rejection rates (39-75%) that justify the use of a heteroskedastic technical inefficiency function. Furthermore, the likelihood ratio test for the null hypothesis that the male and female production frontiers are similar was rejected at a rate of 40% across all surveys, which supports the fact that male and female crop farmers in Ghana operate under heterogeneous technologies.[6]

Table 2 indicates that the mean of the proportion of crop production variance due to technical inefficiency [$\gamma = \sigma_u^2/\sigma^2$] across the models averaged 0.21 and 0.30 for males and females, respectively. Since these ratios are all less than 0.50, they suggest that a considerable amount of the observed variation in crop output could not be attributed to the inefficient use of inputs but

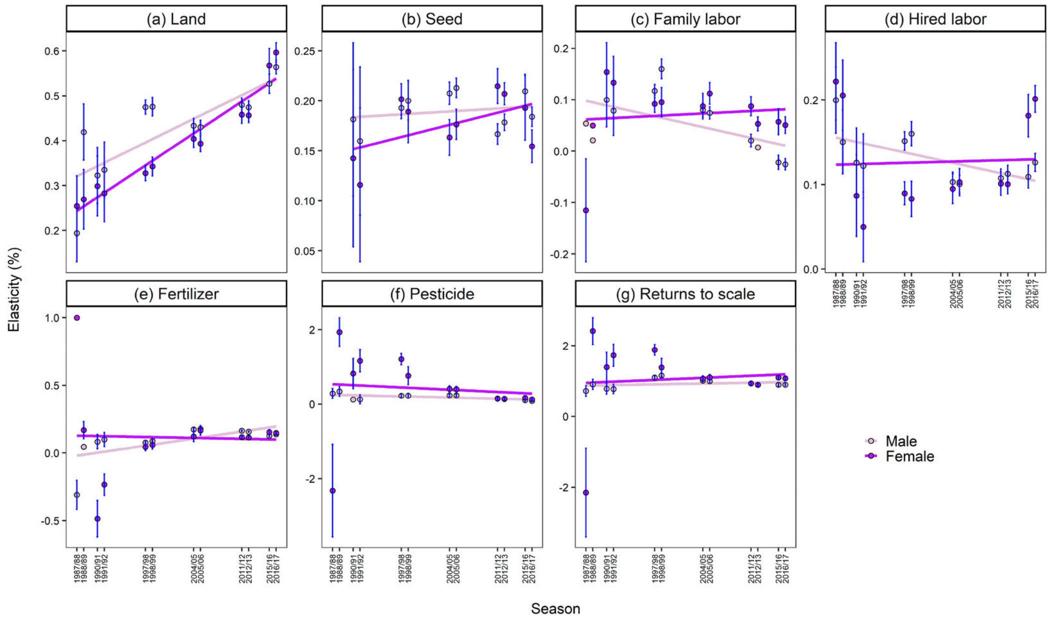

Figure 1. Temporal Dynamics of Crop Production Elasticities by Gender in Ghana (1987-2017).

Notes: Farmer-level elasticities were first estimated via a Meta-stochastic frontier (MSF) analysis applied separately to 7 population-based surveys that represent 30 years of farmer-level data collection in Ghana. The surveys used included; Ghana Living Standards Surveys [wave 1-7]. The farmer-level elasticities were subsequently averaged across seasons and gender via a regression framework to account for controls. Each point on a sub-panel represents the mean of the estimates.

rather to idiosyncrasies such as biotic and abiotic shocks, statistical errors in data measurement, and the model specification. The mean of the estimated γ for the meta-frontier across all the models was 0.44, implying that 44% of the observed variation in crop output, given the gender frontiers, could be attributed to technological gaps.

5.2 Output elasticities

The production elasticities by gender and season are shown in Table 2 and Figure 1, respectively. Across the models, the output elasticities are all positive for both the gender – and meta-frontier and are like those estimated by previous studies (Asravor et al. 2019; Onumah et al. 2013; Owusu, Donkor, and Owusu-Sekyere 2018; Tsiboe et al. 2018, 2019, 2021). The greatest contributor to crop production is land, with an estimated elasticity of 0.45% for the meta-frontier. Land is followed by pesticide (0.22%), planting material (0.18%), hired labour (0.13%), fertiliser (0.11%) and then family labour (0.06%). The gender-specific elasticities presented in Table 2 show that the responsiveness of output to land, planting material, hired labour, and fertiliser for female farmers are respectively 7.82, 3.44, 1.44, and 19.57% lower than that of their male counterparts. On the contrary, the responsiveness of output to family labour and pesticide for male farmers is 77.73 and 144.83% lower than that of their female counterparts. The difference between elasticities along the gender dimension may not necessarily mean that females are technically worse farmers than their male counterparts (Croppenstedt, Goldstein, and Rosas 2013). However, static results of these gender gaps are expected. Literature on gender and agriculture indicates that female farmers in most developing countries have a lower yield than their male counterparts (Croppenstedt, Goldstein, and Rosas 2013), even for female and male farmers from the same household who farmed the same crops (Goldstein and Udry 2008). This is however attributed to the female farmer's low commercialisation of output, low access or use

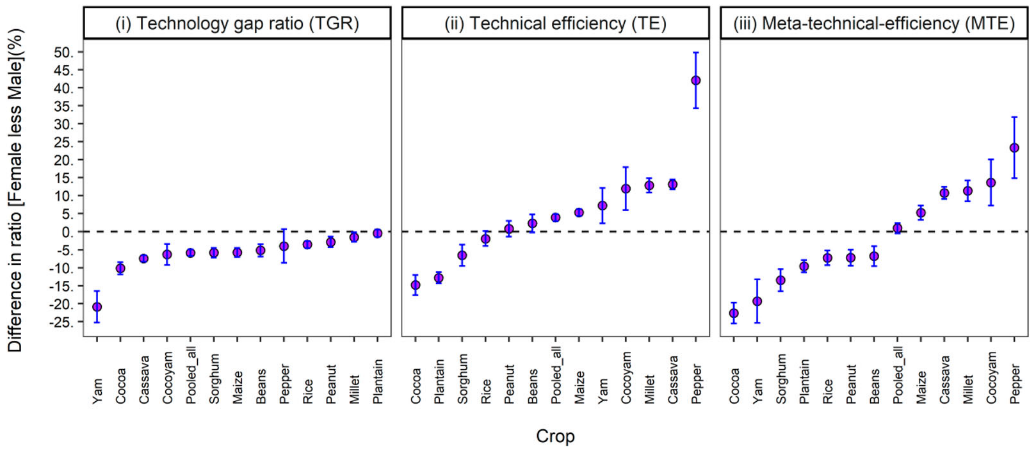

Figure 2. Gender Gaps in Specific Crop Production Technology Adoption and Technical Efficiency in Ghana (1987-2017).

Farmer-level scores were first estimated via a Meta-stochastic frontier (MSF) analysis applied separately to seven population-based surveys that represent 30 years of farmer-level data collection in Ghana. The surveys used included Ghana Living Standards Surveys [wave 1-7]. The farmer-level elasticities were subsequently averaged across seasons and gender via a regression framework to account for controls. Each point on a sub-panel represents the mean of the estimates.

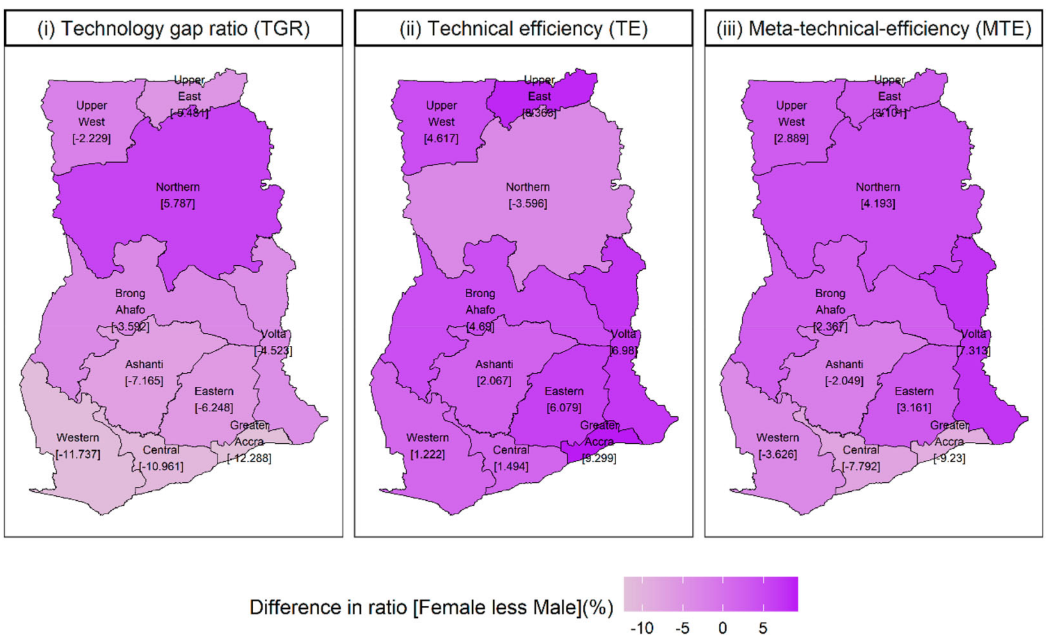

Figure 3. Spatial Dynamics in Crop Production Technology Adoption and Technical Efficiency in Ghana (1987-2017)

of key inputs and services as well as limited control over resources. In Ghana, individuals who were central to networks of social and political power had more secure tenure rights and therefore they could fallow their lands longer and achieve substantially higher yields (Goldstein and Udry 2008). The gender dimension in this pattern was against the female farmers as they were rarely in positions of sufficient political power to warrant their land tenure security. Other research evidence suggests that female farmers are more susceptible to poorer-quality inputs. For example, female farmers in Malawi could only afford fertiliser that had been repackaged from 50 kg to smaller sizes (Uttaro 2002).

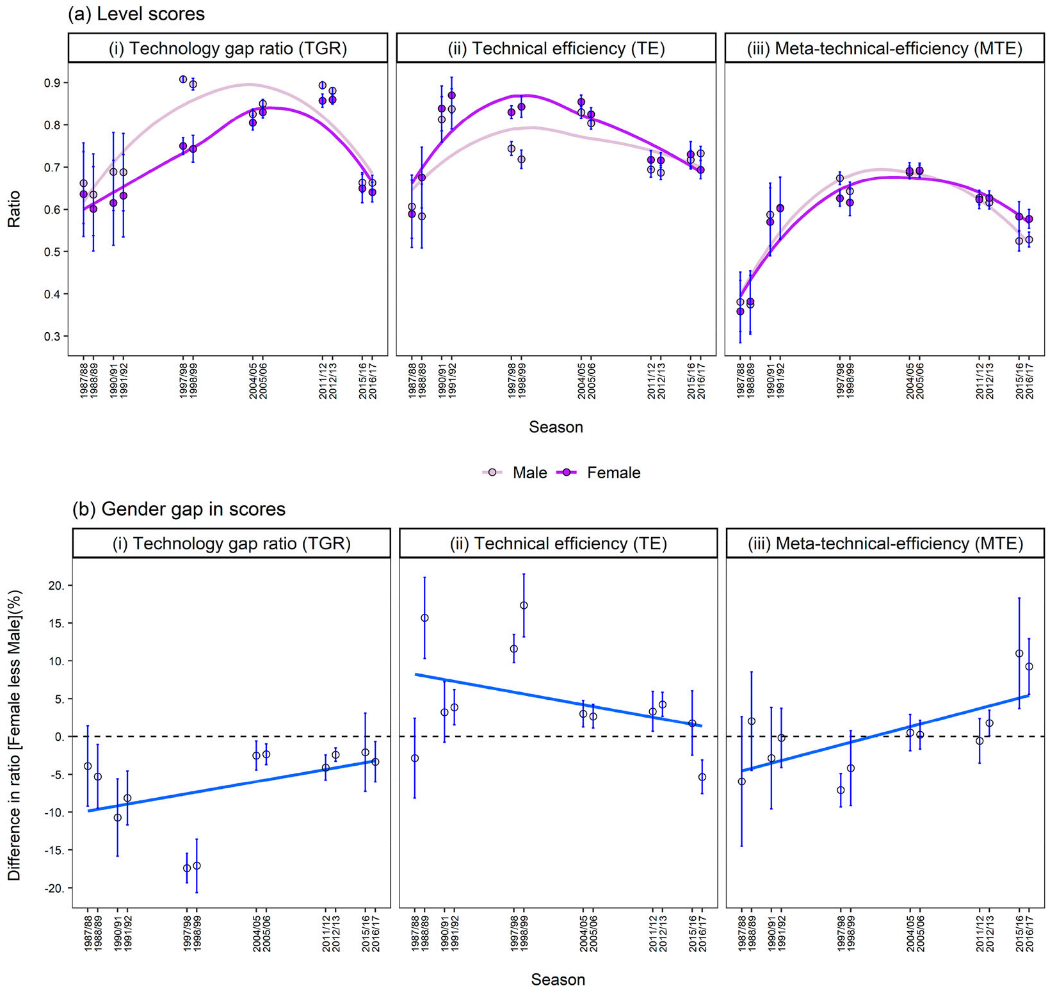

Figure 4. Temporal Dynamics in Crop Production Technology Adoption and Technical Efficiency by Gender in Ghana (1987-2017). Farmer-level scores were first estimated via a Meta-stochastic frontier (MSF) analysis applied separately to seven population-based surveys that represent 30 years of farmer-level data collection in Ghana. The surveys used included Ghana Living Standards Surveys [wave 1-7]. The farmer-level elasticities were subsequently averaged across seasons and gender via a regression framework to account for controls. Each point on a sub-panel represents the mean of the estimates.

However, repackaged fertiliser was often adulterated with sand (Uttaro 2002). Female farmers who could not afford the needed levels of fertiliser were less likely to use improved seed varieties (Uttaro 2002) and hence would have relatively lower yields. Among cocoa farmers in Ghana, female farmers have been noted to lack the cash to finance communal labour parties (Croppenstedt, Goldstein, and Rosas 2013) which the male farmers have been known to use. When married female farmers hire labour their household responsibilities limited their ability to supervise (Pierotti, Friedson-Ridenour, and Olayiwola 2022). The hired labourers have also been noted to prioritise male farmers early in the day and work for female farmers when they are less productive (Pierotti, Friedson-Ridenour, and Olayiwola 2022).

Figure 1a shows that, overall, the responsiveness of crop production to land has improved and its associated gender gap against female farmers has progressively been closing. For the case of planting material, Figure 1b shows that its elasticity has also improved and its associated gender gap against female farmers has essentially closed. For family labour Figure 1c shows that the elasticity for male crop farmers has declined from 1987 to 2017 while that of their female counterparts has improved over the same period. This has led to a switch in the gender gap against female farmers to a gender gap against male farmers. An opposite dynamic is observed in the case of fertiliser where the elasticity for female crop farmers remained constant whiles that of male crop farmers improved and ultimately led to a switch to a gender gap against female farmers (see Figure 1e). The responsiveness of crop production to hired labour has generally seen a deterioration for male crop farmers while that of females essentially remained the same over the study period, leading to a reduction in the gender gap against female farmers. Generally, these results indicate that the stylised fact that female farmers are less productive does not hold over this period in Ghana. The responsiveness of the females' crop production to input use has evolved over the period, leaving a gender gap against male farmers.

Returns-to-scale (RTS) is an important economic and technological characteristic of the production structure, which has implications for the transformational patterns of agricultural and distributional effects of policies (Takeshima, Houssou, and Diao 2018). Table 2 demonstrates that crop production amongst females exhibits increasing returns to scale of 1.14, while their male counterparts exhibit diminishing returns of 0.93, i.e., a 1% increase in all inputs will result in a 1.14% increase in output for female farmers, and only 0.93% for male farmers. Increasing returns to scale suggests that long-run average costs are declining, an indication of economies of scale (Truett and Truett 1990), thus there is room for female crop farmers in Ghana to scale up to increase production.

5.3 Technology adoption

Recall that the range of values for the technology gap ratio (TGR), a measure of technology use concentration and by extension technology adoption, is [0,1]. Here closeness to zero [one] implies that there is some [no] room for technological improvement through the adoption of technology already available in the country. Ultimately, the dynamics in the gender gap in the use of inputs and the responsiveness of output to their use results in different observed values in the TGR along gender lines. Table 2 shows that female crop farmers had a mean TGR of 0.75 between 1987-2017, whilst their male counterparts had a mean TGR of 0.80 for the same period. This means that female farmers faced a technology gap of about 25% and male farmers of 20%. This difference could be narrowed down to the unique constraints that each faces when adopting technology (Ragasa et al. 2014). If female farmers faced the same constraints as their male counterparts, their production level would increase by about 5%. Furthermore, if there were no constraints to technology adoption, the production level would increase by 25% and 20% for female and male farmers, respectively. The gender gap in technology adoption between male and female crop farmers is robust across different crops. Figure 2 shows that between 1987-2017, the mean gender gap (against females) was highest for yam (21%) and lowest for plantain (0.45%). Figure 3 shows that there exists a gender gap in technology adoption against female crop farmers in all regions except the Northern region where the gap is against male crop farmers.

Of interest is how this gap has evolved over the past 30 years (Figure 3). Particularly it can be observed that the gender gap against females was as high as 18% in 1997/98. Since then, it has reduced by about 83% to 3% in 2016/17. This could be attributed to the measures such as the establishment of the Women in Agricultural Development Directorate and the implementation of the Gender and Agricultural Development Strategy (GADS) under the Ministry of Food and Agriculture Ghana since 2004 (MoFA 2015), to mainstream gender concerns.

5.4 Technical efficiency gap

Values of pure farmer technical efficiency (TE) closer to one indicate a higher level of technical efficiency. The estimated mean TE from 1987–2017 for female and male crop farmers is 0.76 and 0.73, respectively, i.e., female crop farmers operated at 76% of the potential possible given the technology available to females and males at 73%. The difference between the TE of female and male farmers translated into a gap of about 4% against the latter. Unlike the case for technology adoption, the gender gap here is not robust across different crops. Figure 2 shows that between 1987-2017, male farmers of cocoa, plantain, sorghum, and rice were technically more efficient than their female counterparts, while female farmers of dry beans, maize, yam, cocoyam, millet, cassava, and pepper were technically more efficient than their male counterparts. For groundnuts, both male and female farmers operated at pure levels that are statistically similar. Figure 3 shows that there exists a gender gap in TE against male crop farmers in all regions except the Northern region where the gap is against female crop farmers. While there were elevated levels of gender gap against women in pure farmer technical efficiency in 1997/98 (12%) and 1998/99 (17%), the gap is estimated at 5% in 2016/17 against male farmers.

The pure farmer technical efficiency (TE) values do not tell us about how male and female farmers perform relative to the overall crop production technology available in Ghana. The technical efficiency of the farmers relative to the overall crop production technology in Ghana is given by their meta-frontier technical efficiency (MTE), which is the product of TGR and TE. Like TE, values closer to one indicate a higher level of technical efficiency. The estimated mean MTE from 1987–2017 for female and male crop farmers is 0.60 and 0.60, respectively. This means that both genders operated at 60% of the potential possible given the overall crop production technology in Ghana.

At the crop level, we observe a gender gap in MTE against female farmers that is robust across cocoa, yam, sorghum, plantain, rice, groundnut, and dry bean production. For maize, cassava, cocoyam, and pepper, the gender gap is against male farmers. These results are similar to Danso-Abbeam, Baiyegunhi, and Ojo (2020) who worked on cocoa in Ghana. Some studies have suggested that male farmers could be identified with cash and export crop production while the females identified in the production of food crops or more marginalised crops and therefore would be technically more efficient in those crops. However, the study on gender patterns of cropping in Ghana indicates that we cannot divide crops into those grown by males and those grown by females (Doss 2002). Female farmers are involved in the production and sale of all the major crops in Ghana (Doss 2002). It is therefore expected that male and female farmers of the same crops may exhibit technical efficiency differences depending on their general characteristics such as educational level, the value of credit accessed, access to extension services, and other resource endowments (Danso-Abbeam, Baiyegunhi, and Ojo 2020). These coupled with the idiosyncrasies of the crops regarding their resource requirements for growth could define the gender gap in their production. For example, the resource requirement for crops such as cocoa, rice, dry bean, sorghum, and plantain with a gap against females have more intensive resource requirements compared with a crop like millet (which females are more technically efficient) and can grow under stressful environments (Peter et al. 2021).

Figure 3 shows that there exists a gender gap against male crop farmers in all regions except the Ashanti, Western, Central, and Greater Accra regions where the gap is against female crop farmers. The gender gap in MTE between male and female crop farmers has substantially reduced since the 1980s but the gap has shifted from a gap which was against female farmers in 1987/88 estimated at 5.94% to a gap against male farmers in 2016/17 estimated at 9.24%.

6. Conclusions

Agricultural performance has been proven to have strong linkages with the growth of developing countries. However, the gains from agricultural growth disproportionately trickle down to the poor. Amongst the many ways of reducing this bias against the poor is to reduce gender differences in agriculture. Over time, however, the validity of statistics on gender differences has been questioned, and the way researchers and policymakers describe gender differences also affects how they perceive and try to address them. This study sought to assess the gender gap in farm output due to technology gaps and technical efficiency. It further evaluates whether gender patterns in technology adoption and technical efficiency have changed over time.

The results indicate that the responsiveness of output to land, planting material, hired labour, and fertiliser for female farmers is lower than that of their male counterparts. On the contrary, the responsiveness of output to family labour and pesticide for male farmers is lower than that of their female counterparts. However, over time the gender gap in output elasticities for land and planting material has nearly closed. The output elasticities of fertiliser, family labour, and hired labour have realised different dynamics, as the gap against males for fertiliser has shifted to a gap against females, and for family/hired labour the gap against females has shifted to a gap against males. The results also indicate that females operate at an increasing return to scale of 1.14 while males operate at a decreasing return of 0.93. This suggests that females have more room to increase their scale of production.

The dynamics in the gender gap in the use of inputs and the responsiveness of output to their use results in a technology gap of about 25% for female farmers whilst their male counterparts faced a technology gap of 20%, and this gap is robust across different crops and in most regions. Over the past three decades, the gap against females declined from 18% in 1997/98 by about 83% to 3% in 2016/17.

The results indicate female farmers are more technically efficient (TE of 76%) compared to their male counterparts (TE of 73%). However, this is not robust across different crops but is persistent in all regions except the Northern region. The technical efficiency gap against male farmers has remained relatively steady over three decades and is estimated at 5% in 2016/2017. The meta-frontier technical efficiency measure indicates that both male and female farmers operate at 60% of the potential possible given the overall crop production technology in Ghana.

These results indicate that both male and female farmers have room to increase their technology adoption and technical efficiency in crop production and the 30-year temporal dynamics suggest that females could also lead in the crop production technology in Ghana, and they should be supported, albeit not at the expense of male farmers. However, for gender interventions to yield their expected results, they must be targeted at specific crops and specific locations.

Notes

1. Agricultural Economics Volume 46 (3) – Gender and agriculture in sub-Saharan Africa (https://onlinelibrary.wiley.com/toc/15740862/2015/46/3)
2. Food Policy Volume 67 – Agriculture in Africa – Telling Myths from Facts (https://www.sciencedirect.com/journal/food-policy/vol/67/suppl/C)
3. Survey specific version of Table 1 con be found in the online appendix as Table S1
4. As of 19 May 2022, 1 US$ was equivalent to 7.1262 GHS.
5. All results can be generated using replication materials available at https://github.com/ftsiboe/Agricultural-Productivity-in-Ghana. The repository includes an excel sheet with easily quarried tables which the one can use to display one at a time, the 316 Translog stochastic frontier models.
6. For the likelihood ratio test, the restricted log-likelihood value is from the national-frontier, and that for the unrestricted is the sum of the regional-frontier log-likelihood values. The test was done separately for each survey-wave.

Acknowledgements

The authors gratefully acknowledge the Ghana Statistical Service for making the dataset publicly available. The findings and conclusions in this publication are those of the author(s) and should not be construed to represent any official USDA or U.S. Government determination or policy. This research was supported in part by the U.S. Department of Agriculture, Economic Research Service. All errors are the responsibility of the authors.

Authors' contributions

Author FT conceptualised the study, sourced, processed, and analysed the data, and partly wrote the abstract, introduction, methods, results, and discussion sections. Author AAA solely wrote the literature review and conclusion sections, and partly wrote the abstract, introduction, results, and discussion sections. Author JC reviewed the methods, results, and discussion sections. All authors proofread and approved the manuscript.

Data availability

Replication materials are available on GitHub at https://github.com/ftsiboe/Agricultural-Productivity-in-Ghana

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Abigail Ampomah Adaku http://orcid.org/0000-0003-2883-0973
Francis Tsiboe http://orcid.org/0000-0001-5984-1072
Joseph Clottey http://orcid.org/0000-0002-4317-1630

References

Aguilar, A., E. Carranza, M. Goldstein, T. Kilic, and G. Oseni. 2015. Decomposition of gender differentials in agricultural productivity in Ethiopia. *Agricultural Economics (United Kingdom)* 46, no. 3: 311–34. doi:10.1111/agec.12167.

Alene, A.D., V.M. Manyong, G.O. Omanya, H.D. Mignouna, M. Bokanga, and G.D. Odhiambo. 2008. Economic efficiency and supply response of women as farm managers: Comparative evidence from western Kenya. *World Development* 36, no. 7: 1247–60. doi:10.1016/j.worlddev.2007.06.015.

Asravor, J., A. Wiredu, K. Siddig, and E. Onumah. 2019. Evaluating the environmental-technology gaps of rice farms in distinct agro-ecological zones of Ghana. *Sustainability* 11, no. 7: 2072. doi:10.3390/su11072072.

Battese, G.E., A.N. Rambaldi, and G.H. Wan. 1997. A stochastic frontier production function with flexible risk properties. *Journal of Productivity Analysis* 8, no. 3: 269–80. doi:10.1023/A:1007755604744.

Battese, George E, D.S.P. Rao, and C.J. O'Donnell. 2004. A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. *Journal of Productivity Analysis* 21, no. 1: 91–103. doi:10.1023/B:PROD.0000012454.06094.29.

Belotti, F., S. Daidone, G. Ilardi, and V. Atella. 2013. Stochastic frontier analysis using stata. *The Stata Journal: Promoting Communications on Statistics and Stata* 13, no. 4: 719–58.

Burke, W.J., S. Li, and D. Banda. 2018. Female access to fertile land and other inputs in Zambia: Why women get lower yields. *Agriculture and Human Values* 35: 761–75.

Christiaensen, L. 2017. Agriculture in Africa – telling myths from facts: A synthesis. *Food Policy* 67: 1–11. doi:10.1016/j.foodpol.2017.02.002.

Coelli, T. 1995. Estimators and hypothesis tests for a stochastic frontier function: A monte carlo analysis. *Journal of Productivity Analysis* 6, no. 3: 247–68. doi:10.1007/BF01076978.

Croppenstedt, A., M. Goldstein, and N. Rosas. 2013. Gender and agriculture: Inefficiencies, segregation, and Low productivity traps. *The World Bank Research Observer* 28, no. 1: 79–109. https://www.jstor.org/stable/24582373?seq=1#metadata_info_tab_contents.

Danso-Abbeam, G., L.J.S. Baiyegunhi, and T.O. Ojo. 2020. Gender differentials in technical efficiency of Ghanaian cocoa farms. *Heliyon* 6, no. 5), doi:10.1016/j.heliyon.2020.e04012.

Doss, C., C. Kovarik, A. Peterman, A. Quisumbing, and M. van den Bold. 2015. Gender inequalities in ownership and control of land in Africa: Myth and reality. In *Agricultural economics (United Kingdom) (Vol. 46, issue 3)*. doi:10.1111/agec.12171.

Doss, C.R. 2001. Designing agricultural technology for African women farmers: Lessons from 25 years of experience. *World Development* 29, no. 12: 2075–92. doi:10.1016/S0305-750X(01)00088-2.

Doss, C.R. 2002. Men's crops? Women's crops? The gender patterns of cropping in Ghana. *World Development* 30, no. 11: 1987–2000. doi:10.1016/S0305-750X(02)00109-2.

Doss, C.R., and M.L. Morris. 2001. How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana. *Agricultural Economics (United Kingdom)* 25, no. 1: 27–39. doi:10.1016/S0169-5150(00)00096-7.

Due, J.M., and C.H. Gladwin. 1991. Impacts of structural adjustment programs on african women farmers and female-headed households. *American Journal of Agricultural Economics* 73, no. 5: 1431–9. doi:10.2307/1242398.

Farrell, M.J. 1957. The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)* 120, no. 3: 253. doi:10.2307/2343100.

Goldstein, M., and C. Udry. 2008. The profits of power: Land rights and agricultural investment in Ghana. *Journal of Political Economy* 116, no. 6: 981–1022. doi:10.1086/595561.

Gutierrez, R.G., S. Carter, and D.M. Drukker. 2001. On boundary-value likelihood-ratio tests. *Stata Technical Bulletin* 10 (60), https://econpapers.repec.org/article/tsjstbull/y_3a2001_3av_3a10_3ai_3a60_3asg160.htm.

Hayami, Y. 1969. Sources of agricultural productivity Gap among selected countries. *American Journal of Agricultural Economics* 51, no. 3: 564. doi:10.2307/1237909.

Hayami, Y., and V.W. Ruttan. 1970. Agricultural productivity differences among countries. In *The American economic review Vol. 60*,895–911. American Economic Association. doi:10.2307/1818289.

Hayami, Y., and V.W. Ruttan. 1971. Agricultural development: an international perspective. Agricultural development: An International Perspective. https://www.cabdirect.org/cabdirect/abstract/19721890134.

Hirshman, D., and M. Vaughan. 1984. Women farmers of Malawi: Food production the Zomba district.

Huang, C.J., T.-H. Huang, and N.-H. Liu. 2014. A new approach to estimating the metafrontier production function based on a stochastic frontier framework. *Journal of Productivity Analysis*, doi:10.1007/s11123-014-0402-2.

Karamba, R.W., and P.C. Winters. 2015. Gender and agricultural productivity: Implications of the farm input subsidy program in Malawi. *Agricultural Economics (United Kingdom)* 46, no. 3: 357–74. doi:10.1111/agec.12169.

Kilic, T., P. Winters, and C. Carletto. 2015. Gender and agriculture in sub-saharan Africa: Introduction to the special issue. *Agricultural Economics* 46, no. 3: 281–4. doi:10.1111/agec.12165.

Koirala, K.H., A.K. Mishra, and I. Sitienei. 2015. Farm productivity and technical efficiency of rural Malawian households: Does gender make a Difference? 2015 Annual Meeting, January 31-February 3. doi:10.22004/ag.econ.196903.

Lambrecht, I., M. Schuster, S. Asare Samwini, L. Pelleriaux, S. Asare, and L. Pelleriaux. 2018. Changing gender roles in agriculture? Evidence from 20 years of data in Ghana. *Agricultural Economics* 49, no. 6: 691–710. doi:10.1111/agec.12453.

Ligon, E., and E. Sadoulet. 2008. *Estimating the effects of aggregate agricultural growth on the distribution of expenditures*. Washington, DC: World Bank. © World Bank.; Washington, DC: World Bank. http://code.google.com/p/inequalitygrowth/source.

Miriti, P., D.J. Otieno, E. Chimoita, E. Bikketi, E. Njuguna, and C.O. Ojiewo. 2021. Technical efficiency and technology gaps of sorghum plots in Uganda: A gendered stochastic metafrontier analysis. *Heliyon* 7, no. 1: e05845. doi:10.1016/j.heliyon.2020.e05845.

Missiame, A., P. Irungu, and R.A. Nyikal. 2021. Gender-differentiated stochastic meta-frontier analysis of production technology heterogeneity among smallholder cassava farmers in Ghana. *African Journal of Agricultural and Resource Economics* 16, no. 2: 140–54.

MoFA. 2015. Gender and agricultural development strategy II (GADS II).

O'Donnell, C.J., D.S.P.P. Rao, and G.E. Battese. 2008. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics* 34, no. 2: 231–55. doi:10.1007/s00181-007-0119-4.

O'Sullivan, M., A. Rao, B. Raka, G. Kajal, and V. Margaux. 2014. Levelling the field: Improving opportunities for women farmers in Africa.

Onumah, J.A., E.E. Onumah, R.M. Al-Hassan, and B. Brümmer. 2013. Meta-frontier analysis of organic and conventional cocoa production in Ghana. Agricultural Economics (Czech Republic).

Owusu, V., E. Donkor, and E. Owusu-Sekyere. 2018. Accounting for the gender technology Gap amongst smallholder rice farmers in northern Ghana. *Journal of Agricultural Economics* 69, no. 2: 439–57. doi:10.1111/1477-9552.12236.

Peter, A.A., A. Richard, W.K. Alexander, and G. Prakash. 2021. Assessing production constraints, management and use of pearl millet in the Guinea savanna agro-ecology of Ghana. *African Journal of Plant Science* 15, no. 11: 288–98. doi:10.5897/AJPS2021.2183.

Pierotti, R.S., S. Friedson-Ridenour, and O. Olayiwola. 2022. Women farm what they can manage: How time constraints affect the quantity and quality of labor for married women's agricultural production in southwestern Nigeria. *World Development* 152: 105800. doi:10.1016/j.worlddev.2021.105800.

Quisumbing, A. 1996. Male-Female differences in agricultural productivity: Methodological issues and empirical evidence. *World Development* 24, no. 10: 1579–95.

Ragasa, C., D. Sengupta, M. Osorio, N. OurabahHaddad, and K. Mathieson. 2014. *Gender-specific approaches, rural institutions and technological innovations*. Rome, Italy: Food and Agricultural Organization of the United Nations (FAO); International Food Policy Research Institute (IFPRI) and Global Forum on Agricultural Research (GFAR). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129039.

Saito, K.A. 1994. Raising the productivity of women farmers in sub-saharan Africa (No. 230; World Bank Discussion Paper).

Schmidt, P., and T.-F. Lin. 1984. Simple tests of alternative specifications in stochastic frontier models. *Journal of Econometrics* 24, no. 3: 349–61. doi:10.1016/0304-4076(84)90058-7.

Sell, M., S. Bäckman, B. TettehAnang, and J.K. Niemi. 2018. The unequal efficiency gap: Key factors influencing women farmer's efficiency in Uganda. *Cogent Food & Agriculture* 4, no. 1, doi:10.1080/23311932.2018.1551750.

Takeshima, H., N. Houssou, and X. Diao. 2018. Effects of tractor ownership on returns-to-scale in agriculture: Evidence from maize in Ghana. *Food Policy* 77: 33–49. doi:10.1016/j.foodpol.2018.04.001.

Truett, L.J., and D.B. Truett. 1990. Regions of the production function, returns, and economies of scale: Further considerations. *The Journal of Economic Education* 21, no. 4: 411–9. doi:10.1080/00220485.1990.10844687.

Tsiboe, F. 2020. Nationally representative farm/household level dataset on crop production in Ghana from 1987-2017. SSRN. doi:10.2139/ssrn.41345181.

Tsiboe, F. 2021. Chronic sources of low cocoa production in Ghana: New insights from meta-analysis of old survey data. *Agricultural and Resource Economics Review*, 1–26. doi:10.1017/age.2021.3.

Tsiboe, F., P. Aseete, and J.G. Djokoto. 2021. Spatiotemporal comparison of dry beans and groundnut production technology and inefficiency in Ghana. *Review of Agricultural and Applied Economics* 24, no. 1: 76–87. doi:10.15414/raae.2021.24.01.76-87.

Tsiboe, F., J. Asravor, and E. Osei. 2019. Vegetable production technical efficiency and technology gaps in Ghana. *African Journal of Agricultural and Resource Economics* 14, no. 4, http://afjare.org/wp-content/uploads/2020/01/3.-Tsiboe-et-al.pdf.

Tsiboe, F., J. Asravor, V. Owusu, and A. Mensah-Bonsu. 2022. Production technology, efficiency, and productivity of cereal farms: Prospects for enhancing farm performance in Ghana. *Agricultural and Resource Economics Review*, 1–31. doi:10.1017/age.2022.16.

Tsiboe, F., I.S. Egyir, and G. Anaman. 2021. Effect of fertilizer subsidy on household level cereal production in Ghana. *Scientific African* 13: e00916. doi:10.1016/j.sciaf.2021.e00916.

Tsiboe, F., J. Luckstead, B.L. Dixon, L.L. Nalley, and J.S. Popp. 2018. Analyzing labor heterogeneity in Ghanaian cocoa production and its implications for separability in household decisions and policy. *Journal of Agricultural and Applied Economics*, 602–27. doi:10.1017/aae.2018.18.

Uttaro, R.P. 2002. Diminishing choices: gender, small bags of fertilizer, and household food security decisions in Malawi. *African Studies Quarterly* 6, no. 1: 77–110.

World Bank. 2007. World Development Report 2008: Agriculture for Development. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/5990 License: CC BY 3.0 IGO.