Information and Communications Technology and Financial Development as Catalysts for Gender Equality in Brazil's Agricultural Sector

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In this study, we examined the effects of information and communications technology (ICT) and financial development on mitigating gender inequality in Brazil, using autoregressive distributed lag (ARDL) approaches, between 1991 and 2022. The ARDL bounds test was employed to find the presence of co-integration within the series of data. Both in the short run and the long run, financial development has a significant negative impact on gender disparity; this means that policies aimed at enhancing women's financial and consumption services should be promoted in the short run. In the long run, we can conclude that ICT developments lead to a decrease in gender inequalities, which may imply the need for strategic, long-term planning to increase ICT infrastructure, especially in deprived areas. This includes subsidising affordable internet, skills training for women in the ICT field, and promoting women's participation in the technology industry. In addition, the impact of optimal financial development varies over time; hence, there is a need for flexibility and sustainability in financial development. Policy makers should therefore continue to strengthen and enhance financial inclusion initiatives, as well as regularly follow up on the impact of these initiatives on gender equality.

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Introduction

Gender inequality is a persistent barrier to decent social and economic prosperity. Disparities in education, employment, and political representation harm women and gender minorities disproportionately (Cech and Waidzunas 2021; Adeosun and Owolabi 2021). Cultural norms and systematic biases have institutionalised gender inequity for centuries, affecting social and economic life (Jayachandran 2015; Kohli 2017). Women's empowerment is crucial for inclusive development, making gender equality a central pillar of the Sustainable Development Goals (SDGs).

Information and communications technology (ICT) has transformed the digital age, aiding economic, innovative, and human development; however, women face barriers to access, literacy, and participation in the digital sector (Palvia et al. 2018; Fernández-Portillo et al. 2020; Appiah-Otoo and Song 2021). Even where ICT can reduce structural inequality, long-term gender inequities persist, hindering opportunities. Access to education, employment, and decision-making platforms can improve gender equity when ICT is inclusive (González et al. 2016; Yeganehfar et al. 2018).

Finance is also crucial to tackling gender inequality. Ghosh and Vinod (2017), and Ozili (2021a) highlight systemic hurdles to lending, savings, and financial market leadership for women. Inclusion in financial systems and the adoption of gender-sensitive policies can enhance women's employment, entrepreneurship, and economic leadership (Cavalcanti and Tavares 2016; Kübler et al. 2018), while financial growth can enhance women's economic freedom and contribute to social justice (Tchamyou 2019; Ozili 2021b).

After the U.S. and Argentina, Brazil is the third-largest exporter of agricultural goods, a result of its favourable climate, plentiful natural resources, and a well-developed agro-industrial sector. Brazil's soybean, corn, and cattle production contribute to global food security and economic growth (World Population Review n.d.). Agriculture, which encompasses forestry, fisheries, livestock, and cereals, has contributed 6–7% to Brazil's GDP for several years. Brazil's GDP grew to 6.24% in 2023, driven by agriculture, forestry, and fisheries, up from 5.77% in 2022, according to the World Bank's 2024 Global Economy report. However, Brazil's percentage is still below the South American average of 7.7% (The Global Economy n.d.). Given the current severe climatic risks, Scot Consultoria (2025) expects a sectoral share of 6.3 to 6.8% in 2023 and

6.1% in 2024. This illustrates the sector's structural strength in the economy, as well as its dependence on production seasonality and overseas demand.

An integrated agrifood system comprising upstream suppliers, agro-processing companies, and logistical networks contributes to GDP; Brazil's integrated industry accounts for 22% of the country's GDP, 40% of its export revenues, and 16% of formal employment, according to the World Bank's Global Monitoring Report (World Bank Group 2025) and domestic sources. CEIC Data shows that agribusiness contributes 23.8% to GDP through services and industrial connections. Brazilian agrifood exports increased from 23% in 2000 to 37% in 2021, indicating improvements in industry productivity and competitiveness (Organisation for Economic Co-operation and Developmen 2023). Thus, while agriculture contributes to a single-digit percentage of GDP, its price chain drives rural growth, job creation, and international trade (World Bank Group 2025). The Gini coefficient (a scale of 0–1), which measures gaps in income, indicates that Brazil has the highest income inequality in Latin America (Mourao and Junqueira 2021; Signor et al. 2019). Brazil has several sources of economic disparity, including education (Faria dos Santos and Cruz Vieira 2015). In addition, countrywide direct monetary income may potentially promote inequality (Medeiros and Souza 2013).

ICT and financial development may reduce gender disparity in the Brazilian agriculture sector. Previous research has explored gender inequity across various sectors, but this study focuses specifically on gender inequality in the agricultural sector. As a major contributor to Brazil's GDP and employment, agriculture is a key area that must be considered, since agrarian reform enhances agricultural productivity and economic prosperity.

Gender inequality in Brazil is now understood primarily in terms of digital access, financial growth, and agricultural inequality. This perspective supports aggregate cross-country or country-level results that overlook sector-specific institutional processes. This study will fill that gap by presenting a sector-specific approach spanning three decades, using Brazil as an example, where agriculture is vital to the economy and gender inequality persists. The report is crucial given Brazil's governmental attempts to promote rural connection and internet access, expand women-specific financial products like Pronaf Mulher, and meet the SDGs. Gender disparity in agriculture is measured by the female-to-male ratio, which is obtained by dividing the number of female employees by the

number of male employees. This statistic lends sectoral depth to Brazilian gender inequality literature.

The remainder of the study is organized as follows: a summary of the literature examined is in The second section. The third section discusses the model, data, and econometric approaches. Details on the empirical findings are presented in the fourth section. Finally, the fifth section provides an overview of the study's key results as well as policy recommendations.

Literature Review

The gender gap in the workplace is still an immense and many-faceted problem that carries wide echoes not only for people as individuals, but also for groups and nations at large. The timely resolution of issues of gender inequality in labour remains crucial as long as women are confronted with the obstacles of equal access, opportunities, and representation at work. Thus, significant scholarly research has investigated the complex relationship between gender inequality and labour to understand its causes, effects, and expressions, and promote workplace inclusion and gender equality. Clark (1997) suggests that labour market inequalities, which may have decreased expectations, may have made women happier at work. Despite a lack of scientific evidence, especially from other nations, this viewpoint is gaining traction. In 2019, Perugini and Vladisavljević evaluated 2013 EU-SILC data to study gender differences in work satisfaction and inequality across 32 European countries. The data suggest that achieving early gender equality can help reduce work satisfaction gaps. Egalitarian women may have similar aspirations to men. In contrast to male-dominated occupations, education does not affect alignment. Rodríguez-Modroño et al. (2022) found gender inequality in digital labour platforms due to asymmetric and segregated interactions. The COLLEEM study in 16 European countries found that women use these platforms for "feminized" tasks, work fewer hours, and earn less than men. According to their research, platform analysis should encompass gender dynamics, workers' reliance on platforms, and labour force diversity.

Vyas (2021) examined gender inequality and the trends of EU women in gig jobs and found that despite digital platforms, outdated labour market stereotypes about women endure. Abuse of flexibility and algorithmic bias exacerbate the precarious conditions faced by women gig workers. After analysing employment practices, intersectionality, and the gender wage gap on traditional and digital platforms, the author concluded that

the EU must protect female gig economy workers to reduce gender inequality. In 2019, Kuitto et al. explored how parental leave affects young Finnish men and women. Multi-trajectory analysis and longitudinal Finnish Centre for Pensions registration data from 2005 to 2016 were utilized to evaluate the labour market links of workers born in 1980. Both sexes have five professional paths, yet early gender pay disparity persists despite similar job lengths. Women take more parental leave than men, resulting in unequal income and employment. The study suggests dividing parental leave more fairly to reduce gender inequalities in early professional development, which may impair women's career progression, pay, and pension. In another investigation, Barth et al. (2021) examine why the gender pay gap persists despite women's gains in the labour market. This discrepancy is explained by the 2000 U.S. Decennial Census and the Longitudinal Employer-Household Dynamics (LEHD) Data. The research indicated that switching occupations and professional progression gaps contribute to increased inequality, with varied consequences for different educational backgrounds. Established companies account for 27% of the income growth gap among college-educated persons. The slight income rise among non-college graduates is due to the establishment. Marriage also contributes to the widening income disparity between educated groups.

From 1980 to 2019, Akhtar et al. (2023) investigated Malaysian economic progress, gender inequality, evaluating trade openness, female labour force participation, and economic development using autoregressive distributed lag models. The nonlinear analysis demonstrates that positive and negative shocks complicate long-term female labour force participation and economic growth. Granger causality research has identified one-way and two-way connections between trade openness, economic growth, gender parity, and the labour force participation of males and females. These data demonstrate that economic growth is facilitated by trade openness, gender balance, and female labour force participation. To strengthen Malaysia's economy, the report recommends government assistance for institutional quality, economic effectiveness, and female professional engagement. Women are overrepresented among low-paid workers; hence, Caliendo and Wittbrodt (2022) study how the 2015 German minimum wage affects the gender wage gap. Regional minimum wages are examined using a difference-in-difference approach, employing data from the Structure of Earnings Survey, which covers nearly one million workers in 60,000 firms. The regional gender wage gap narrowed

in the lowest salary percentiles. The 10th percentile gender earnings gap in minimum wage areas reduced by 4.6 percentage points (32%) between 2014 and 2018. By 18%, the 25th percentile declined. The minimum wage can reduce the gender wage gap outside of low-wage industries and into higher-income categories, but less so near the mean salary.

In regard to ICT and inequality, Singh (2020) examines the research on female equality and shared mobility in the rapidly growing mobile sector, driven by smartphones and apps. Private transportation has revolutionized transportation, but its consequences on gender equality remain uncertain. Recent research has examined the impact of shared mobility on modal shift, car ownership, environmental challenges, congestion, and transit ridership. The benefits of shared mobility, including comfort, security, and accessibility, are often disregarded by women. A lack of research suggests that expanding shared mobility services may increase men's use and reduce the mixed-gender female urban mobility gap. Comprehensive empirical studies in strong economies are recommended to identify why this gender propensity has developed and how to overcome it for achieving urban transportation gender equality.

Segovia-Pérez et al. (2020) examined gender inequalities that persist in ICT employment, despite legislative measures aimed at helping women attain IT careers. Environmental constraints, gender bias, and separation affect women's educational and career choices in this male-dominated area. ICT professionals have emerged in all engineering specializations as new sectors develop. However, gender inequity endures. Women working in ICT-dominated companies can help minimize ICT discrimination and the gender wage gap, according to the study. Incomes are categorized using wage decomposition from the 2018 Spanish Income Structure Survey. Research shows female ICT professionals dislike tech and skill-based employment. Qazi et al. (2022) examine the relationship between gender and ICT learning, use, and competency. Eight journal databases were searched using stringent selection criteria to identify forty-two empirical, peer-reviewed papers and conference presentations published between 2006 and 2020. Such a small-scale meta-analysis can help determine the gender gap in attitudes using a limited number of publications. Statistics demonstrated boys' advantages despite the minor effect size. Qazi et al. (2022) note that more meta-analysis research utilizing several ICT use and skills criteria is needed to validate these effects, but they are promising. Collaboration between stakeholders to enhance IT skills and laws that limit school ICT use to beneficial purposes were

also reviewed. The paper recommends future research and stresses the necessity to overcome current obstacles.

Abdu et al. (2015) examined how financial inclusion reduces poverty and enhances society's ability to meet the World Bank Group's universal target for financial inclusion. This study uses the Global Findex 2011 to evaluate gender disparities and financial inclusion in Nigeria. Financial inclusion is determined by age, income, and education using the Binary Probit Model and Fairlie decomposition. Economic inclusion is higher among younger, wealthier, and better-educated people. Women, poor individuals, and seniors lower these odds. The analysis found that male-headed households had higher financial options. This gender gap is attributed to wealth and access to secondary education. Education and income disparities affect gender financial access. To achieve the Sustainable Development Goals concerning poverty and gender equality, Nwosu and Orji (2017) evaluated Nigerian credit and firm performance. Using 2010 Nigerian Enterprise Survey data, propensity score matching (PSM) examines how formal credit influences key performance measures. Econometrics shows that credit-limited enterprises have reduced production, capital, labour, employment, and fixed asset investment. Biases hurt women-owned businesses more. This persists despite bias-adjusted computations and the use of sampling weights. Protecting Nigerian small, middle, and micro enterprises from loan access concerns could improve business growth by easing credit laws and mainstreaming government assistance for SMEs.

Between 1996 and 2014, Tchamyou et al. (2019) examined the impact of ICT on income inequality in 48 African countries with financial development. The Generalized Method of Moments (GMM) measures financial depth, efficiency, activity, scale, and ICT linkages. ICT reduces the negative relationship between nations with deeper and larger financial systems and inequality, but only the positive relationship in time-invariant variables is stable. Research classifies financial depth as formal, semi-formal, informal, and non-formal. ICTs make finance accessible to people with low incomes, formalizing it. This study examines the growth of the financial sector and ICT-supported financial access to close post-2015 SDG gaps in Africa, with the aim of improving microfinance.

Poverty, income inequality, and financial inclusion are studied using model nation data from 116 wealthy and developing nations by Omar and Inaba (2020). A financial inclusion index was created using outreach and skewed annual panel data from 2004 to 2016. The study examines

how internet use, age dependence, inflation, income inequality, and GDP per capita affect financial inclusion in emerging nations. Financial inclusion may lessen poverty and income inequality somewhat. This illustrates how expanding access for the poor to formal financial services benefits society as a whole.

Ratnawati (2020) states that financial inclusion enhances social development, economic progress, poverty reduction, income inequality, financial stability, and overall well-being in many Asian countries. GMM is used to evaluate financial inclusion in household banking use, banking access, and financial sector activity. The Gini coefficient and poverty rates illustrate income and poverty imbalance nationwide. Nonperforming loans and the bank's Z-Score reflect stability. Hypothesis testing indicates that comprehensive financial inclusion promotes financial stability, reduces income inequality, contributes to poverty reduction, and fosters economic development. Unfortunately, financial inclusion has a limited impact on outcomes in eleven Asian nations. This article suggests that regulators evaluate these data to create financial inclusion regulations that align with the Sustainable Development Goals and enhance citizen well-being.

Chisadza and Biyase (2023) examine global economic inequality and financial growth from 1980 to 2019. This approach is unique because it utilizes a collective financial growth index that incorporates both historical and current financial success indicators. Also examined are the consequences of income disparity in industrialized, emerging, and least developed nations. This study demonstrates how the ambiguity of financial development influences social class income disparities. Financial development is associated with poverty in developing nations but not in prosperous nations. When financial markets and institutions are fragmented, economic development and income disparity are problematic. Banking helps reduce income disparity in most emerging and least developed economies, but stock markets exacerbate it. Analysis indicates complex and nonlinear relationships between the least developed and emerging states, as well as between the developed and emerging nations. According to the findings, financial inclusion and inequality reduction must take into account the distinctive characteristics of emerging nations, which affect financial growth.

Altuzarra et al. (2021) examined gender inequality as a barrier to economic growth in SSA, SA, MENA, LAC, and EAP from 1990 to 2017 using the World Bank Development Indicators database. The study's GMM

analysis suggests that gender equality in schooling promotes economic growth. Educational equality may have helped SSA nations more than other developing nations. There is no statistically significant gender gap in employment. All emerging nations have a strong link between women in parliaments and economic growth, while SSA countries do not. However, even in countries with increased female political engagement, women may struggle to influence political agendas and economic growth.

Kam et al. (2022) examined gendered inequalities in Nigeria's civil service, female labour participation, and economic growth using several approaches. The paper calculates the gender gap in economic growth effects using panel data regression. A content- and consistency-focused study reveals gender inequality and challenges faced by Nigerian women in the civil service. Gender imbalance damages the human capital of public service personnel and hinders economic growth, according to the report. The data suggests that strengthening education and civil service job criteria can minimize gender disparity and increase economic growth.

Iheonu et al. (2020) analysed Western African female labour force participation and income discrepancy from 2004 to 2016. The study examines unemployment, female workforce participation, and income inequality measures, including the Gini coefficient, Atkinson index, and Palma ratio. Fixed-effect and instrumental variable models are used. Most empirical studies suggest that income inequality hinders the participation of West African women in the workforce. An inverted U-shaped relationship exists between inequality and female unemployment. Policy recommendations based on the results finish the report.

Kim (2021) uses multi-level, multi-perspective analysis to examine gender imbalance in institutions, societies, and cultures. Hypothetical comparisons of OECD and non-OECD nations across five categories, utilizing 17 variables, reveal macro- and micro-level gender inequality. Regression analysis is employed to examine the impact of commercial and political freedoms, women's representation in government, human development, health, and demographic factors on gender inequality in 18 OECD and 16 non-OECD countries. The fertility rate and business attitude limit gender equality the most in the five models. One of the 11 important model factors for non-OECD nations states that politicians must reform their institutions. We also noted employee-level problems. The study reveals how institutional networks and financial independence balance gender disparities, setting the stage for political changes

to ensure equal rights and change formal and informal institutions that discriminate against women. Ishfaq et al. (2023) argue that Pakistan's female labour force participation rate inequality hinders economic growth. A 1991–2021 World Development Indicators (WDI) time series dataset is used to identify socioeconomic and environmental elements affecting FLPR operations. The ARDL model calculates the effects of long-term CO_2 emissions, female education, fertility rate, GDP, and FLPR. GDP and education increased FLPR over time, but CO_2 emissions and fertility rate decreased it. The study concluded that improving health, education, and training can improve public support for Pakistan's success.

While national-specific context matters, discussions of gender inequality have focused on transnational or continental topics; however, Brazilian literature on female empowerment, resource allocation, and agriculture is growing. Historical and sociocultural institutional variables contribute to the gender imbalance in Brazilian agriculture. Brazilian literature explores the complex interrelationships between work, gender, social progress, and rural agriculture. These studies demonstrate that rural Brazilian women are excluded from decision-making and empowerment due to restrictions on land, credit, productive inputs, and institutions.

Agricultural control and resource limitations contribute to gender disparity. Deere (2003) states that women's limited access to land and other production tools perpetuates structural inequality and restricts their economic involvement. Institutional insensitivity and cultural gender norms exacerbate these limitations, especially in semi-arid and disadvantaged Brazilian regions (Silva et al. 2020; Medeiros 2014). According to 2015 microdata, non-urban women earn less than men. Santos and Garibaldi de Hilal (2018) argue that employment market discrimination exacerbates this discrepancy. Leoncini et al. (2024) attribute the salary gap to systemic bias and occupational segregation.

Academics should worry about the gender digital divide. Infrastructure and social issues such as gender role limits and educational inequalities hinder rural Brazilian women's ICT access, the poll revealed (Kuhnen and Rosendo 2018). Digital barriers impede women's access to markets, financial services, training, and agricultural innovation. Digital illiteracy and gender-sensitive ICT policies are needed to close this gap and boost agricultural output. Women are more likely to migrate from rural to urban areas in Brazil, and emerging areas get jobs and enterprises from industrialized agriculture (Kuhnen and Rosendo 2018).

Brazil has made progress in implementing specific policy concepts and rural development programmes; however, the lives of farm women have not yet improved uniformly. Multi-component methods, such as asset redistribution (e.g. land and financial resources), social protection, legal reform, and targeted capacity building, must address these inequities. These policies acknowledge regional differences, particularly in marginalized rural communities, and engage women in active agricultural and rural policymaking.

Methodology and Data

The purpose of this research is to analyse the role of information and communications technology (ICT) and financial development in bridging the gender inequality gap in Brazil, with a focus on the agricultural sector. To carry out this research, the economic model adopted for the study is as follows:

$$GI = f(ICT, FINDEV, HDI, GDP) \tag{1}$$

In the equation above, *GI*, as indicated in the model, is a representation of Gender Inequality in the agricultural sector calculated as the employment in agriculture of females (% of female employment) divided by employment in agriculture of males (% of male employment). Although this variable sheds light on the differences in labour force participation, it fails to reflect the full range of GI, namely, wage differentials, unequal access to productive assets, and institutionalized limitations in the decision-making process. The purely empirical selection of this single-dimensional proxy was conditioned by the fact that there are consistent, sector-specific time series covering the study period (1991–2022). More comprehensive composite indices, such as the Gender Inequality Index (GII) or the Women's Empowerment in Agriculture Index (WEAI), would have provided more detailed information. However, their time and coverage duration are not as broad as required here. In turn, the employment-based indicator can be taken as a practically oriented and reasonable indicator of sectoral gender inequality over time. It should be noted, however, that future research on GI will be strengthened by the inclusion of multidimensional indices once such data becomes more accessible in disaggregated form.

ICT is a surrogate for information and communications technology, reflecting individuals using the internet (% of population). FINDEV rep-

resents financial development, quoting domestic credit to the private sector (% of GDP). HDI is a proxy for the human development index, and lastly, GDP represents gross domestic product per capita (constant USD 2015). All the data in this study were sourced from the Brazilian annual statistics from 1991–2022, taken from the World Development Index of the World Bank, except the HDI, which is from the UNDP (United Nations Development Programme) database.

The empirical model's linear requirements are represented in Equation (2):

$$GI_{it} = \beta_0 + \beta_1 ICT_{it} + \beta_2 FINDEV_{it} + \beta_3 HDI_{it} + \beta_4 GDP_{it} + \varepsilon_{it} \quad (2)$$

Subscripts i and t above in Equation 2 denote country and time, respectively, β_0 stands for the constant term, while the coefficients β_1, β_2, β_3, and β_4, indicate the elasticities of gender inequality, information and communications technology, financial development, human development index, and gross domestic product, respectively, and ε represents the error term.

The ARDL model (Pesaran and Shin 1999; Pesaran et al. 2001) was used in this study. It combines partial sum decompositions with both positive and negative decompositions to produce asymmetric effects in the short and long run. Each variable in the ARDL model had its lag lengths chosen based on the Schwarz Information Criterion (SIC), which is best applied in small samples. According to this criterion, only Gender Inequality (GI) and Financial Development (FINDEV) were left to include in lagged forms since they demonstrated considerable dynamic effects. The SIC did not imply later lags of the variables of ICT, HDI, and GDP, but including them in the model in their contemporaneous form, the model also excluded them altogether. This method achieves the parsimony of the model and also considers the most pertinent form of temporal dynamics that shape gender inequality. This model represents a standard method of modelling ARDL where variable-specific lags are not imposed, but are data-driven instead. The asymmetric ARDL allows for the unrestricted examination of non-stationarity and nonlinearity in an error-correcting model. The linear ARDL model is effective at detecting cointegrating associations in small data sets. Furthermore, it allows for statistical conclusions on long-run estimates that other cointegration methodologies cannot, regardless of the regressors' integration order (I (0) or I (1)). However, in the presence of I (2) variables, the linear ARDL cointegration

strategy is unsuccessful. When applied in its broadest sense, the ARDL model can be described as follows:

$$\phi(L)Y_t = \alpha_0 + \alpha_1 w_t \beta^1 X_{it} + U_t. \quad (3)$$

Results and Interpretation

DESCRIPTIVE STATISTICS

Descriptive statistics are the foundation of any empirical study, which comprises the summary statistics represented by the measures of central tendency and variation. They are gathered in table 1.

The descriptive statistics shed light on the gender inequality study using a variety of variables, including Gender Inequality (GI), Information and Communications Technology (ICT), Financial Development (FINDEV), Human Development Index (HDI), and GDP. The mean Gender Inequality score is 0.422, indicating a modest degree. Information and Communications Technology and Financial Development have means of 31.91 and 52.85, respectively, with significant variability reflected in their standard deviations. Human Development Index and GDP have means of 0.702 and 7640.16, respectively, indicating a substantially higher level of development than the other metrics. Skewness and kurtosis values indicate varied degrees of divergence from the normal distribution, as demonstrated in Financial Development: 1.510930 and 6.834944, respectively. The Jarque-Bera test highlights the divergence from normality, which is particularly noticeable in Financial Development (31.78458) and warrants additional examination. The summary statistics, together with

TABLE 1 Descriptive Statistics

	GI	ICT	FINDEV	HDI	GDP
Mean	0.422193	31.90528	52.84752	0.702156	7640.160
Median	0.397478	29.52919	50.12947	0.704500	7722.184
Maximum	0.591767	81.34269	134.1136	0.764000	9216.132
Minimum	0.319116	0.003288	27.68567	0.624000	5911.687
Std. Dev.	0.082026	29.14426	21.94003	0.046639	1070.321
Skewness	0.688898	0.335236	1.510930	−0.144795	−0.063482
Kurtosis	2.213084	1.674739	6.834944	1.635970	1.491497
Jarque-Bera	3.356746	2.941133	31.78458	2.592586	3.055603
Probability	0.186677	0.229795	0.000000	0.273544	0.217012
Sum	13.51016	1020.969	1691.121	22.46900	244485.1
Sum Sq. Dev.	0.208575	26331.02	14922.31	0.067430	35513193
Observations	32	32	32	32	32

a total of 32 observations for each indicator, provide a complete picture of the dataset, which is critical for understanding and interpreting gender disparity patterns and associated causes.

STATIONARY TEST

The stationarity of the data was determined using both the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller 1979) and the Phillips-Perron (PP) test (Phillips and Perron 1988). The demand for unambiguous distinctions and exact measurements drove the selection of these methods. An important condition for using an ARDL technique is that all variables be classified as either I(0), I(1), or a combination of I(0) and I(1), with none falling under I(2). Tables 2 and 3 represent the ADF test and PP test, respectively.

The critical finding is that all variables are deemed statistically insignificant at level I(0), which shows that none of them are stationary. Nonetheless, stationarity is asserted by the first difference, because all variables are statistically significant in the ADF test. Moreover, the PP analysis also establishes that all variables are integrated of order one I(1) instead of I(0).

ARDL BOUND TEST

The ARDL bound test was employed to determine the presence of co-integration within the series of data. If the estimated value of the F-statistic is located below the level corresponding to the critical value, then the null hypothesis is sustained. The null hypothesis that there is no co-inte-

TABLE 2 ADF Test Result

Variables	Level	Prob	1st difference	Prob
GI	−1.162614	0.6771	−3.569533	0.0127
ICT	1.764465	0.9995	−4.029013	0.0041
FINDEV	−2.769712	0.0747	−5.390861	0.0001
HDI	−1.778172	0.3838	−3.965960	0.0048
GDP	−1.018282	0.7342	−4.382068	0.0017

TABLE 3 PP Test Result

Variables	Level	Prob	1st difference	Prob
GI	−1.138693	0.6875	−3.586073	0.0122
ICT	1.231832	0.9976	−4.188736	0.0028
FINDEV	−2.355266	0.1622	−5.676273	0.0001
HDI	−1.703994	0.4194	−3.888572	0.0059
GDP	−1.034056	0.7284	−4.398716	0.0016

TABLE 4 ARDL Bound Test Result

F-statistic		10.207944				
		10%		5%		1%
Sample Size	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
30	2.525	3.560	3.058	4.223	4.280	5.840
Asymptotic	2.200	3.090	2.560	3.490	3.290	4.370

NOTES I(0) and I(1) are respectively the stationary and non-stationary bounds.

gration is rejected if the statistics breach the upper threshold for I(1) (Pesaran et al. 2001). The computed F-statistic value (10.207944) indicates that the null hypothesis is rejected, suggesting a long-run connection between the independent and dependent variables at the 1%, 5%, and 10% signi1ficance levels.

ARDL LONG-RUN RESULT

Long-run analysis is helpful in empirical research because it enables researchers to establish the long-run coefficients and relationship between variables that would otherwise be hard to discover in the short run. This is important because when researchers focus on the long run, it is easier for them to distinguish between variability and change, therefore enhancing the understanding of what causes the occurrences in the long run. This is useful for creating effective policies and strategies, especially regarding the timing and persistence of actions. In this study, the ARDL long-run results for the dependent variable, Gender Inequality (GI), presented in table 5, reveal significant connections with the independent variables. Specifically, the lagged GI values, which show how past values influence current outcomes, have a significant impact on current levels of gender inequality, with coefficients of 1.268076, −0.889524, and 0.463907 for lagged periods of one, two, and three, respectively. This suggests that previous levels of gender inequality continue to have an impact on the current condition, with the most recent lag having the most effect.

In addition, information and communications technology (ICT) has a strong negative correlation with gender inequality, much like we observed a value of −0.00495 and a t-stat of −4.273326, meaning that access to internet services can promote gender equality. This study verifies the study of Shah and Krishnan (2024), who studied the relationships between ICT, gender inequality, and income inequality from 86 nations between 2013 and 2016. The findings conclude that ICT can reduce gen-

der disparity. Also, Valberg (2020) investigated how ICT influences the gender balance within workforce participation. The research provides empirical evidence supporting the assertion that ICTs have a positive effect on reducing gender disparity in the labour force rate, primarily due to the increased female labour force participation rate globally, as evidenced by panel data from 156 countries spanning 1991 to 2014. Despite the anticipated improvements in the gender share in employment and female literacy rate for employment, the change is lower in developing countries, and therefore, a reminder that ICT is not always a 'leapfrogging' technology. Other researchers (Amanze 2023; Javed 2023; Noor et al. 2021) also emphasize the importance of ICT development in addressing gender inequality.

In some ways, ICT has the potential to perpetuate the existing gender disparity within the agricultural sector. Women, more often than men, have limited access to ICT resources and accompanying tools that include digital literacy, even internet connection, and cellphones. This difference also limits their access to crucial agricultural information that can enhance income and production rates, including product prices, weather conditions, and related technologies. It may also help to supply female farmers with the needed educational content by addressing some of the identified deficits and targeting interventions that would allow for the proper ICT education and training of female farmers. Thus, there are numerous ways through which women can improve their efficiency and economic condition; they can use internet services and mobile applications for financial services and business opportunities, as well as for gaining recommendations regarding agriculture and farming. ICT can also help women participate in policymakers' forums and agricultural groups and co-operatives, thereby enhancing their voice in the sector. Long-term strategies should prioritize the growth of ICT infrastructure, particularly in underserved and rural areas, to ensure that women have equitable access to digital technology. This could include investing in low-cost internet access, offering ICT training programmes for women, and encouraging female engagement in tech-related industries.

Financial Development (FINDEV) also demonstrates a significant impact, with both current and lagged values showing significance. This is evident from coefficients of 0.009445, −0.004364, 0.001445, and −0.001736 for FINDEV and its lagged values. This result on the effect of financial development on inequality can be compared with the out-

come of studies by other researchers (Ratnawati 2020; Tchamyou 2021), who confirm the crucial role financial development plays in combating inequality, especially as related to gender. Previous research, including Bittencourt (2010) and Kanat et al. (2024), has also indicated a significant relationship between financial development and gender inequality. Financial development still plays a crucial role in the struggle for gender equality in supporting the sustainable growth of agriculture, since it provides suitable financial solutions that meet the various challenges that women encounter. This is useful in the fight against gender inequality in the agriculture industry as it offers women the required capital by coming up with the right financial products and structures that will give them a better standing economically. Since the keys to productivity enhancement through funding of profitable investments, adoption of efficient techniques for promoting agricultural productivity, and managing risks are provided by credit, insurance, and savings, the gender barriers to accessing these services by women farmers can be addressed through the application of integrated financial services.

In addition, the Human Development Index (HDI) reflects a direct correlation with gender inequality. With a coefficient of 3.808932 and a t-statistic of 3.981399, this suggests a positive association between the advancement of human development and the promotion of gender inequality. The HDI coefficient has a surprisingly positive and significant value, indicating that human development growth is not necessarily associated with low gender inequality in the agricultural sector. This finding can be attributed to the persistence of institutional and structural bottlenecks, such as limited land ownership, inequitable use of agricultural resources, and ingrained gender norms, which continue to hinder the equitable distribution of developmental benefits (Schwaab et al. 2019). This finding is similar to that of Ghosh (2018), who studied the relationship between gender equality, growth, and human development in India. The study found that, despite increasing literacy and educational levels among women, their participation in the labour force decreases, along with a narrowing of wage and income gaps. Additionally, Branchi and Bozon Penteado (2020) found that women in Brazil have higher levels of education than men. Nevertheless, the percentage of political representation of women is intolerably low, meaning that the level of human development does not necessarily reduce the rate of gender inequality in Brazil. Additionally, due to the prevalence of structural and cultural barriers, the gender disparity in the agricultural labour force in Brazil has not declined

over time with human development (Valencia et al. 2021; Schwaab et al. 2019; Bezner Kerr 2017). Women, therefore, may lack access to resources and may not own property or be qualified for decision-making roles in the agricultural industry despite the betterment of women's health, education, and overall livelihoods (Valencia et al. 2021; Bezner Kerr 2017). Also, the countryside often falls behind in implementing larger-scale social changes, and it is the women who are now locked out of training, financial services, technology, etc. These structures mean that a strategic approach to change might not fully address the causes of unequal gender access to agriculture, even when human developmental indicators improve.

The Gross Domestic Product (GDP) variable in table 5 shows a coefficient near −4.99E−05 and a p-value barely exceeding the standard 0.05, thereby implying a negative and notably non-significant association between GDP and gender inequality. This observation indicates that there is a statistically insignificant, economically trivial relationship between GDP per capita and gender inequality in Brazil, especially in its agricultural sector. Although this result suggests that economic growth as measured by GDP per capita does not possess a significant direct impact on gender gaps in either of the outcomes in question, it would be methodologically inadequate to conclude that GDP does not affect shaping gendered outcomes. Instead, the finding aligns with previously published literature, indicating that economic growth is a necessary but insufficient condition to halt the vicious cycle of gender injustices, as it must be complemented by institutional reforms, open labour policies, and equitable access to economic opportunities (Seguino 2001). Disadvantaged structural conditions, such as unequal access to land, financial resources, and unfair labour policies, along with persistent sociocultural norms, often hinder complete female economic participation, despite aggregate income growth in a country.

The short-run ARDL test provides the basis for understanding the immediate dynamics and correlation coefficients between the variables in question. In brief, it is apparent that the short-run ARDL test results and findings augment the long-term analysis, furnishing a better understanding of the data and providing keen insights into the temporal impacts and instantaneous implications. For decision-making systems where responses must be made at short time intervals, these results are highly constructive in defining the short-term cause-and-effect and feedback dependencies.

TABLE 5 ARDL Long-run Result (Dependent Variable: GI)

Variable	Coefficient	t-Statistic	Prob.
GI(−1)	1.268076	8.822388	0.0000
GI(−2)	−0.889524	−4.084219	0.0008
GI(−3)	0.463907	2.866093	0.0107
ICT	−0.004951	−4.273326	0.0005
FINDEV	0.009445	3.910148	0.0011
FINDEV(−1)	−0.004364	−4.484829	0.0003
FINDEV(−2)	0.001445	4.144681	0.0007
FINDEV(−3)	−0.001736	−5.720611	0.0000
HDI	3.808932	3.981399	0.0010
GDP	−4.99E−05	−2.021849	0.0592

TABLE 6 ARDL Short-run Result

Variable	Coefficient	t-Statistic	Prob.
CointEq(−1)*	−0.157540	−8.902903	0.0000
D(GI(−1))	0.425617	4.152937	0.0004
D(GI(−2))	−0.463907	−4.302443	0.0003
D(FINDEV)	0.009445	8.873359	0.0000
D(FINDEV (−1))	0.000291	1.580773	0.1282

Table 6 shows the ARDL short-run results, which provide evidence of the immediate implications of variables on Gender Inequality (GI) and Financial Development (FINDEV). The coefficient for the lagged relationship Cointegration Equation (CointEq(−1)) is −0.157540, and the t-statistic is −8.902903, indicating a significant negative impact. This implies that any deviation of the long-run equilibrium relation in the short run is corrected automatically, which represents a dynamic adaptation process towards equilibrium. The coefficients for the first and second lagged differences in GI are 0.425617 and −0.463907, respectively. Both coefficients exhibit significant t-statistics, implying a strong short-term link between changes in gender inequality levels across time.

The coefficient for the first lagged difference of FINDEV is 0.009445, with a high t-statistic of 8.873359, demonstrating a substantial positive link between changes in financial development and changes in gender inequality in the near term. However, the coefficient for the second lagged difference of FINDEV (D(FINDEV(−1))) is modest (0.000291) and statistically insignificant, implying that the effect of earlier financial development on gender inequality in the current period is minimal and not significant. These findings shed light on the short-term dynamics

between gender inequality and financial development, highlighting the importance of considering the immediate effects in understanding their relationship.

RESIDUAL DIAGNOSTIC TESTS

Diagnostic tests on the model's residuals give information about its adequacy and possible flaws. The first step is the Breusch-Godfrey LM Test, which is used to detect serial correlation in the residuals. The derived statistic value of 1.103240 is less than the critical limit, and the corresponding probability of 0.3573 shows that there is no significant evidence of serial correlation. This proves that the residuals do not have a regular pattern over time, and hence, the independence assumption required for the model's reliability is proved.

Moving on to the Ramsey RESET Test, which looks for potential model misspecification by testing for omitted non-linear variables, the low statistic value of 0.033578, along with a high probability of 0.8569, suggests that there is no meaningful evidence to reject the null hypothesis. As a result, the model appears to reflect the nonlinear interactions between the variables appropriately. Lastly, the Breusch-Pagan-Godfrey Heteroscedasticity Test, which is applied to check the presence of heteroscedasticity in residuals, gives a statistic value of 1.063227 and a probability of 0.4405. The probability goes beyond the traditional significance criteria; therefore, there is no convincing evidence of heteroscedasticity, meaning that the variance of the residuals stays the same for all observations. The structural stability of the model was also evaluated using the CUSUM and CUSUM of Squares tests (figures 1 and 2). The model stability is visually represented by the blue lines that cross the top and bottom red lines in the diagrams, respectively, and show that there is no variation from the 5% significance plot.

To summarize, these diagnostic tests collectively demonstrate that the model assumptions are reasonably met, increasing confidence in the dependability of the model's outcomes and interpretations.

Summary and Recommendations for Policy

The paper has provided a discussion on the interaction between information and communications technology (ICT), financial development and gender inequality in the agricultural sector of Brazil between 1991 and 2022 using the ARDL analysis strategy. To examine gender inequality, sectoral employment ratios were utilized, whereas ICT and financial

TABLE 7 Residual Diagnostic Test Result

Name of the Test	Statistics value	Probability
Breusch-Godfrey LM Test	1.103240	0.3573
Ramsey reset test	0.033578	0.8569
Heteroscedasticity Test: Breusch-Pagan-Godfrey	1.063227	0.4405

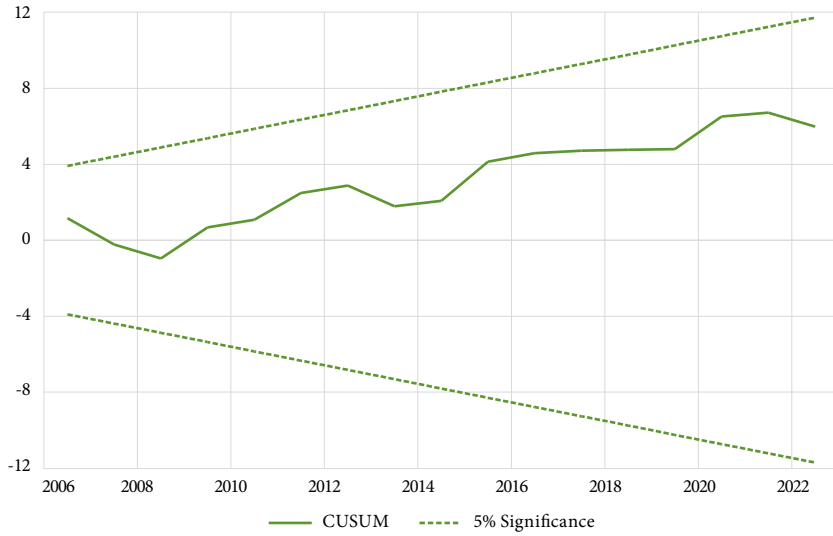

FIGURE 1 CUSUM Test

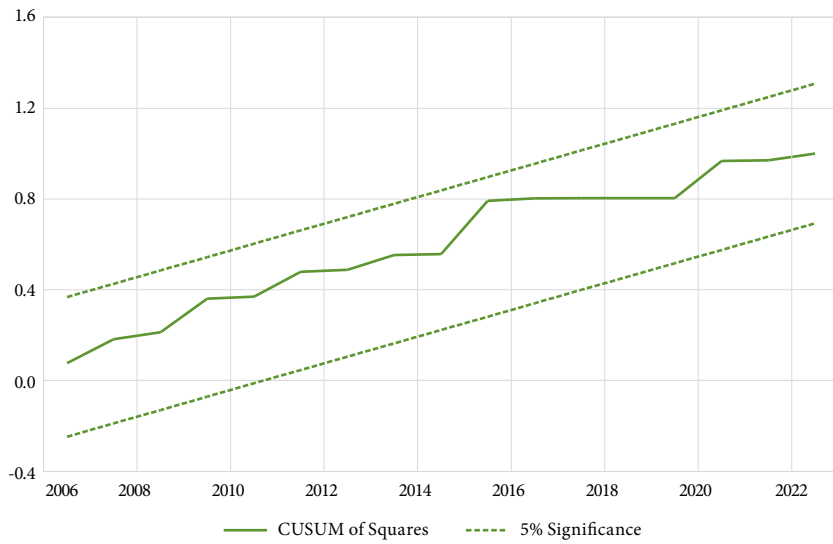

FIGURE 2 CUSUM of Squares Test

development were symbolized by internet use and domestic credit to the private sector, respectively. Also included were the Human Development Index (HDI) and GDP per capita. The results are confirmation of substantial and policy-relevant correlations, with long-standing results on gender equity, rural development, and inclusive economic growth.

The conclusion made, which is one of the most important, is that there exists a negative correlation between ICT and gender inequality in the long term, which supports the idea that digital inclusion is a transformative aspect. ICT helps expand the use of market information, finance services, and capacity development platforms for women. In the Brazilian context, where the rural areas are still digitally excluded, this highlights the immediate necessity of coordinated investment on the federal and state levels in affordable broadband services, mobile communications, and digital literacy initiatives among women. Collaboration among the Ministry of Communications, local municipalities, and agri-tech firms can accelerate the rollout of this. Also, digital empowerment is in line with the national strategies in Brazil on digital transformation, as well as its role in agricultural productivity and innovation.

Financial development plays a more complicated role. Although access to credit leads to less gender disparity in the short run, in the long run, this is the variable, indicating that structural adjustments in the financial system are required. Such programmes as Pronaf Mulher should be extended and transformed to consider collateral needs, enhanced outreach, and provision of custom financial products to women farmers. Gender-disaggregated reporting should be prescribed by financial regulators, such as the Central Bank of Brazil, to hold them accountable. Fintech and cooperative banks can be supported in providing their inclusive services by promising to provide them with subsidies and boosting their innovativeness.

Notably, the research notes that HDI gains are not enough to improve gender inequality in agricultural practices. Regardless of achievements in education and health, citizen inertia is still practiced in terms of systematic cultural and institutional limitations, particularly in the areas of land ownership, political representation, and access to resources. This requires legal and policy changes to address protection of women's rights over their land, inclusion of gender-responsive budgets in rural development initiatives, and encouraging female membership of the cooperatives and agricultural leadership mechanisms.

These findings are of direct concern to the industry. There is a growing concern to guarantee ethical sourcing, gender equity, and sustainability by agribusinesses, cooperatives, and food exporters. Inclusion of women in the agricultural value chains, workforce capacity, and leadership enhances resilience, productivity, and market competitiveness. By developing gender-sensitive approaches, the actors in the industries, particularly when cooperating with public institutions, may strengthen the position of Brazil in world markets, discharging SDG-oriented duties.

Nevertheless, an important weakness of this work is the aggregation of countrywide data, which fails to take into consideration the structural variety of the Brazilian agricultural sector. The combination of small, family-based farming systems with large export-oriented agriculture agribusiness also makes for many differences in labour systems, access to finance and technologies, and gender relationships. Accordingly, the relationships between variables in the findings are average sector-wide relationships that could conceal key variance in the expression of gender inequality across these relatively different agricultural subsectors. Future studies should focus on including disaggregated data or micro-level data to differentiate between farm types, production scales, and regional dynamics, thereby providing a more accurate picture of gender disparity in the Brazilian agricultural sector.

Conclusively, the treatment of gender inequality in the Brazilian agricultural sector requires multi-sector coordination and working within realities. ICT and financial development are a potent tool, their effectiveness being determined by the degree to which they are entrenched in policies, institutions, and market structures. Policymakers, development agencies, and even the private sector should coordinate efforts that integrate technological growth, inclusive finance, cultural transformation, and institutional responsibility. It is by these kinds of broad-based and all-encompassing measures that Brazil will be able to realize a more equitable, productive, and internationally competitive agricultural economy.

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