FAILURE AND SURVIVAL OF WEST AFRICAN ECONOMIC AND MONETARY UNION BANKS : THE ROLE OF REGULATORY CAPITAL

Vigninou Gammadibe

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By

Dr. Vigninou GAMMADIGBE

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P.O. Box 62882 - City Square Nairobi 00200,
Kenya

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Abstract

This paper analyzes the contribution of capital and its ownership structure on the failure of WAEMU (West African Economic and Monetary Union) banks. The study covers 147 banks observed over the period 2003-2017 and is based on non-parametric, semi-parametric, and parametric survival models. The results of the estimates using the partial maximum likelihood method show that the capital ratio plays a key role in the survival of banks by significantly reducing the probability of failure. Findings revealed that they can predict banking difficulties over a time horizon ranging from one to three years. Foreign ownership seems to reduce the probability of default. The increase in bank capital from 2007 seems to be accompanied by a faster acceleration of total bank assets as compared to equity. The estimates showed that low market share is an indicator of banks' vulnerability. Based on these findings, the paper recommends special supervision of small and newly established banks with small market shares and better management of banking institutions concerning capital management and risk-taking. Furthermore, the study urges the regulator to consider the structure of the market while issuing new licenses, to avoid a highly competitive banking sector that is not conducive to the stability and survival of banks.

Keywords: Bankruptcy, duration models, bank supervision, WAEMU.

JEL Classification Code: C24, G21.

1. Introduction

A healthy banking system is an important prerequisite for effective monetary policy, financial stability, and economic growth. Recent financial crises, especially the successive failures of major international banks, brought to the forefront the issue of banking risks, including systemic, liquidity, and insolvency risks. These events highlighted the importance of strengthening the macroprudential approach and rethinking the micro-prudential standards for the supervision of banking institutions. In the West African Economic and Monetary Union (WAEMU), the question of the banking system's stability is particularly acute insofar as commercial banks dominate the financial system of the region in the context of indirect finance.[1] The vulnerabilities specific to each bank not only contribute to costly systemic crises but also constitute "grains of sand" in the machinery of monetary policy and a risk of a negative shock on the flow of credit essential for economic growth. From this perspective, the authorities in charge of banking supervision face major challenges in ensuring the resilience of the banking industry and the survival of the component banks.

In response to the banking crisis that shook large parts of the banking system in the WAEMU zone from 1980 to 1995, banking supervision emerged as an effective solution. Major reforms were implemented during this time, particularly for financial liberalization, as defined by McKinnon (1973) and Shaw (1973), and the establishment of the Banking Commission in 1990 to supervise and control credit institutions with a particular emphasis on regulatory capital. Since then, the regulatory environment has evolved and incorporated the efficient banking supervision standards set by the Basel Committee. In 2007, the WAEMU monetary authorities decided to gradually double the minimum regulatory capital stock of the constituent banks and financial institutions and thus increase their financing capacities and solvencies. This reform also aimed to reduce the risk of bank failure. The authorities then initiated a review of the prudential rules, which were initially based on the Basel I framework, in line with the new Basel II and III frameworks that came into effect on January 01, 2018. The new system had a controlled risk profile and aimed to preserve the robustness and resilience of the banking system to meet the needs of WAEMU economies and ultimately improve the survival of banks (BCEAO, 2017).

Analyses of the role of regulatory capital in preventing bank failures are typically based on asymmetric information and regulation theories. Regulatory capital serves as a buffer that absorbs losses and reduces the probability of bank failure. It protects bank creditors and, in systems with explicit or implicit public guarantees, taxpayers. Regulatory capital also plays a preventative role by improving incentives for better risk management. When asymmetric information prevents creditors from assessing bank risk-taking, banks operating with limited liability protection tend to take excessive risks (Dagher et al., 2020). The use of capital and the consequent increase of shareholders can limit these excesses. In this regard, regulatory capital can help minimize market discipline distortions associated with deposit insurance and implicit too-big-to-fail government guarantees (Repullo, 2004; Hellman et al., 2000). Risk-taking may increase if bank equity capital is held by external investors with high-risk preferences or concentrated ownership. Indeed, passive external investors are likely to have a limited disciplinary role; therefore, the distribution of bank ownership is important to consider (Laeven and Levine, 2009).

The WAEMU banking landscape has undergone profound changes over the past decade, marked by the diversification of credit institutions' activities and the emergence of cross-border banking groups that dominate the Union's banking activities. Over the same period, it was noted that not all banks complied with capitalization ratios (BCEAO, 2017). The steady growth in the number of credit institutions in the area illustrates the hegemony of the banking groups that are

[1] Indirect finance corresponds to a situation in which economic agents (household, company, public administration) borrow capital from financial institutions to finance their investments. In contrast, direct finance involves agents with financing needs directly accessing the resources of agents with financing capacity in financial markets.

expanding in the region based on the single license principle.2 Thus, it masks bank failures and registered acquisitions and takeovers. Furthermore, the failure of all banks to comply with the minimum capital requirement and the solvency ratio indicates the systemic risk carried by banks in times of difficulty. These changes in the banking system in the region have given rise to new risks that must be identified and controlled with effective banking supervision and capital control practices to reduce bank failures in the eurozone.

The WAEMU banking system was more or less spared from the financial crisis of 2007–2008. The numerous bankruptcies recorded (liquidation, approval withdrawals, mergers, and acquisition/absorption) in the zone during a period of relative financial stability (2003-2017) raised questions about the determinants of the failure or survival of banks and the distinctive role of regulatory capital. Considering how the failure of a financial institution can trigger banking crises as well as the enormous costs that such institutions generate for the economy, it is crucial to analyze the failure and survival of WAEMU banks over the recent period (2003-2017). Doing so can help regulators identify early warning indicators of bank failures and take appropriate action. The analysis results may also be of major relevance to regulators implementing the new Basel II and III standards.

Accordingly, the general objective of this study was to investigate the failure and survival of WAEMU banks over the period from 2003 to 2017. More specifically, the study objectives were (i) to identify the main determinants of failure and survival of WAEMU banks and (ii) to isolate the role played by banking variables, particularly equity. In addition, the study attempted to analyze the effects of the increase in bank capital in 2007 as well as the role of the capital ownership structure on bank defaults in WAEMU countries. Indeed, WAEMU countries provide a conducive framework for analyzing bank failure and survival over the recent period of relative financial stability, as these countries form a monetary union in which over a hundred banks across the eight countries are subject to the same prudential regulations. In addition, these banks share a single money market, uniform legal framework, supranational supervisory authority, banking crisis resolution authority, and regional deposit guarantee scheme. Economic research has proven to be effective in analyzing resilience and bank failures. However, to the best of our knowledge, few studies have addressed specific cases related to the failure and survival of WAEMU banks to analyze the role played by regulatory capital. The present study fills this gap.

A survival analysis was conducted in this study, and banking variables were found to be the main determinants of WAEMU banks' survival during the 2003–2017 study period. Capital ratios were found to significantly reduce the probability of failure and thus play a key role in the survival of banks. The findings revealed that they can predict banking difficulties over a time horizon of one to three years. Furthermore, foreign ownership seemed to reduce the probability of default; however, this effect was not robust. The increase in bank capital from 2007 was accompanied by a faster acceleration of total bank assets than equity.

The rest of the article is structured as follows: Section 2 presents some stylized facts on the WAEMU banking system. Section 3 reviews the literature on the determinants of bank failures, with a particular focus on the role of capital. The methodological approach, estimation strategy, and data collected are presented in Section 4. The results of the econometric estimates and their implications are discussed in Section 5. Section 6 concludes the article.

2. Stylized facts

As given in Table 5, 34 banks were in default during the study period: eight in Côte d'Ivoire, seven in Togo, and six in Benin. The descriptive analysis revealed that 76% of the failing banks were private banks and 68% were small banks (Table 6). The year 2012 recorded the highest number of bank defaults due to the absorption of all branches of a cross-border banking group. In addition, six out of the nine banks were placed under temporary administration in 2017.

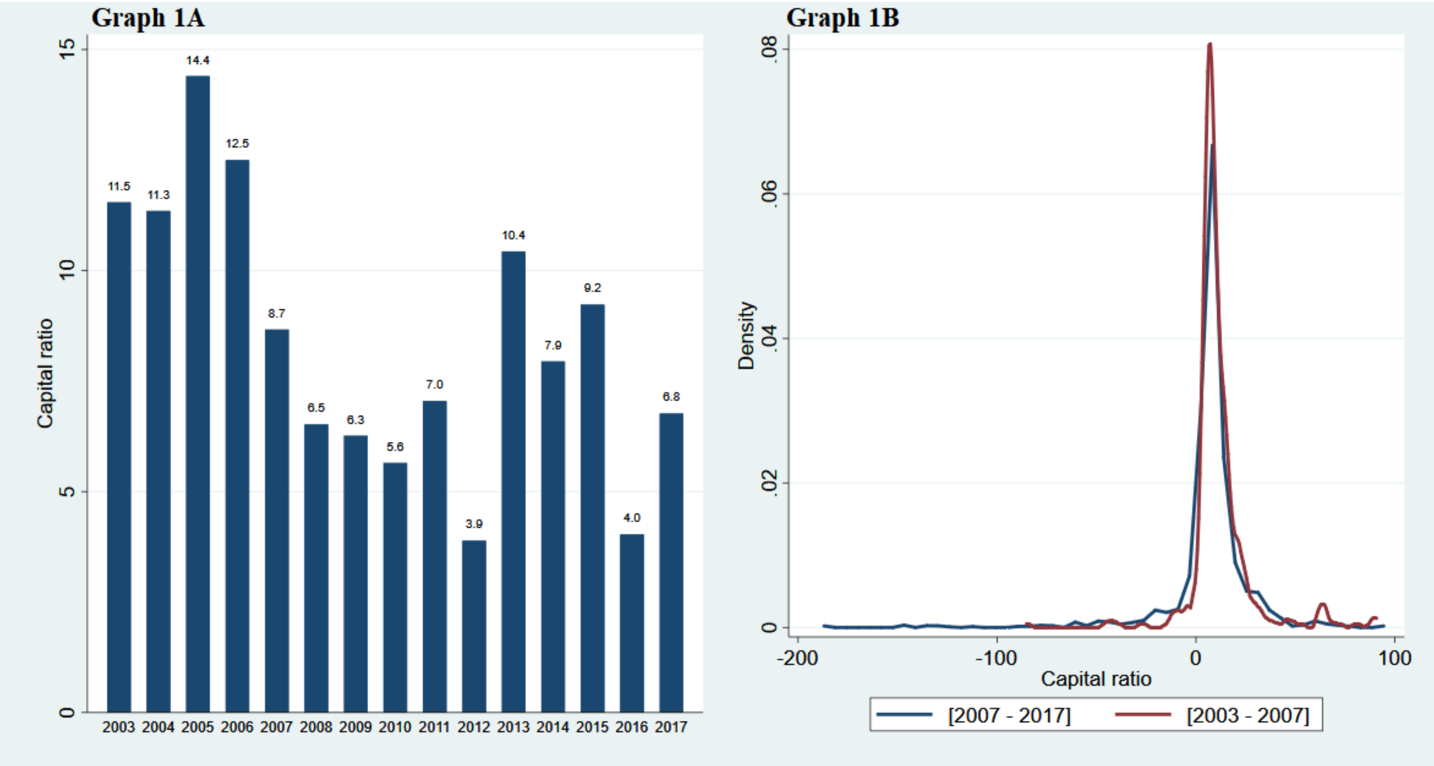
Graph 1 below depicts three phases of the evolution of WAEMU banks' capital ratios over the 2003–2017 period. The first phase, that is, from 2003 to 2007, was characterized by high ratios and a low number of bank defaults (Table 4 in the Appendix). The second phase, that is, from 2008 to 2012, was marked by a decline in the capitalization ratio. Over this period, 18 banks defaulted (Table 4). The WAEMU monetary authorities decided in 2007 to raise the minimum share capital

[2] The principle of the single agreement is the possibility offered to cross-border banks operating in a WAEMU country to extend their networks to other countries of the union by setting up new subsidiaries. These subsidiaries are generally endowed with management autonomy and considered in the banking system as a new entity in the host country.

applicable to banks to CFA 10 billion as of January 1, 2008. The implementation of this decision (capital increase) was sequenced in two phases. First, the minimum share capital of banks was raised to FCFA 5 billion as of January 1, 2008. Banks had to comply with this requirement by December 31, 2010, at the latest. July 1, 2017, marked the end of the second phase, by which banks had to increase their minimum capital from FCFA 5 billion to FCFA 10 billion. This capital increase aimed, among other things, to increase the resilience of the Union's banks. However, it was accompanied by a higher increase in risk-taking, which caused the ratio to decline significantly in the 2008–2012 period. Financial stability during this period was safeguarded by the sound economic environment and supervision by the banking commission. Notably, the banking system remained stable during this period due to the Banking Crisis Resolution Committee's monitoring of the zone, with recovery procedures initiated when a bank was in serious trouble. The third and final phase, that is, from 2013 to 2017, saw an increase in the capital ratio due to the completion of the capital adequacy doubling process.

Analyzing the distribution of banks' capital ratios (Graph 1B) over the periods before and after the increase in social capital revealed that banks had significantly deteriorated capital ratios over the 2008–2017 period compared to the 2003–2007 period.

Graph 1: Variation in the capital ratios of WAEMU banks from 2003 to 2017



Source: author

Table 7 in the appendix presents the market shares of cross-border banks and their origins. It shows that the banking market in WAEMU was essentially dominated by cross-border banks during the study period, with single-country (non-affiliated) banks holding an average market share of 14%. Cross-border banks from the WAEMU zone accounted for one-third of the market share, while Maghreb banks had the second largest market share (30.2% in 2019). European banks held a market share of around 14%, which remained relatively stable over the period from 2005 to 2019.

3. Literature review

This section begins with a review of the theoretical justifications for capital regulations and their roles in preventing bank failures. Empirical work on the determinants of bank failures is then presented.

A. Theoretical review

Financial intermediation, the main activity of banks, involves collecting deposits, usually in the short term, to finance short- and long-term loans for businesses and households. Like any company, banks must meet the return on equity required by their shareholders; in addition, they must comply with prudential standards that require them to strictly cover their risks with equity capital. A bank becomes insolvent when losses on loans granted cause the bank's funds to be absorbed. Therefore, a bank's survival for a given period is linked, in part, to the dynamics of its capitalization level. A systemic crisis occurs when a significant part of the banking system suffers substantial losses that erode capital. Thus, the literature indicates that shocks that negatively affect bank borrowers' performance are positively correlated with systemic banking crises. In addition, for any given shock, less capitalized banking systems tend to be more vulnerable (Leaven and Valencia, 2018; Demirgüç-Kunt and Detragiache, 1998).

Asymmetric information and regulation theories are generally used to analyze the role of capital in the prevention of bank failures. Indeed, capital requirements form the cornerstone of banking regulation in this context. Their use is justified in the literature for several reasons. The first is related to protecting depositors and consumers from the complete loss of their assets in the event of bank failure (Dagher et al., 2020; Freixas and Rochet, 2008). Indeed, bank failures can be very costly, particularly for the creditors of the defaulting bank (depositors, shareholders, and other banks) and, to a lesser extent, for borrowers who had previously developed a close relationship with the defaulting bank. In addition, a bank failure can spread to other banks, jeopardize the solvency of sound non-financial businesses, and temporarily damage the payment systems. As depositors do not have all the information on how banks are managed, they are not in a position to effectively monitor banks. As they are asymmetrically informed about the quality of banking assets, depositors need to be represented by regulators (Delaite, 2012).

The second justification for capital requirements is related to systemic risk. Capital standards are intended to prevent bankruptcies and the resulting systemic crises. Indeed, bank failures can be transmitted, sometimes quickly, from one bank to another because of contagious fears on the part of customers or because of important banking interdependencies. Regulators must, therefore, ensure that bankruptcies are limited to the local level so that they do not spread to the entire sector; doing so requires the presence of institutions that can maintain a protective buffer to absorb losses and thus preserve solvency (Dagher et al., 2020; Plihon et al., 2006).

Asymmetric information theories justify capital requirements based on the reduction of moral hazard problems associated with certain forms of public deposit insurance. Deposit insurance was initially intended to protect depositors from bank failures without necessarily preventing bank failures (Kose et al., 1991). In the presence of a deposit guarantee, which serves as a safety net, bankers may be more inclined to take risks. The necessary market discipline no longer works. In addition, the regulation of banks' capital is also aimed at reducing the moral hazard problems associated with the so-called too-big-to-fail principle. Indeed, the public guarantee granted to large institutions by governments can not only lead to excessive risk-taking by the institutions but also to a distortion of competition compared to smaller institutions. Reinforcing the regulatory capital constraints would at least be a partial solution to the moral hazard problem (Plantin, 2015; Mishkin, 2007). Capital standards also help to limit the problem of adverse selection. Indeed, when depositors are protected by a public safety net, they have fewer incentives to control their banks, and the banking industry becomes attractive to risk-tolerant entrepreneurs, especially in the absence of regulatory interventions. Thus, by setting a capital standard, regulators have the opportunity to mitigate the risk of adverse selection. The introduction of a rigid and imposing rule will, through regulatory pressure, prevent excessive risk-taking and force opportunistic banks to adopt prudent behaviors or exit the market (Mishkin, 2007; Morrison and White, 2005).

Despite the advantages of the prudential mechanism of regulatory capital, the theoretical literature questions its effectiveness by pointing out that it can have unexpected effects on a bank's behavior (Saadaoui, 2010). Indeed, when the capital standard is defined as independent of risk, that is, by setting a minimum capitalization threshold proportional to the volume of loans; this can lead a bank, which aims to optimize the risk/return combination of its portfolio, to increase the relative level of risky loans. Thus, capital requirements are likely to place a bank's loan portfolio below the efficiency frontier on which the optimal composition of the portfolio is based. This will not allow it to achieve the return/risk combination that maximizes its portfolio value. This explains why a bank might migrate its portfolio to a composition dominated by risky loans (Koehn and Santomero, 1980; Kim and Santomero, 1988).

Concerning equity-related financing costs, banks are tempted to undertake more risky behaviors when the level of capital is high to offset the cost of owning additional capital. However, this would increase the probability of bank failure. In this context, Blum's (1999) work shows the existence of an intertemporal effect of capital regulation. In the presence of constraining capital requirements, an additional unit of capital has more value in the following period. Thus, when the cost of issuing capital is relatively high, the only way to increase capital in the next period is to take more risks in the first period. In addition, a bank tends to face a trade-off between the loss of yield resulting from its compliance with regulatory requirements and the costs associated with legal sanctions if it violates regulatory rules. Therefore, if the contract between a regulator and a bank involves an incentive constraint, then the regulatory capital mechanism will encourage banks to exercise caution. However, in some circumstances, the factors that drive a bank toward excessive risk-taking may dominate over factors that encourage caution (Saadaoui, 2010).

Moreover, the effectiveness of capital standards in limiting banks' risk-taking behaviors is subject to the implementation of additional measures (Kose et *al.*, 2000). To this end, in addition to the minimum capital requirements related to risks (credit, operational, and market risks), the Basel II and III framework has been implemented based on the principles of prudential supervision and the related regulatory framework as well as the leading principles governing market discipline, which aim to strengthen institutions' transparency and public communications regarding risk exposure. Notwithstanding the abovementioned limits, equity capital ratios are subject to particular attention and supervision by the Basel Committee and national regulators. Thus, they occupy a prominent place in the Basel II and III prudential frameworks, which have been in force in the WAEMU zone since January 1, 2018, with a wide range of capitalization ratios to be respected by banks.

B. Empirical works

Several studies have empirically analyzed the relationship between capital requirements and bank failure, but the results do not converge on the fact that bank capitalization reduces the risk of bankruptcy. The first studies go back to Boyd and Graham (1986), who showed using a sample of American banks that an increase in the unweighted risk capital ratio reduces the risk of bank failure. Goyeau and Tarazi (1992), focusing on the difficulties faced by banks in Europe, highlighted insufficient risk coverage as a crucial factor of default. Jeitschko and Jeung (2004), using the unweighted risk capital ratio, produced the same result for well-capitalized banks. However, they did not find any significant relationship between capital and default risk for less-capitalized banks. Bichsel and Blum (2004) studied the relationship between capital and the risk of failure of European banks on the one hand and the correlation between capital and the probability of failure for a group of Swiss banks on the other, obtaining mixed results. The signs of the coefficients of the estimated models depended on the proxies used, estimation method, and sampling.

In contrast, Sheldon (1995) found that banks with high unweighted capital levels were more likely to fail, which is in accordance with the logic that capital increases are accompanied by high risk-taking behaviors. Similar results were obtained in Camara's (2010) study, which involved a sample of 3,411 banks from 17 European countries in 1992–2006. Using the z-score as a measure of default risk, the author noted that an increase in the capital ratio did not reduce default risk but, rather, contributed to it. Other studies focused on the relationship between capital requirements and banks' risk-taking. Shrives and Dahl (1992), using data from 1,800 US banks over the 1983–1987 period, found a positive relationship between changes in risk and changes in capital. This result was valid for banks with insufficient capital as well as those with capital levels above the required minimum; both tended to take greater risks with capital increases and vice versa. Using the z-score as a risk measure, Delis and Staikouras (2011) found that capital requirements, even when reinforced by supervisory activities, are not effective in reducing a bank's risks.

The 2008 financial crisis paved the way for more recent work on bank failures. Examining a sample of 560 US banks during the 2003–2009 period, Abou-El-Sood (2015) investigated whether the capital adequacy ratios required by regulators were associated with bank failures. His findings revealed that regulatory capital is not the only factor associated with banks' distress, and other significant reasons need to be considered. Market-based default probability measures and bank-specific characteristics, such as size and loan provisioning, were proven to be relatively more significant contributors to bank distress. Evzen and Ichiro (2019) analyzed bank survival by using the Cox proportional hazards model with a large dataset of 17 Central and Eastern European markets during the 2007–2015 period. Their results showed that progress in banking reforms positively affected bank survival. In fact, during the European sovereign debt crisis and afterward, banking reform progress substantially contributed to improving the probability of survival. From the same perspective, Mare (2015) focused on small Italian banks in 1994–2006 and, based on survival models, developed a model for predicting bankruptcy. He found that macroeconomic factors, both at the regional and national levels, are significantly related to the risk of failure among cooperative banks.

Some studies have used alternative approaches to survival analysis. In a recent study of East Asian commercial banks, Lin and Yang (2016) used a fixed-effects logit model for panel data regression and a split population survival time model to investigate the impact of banking fundamentals and economic conditions on bank failures and survival time; they considered 11 East Asian markets from 1999 to 2011. Their findings revealed that strong banking fundamentals, including capital adequacy, asset quality, management, profitability, and liquidity, as well as favorable economic conditions measured by gross domestic product (GDP) growth rates, inflation rates, and real interest rates, reduce the failure probability of East Asian banks. In addition, survival times were found to be primarily described using measures of economic conditions, and the banking fundamentals exerted marginal effects. Furthermore, Lee et al. (2019) aimed to develop a loan portfolio risk (LPR) variable that could measure time-varying volatility in default risk for a portfolio of bank loans. Using 538 bank failures from 2003 to 2017, they found the equity-to-LPR ratio (ELPR) to be incrementally important in predicting bank failures up to five years in advance, even after controlling for all the CAMELS variables (capital, asset quality, management, earning, liquidity, and market risk sensitivity).

Notably, Dannon and Lobez (2014) empirically analyzed the impact of banking regulation on the risk of default of 48 WAEMU banks from 2000 to 2010 using a fixed-effects panel model. The z-score was used as the default risk indicator. The results of their estimates suggested that banks with high solvency ratios, banks focusing on credit activity and large banks have a lower risk of default. Ndiaye (2014) observed a sample of 98 banks over the period from 2001 to 2011 and found similar results to those of Dannon and Lobez (2014). The main results obtained using the dynamic panel generalized moment method (GMM) showed that Basel capital reduced the risk of bank failure among banks in the total sample as well as the sub-sample of large banks during the study period. On the other hand, equity contribution was found to reduce the probability of bank failure in the total sample but to increase the risk of bankruptcy in the sub-sample of large banks. Subsequently, Kanga et al. (2020), based on a sample of 113 banks observed from 2000 to 2014, conducted a simultaneous estimation of the relationship between bank capital, bankruptcy risk and profitability, taking into account the effects of banking groups. The results revealed that bank profitability was sensitive to capital ratios, justifying the implementation of the new Basel standards in the WAEMU. In addition, foreign banks and cross-border banks were found to reduce credit risk and profitability in the banking sector.

In addition, several empirical studies have reported the causes of bank failure, which can be classified as follows: (i) endogenous factors captured by bank or microeconomic variables (in this case, a bank's failure is the result of ineffective management) or (ii) exogenous factors such as macroeconomic conditions and the structure of the banking market. The methodologies involved several approaches, such as logit and probit models and discriminant and survival analyses. Survival analysis, a statistical method primarily used in the areas of medicine, biology, and engineering (Hosmer and Lemeshow 2008), was first applied in the field of economics by Lane et al. (1986), who identified the factors related to bank failures in the United States during the 1979–1984 period. They noted that the specific characteristics of individual banks, as they appear in financial statements, have the explanatory power required to identify the early warning signals of bank distress. Gonzalez-Hermosillo et al. (1997) conducted the first case study for Mexico after the 1994 monetary crisis. Using bank variables, they found higher values of non-performing loans and unsecuritized loans to be associated with higher probabilities of default. Dabos and Escudero (2004) examined the Argentine banking system using a survival analysis and banking data. They concluded that an increase in profitability and liquidity reduces a bank's default risk. As for macroeconomic variables, Demirgüç-Kunt and Detragiache (1998) concluded that the unfavorable macroeconomic environment (low GDP growth, high inflation) in both developing and industrialized countries, by negatively affecting portfolio quality and bank profitability, increases the probability of bank crises.

Powo (2000) used a logit econometric model to analyze the determinants of bank failures in the 1980s in the WAEMU. High indebtedness of commercial banks to the WEAMU central bank, low levels of banking, undercapitalization, a decline in the credit-to-total assets ratio, and a deterioration in economic profitability were found to be associated with a high probability of bankruptcy. Angora (2006) used the same methodology to analyze the determinants of banking crises in WAEMU countries from 1975 to 1995. The results revealed that the crises were linked to unfavorable macroeconomic contexts that involved a decline in economic growth and a drastic drop in inflation, which led banks to adopt restrictive credit policies.

Economic research has proven its effectiveness in analyzing bank resilience and failures. However, to date, no study seems to have addressed the specific case of WAEMU banks' survival amidst relative stability and a sound economic environment. The present study aimed to fill this gap in the literature. Considering the study objectives, previous empirical work, and the specific features of the WAEMU banking system, it was hypothesized that equity capital, along with microeconomic and macroeconomic variables, plays a decisive role in the survival or failure of WAEMU banks; in addition, increase in bank capital and the capital ownership structure could drive the default of WAEMU banks.

4. Methodological approach

This study began with the use of statistical and econometric methods to identify the main determinants of WAEMU banks' survival. To this end, survival (or duration) models were deemed more appropriate than traditional classification techniques for this context, such as discriminant analysis and binary choice models (Logit and Probit). Indeed, unlike other methods, the parameters determining bank survival can be estimated using semi-parametric survival models that do not require the distribution of bank lifespans to be hypothesized. Second, a survival analysis recognizes the continuous nature of the probability of bank failure. Third, censored data and complete lifetime data can be easily taken into account in this approach (Shumway, 2001; Evrensel, 2008; Mare, 2015; Lin and Yang, 2016). Finally, unlike other available techniques, survival models enable the estimation of the time required for bank failure—information that can be useful for banking supervisors.

Finally, a survival analysis provides more flexibility for analyzing the determinants of bank failure than an ordinary least squares (OLS) regression analysis because the latter requires a proxy, such as the z-score, for bank failure or insolvency risk (Pappas et al., 2017). The major disadvantage of a z-score regression is that the z-score, being a proxy, does not capture information about the current default event. In addition, calculating the z-score requires the availability of data for a sufficient time for each bank, which, in the context of this study, would have eliminated several newly established banks from the sample.

A. Duration models

Survival analysis is a statistical technique that models the time it takes for an event (bankruptcy, death, finding a job, etc.) to occur, given a set of determining factors. It is based on the concepts of survival function and risk or hazard function.

Past studies have used three survival analysis approaches: non-parametric, parametric, and semi-parametric. The non-parametric approach allows the survival function to be estimated and represented when no hypothesis is to be made about the lifetime distribution. The most commonly used estimator of the survival function in this framework is the Kaplan-Meier estimator also known as the product-limit estimator. It integrates information from all available observations, both censored and uncensored, since survival at any point in time is considered a series of steps defined by the observed survival times and censored times. The Kaplan-Meier estimator of the survivor function considers survival up to a particular point in time as a series of steps defined by the observed survival and failure times. It estimates the conditional probabilities of survival at the current time point given survival up to the previous time point and multiplies them to provide an estimate of the survival function. The estimated survival function $\hat{S}(t)$ can be shown as:

$$\hat{S}(t) = \prod_{y(i)\leq t} \frac{n_i - d_i}{n_i} \quad (1)$$

Where $y(i)$ denotes the i[th] distinct ordered censored or uncensored observation, n_i and d_i indicate respectively the number of observations and the observed number of failures. The non-parametric approach does not enable us to identify the contribution of the determinants of survival.

In semi-parametric survival analysis, it is possible to estimate the contribution of various covariates to bank failure. The Cox proportional hazard model, a semi-parametric method, has been popular, because one may want to adopt a distributionfree approach to survival analysis. In this model, the hazard function is the basis of the regression model. This approach decomposes the hazard or instantaneous risk into a non-parametric baseline ($h_0(t)$), shared across all banks, and a relative risk (exp $[\beta_i X_i(t)]$), which describes how individual covariates affect risk (equation 2). The Cox proportional hazard model is specified as:

$$h[t|X_i(t)] = h_0(t)\exp[\beta_i X_i(t)] \quad (2)$$

Where β_i are unknown parameters that represent sensitivities to variables of interest, $h_0(t)$ is the baseline risk function common to all banks that is not assumed to follow any distribution in the case of Cox's model. The X_i variables multiplicatively affect the failure rate. A value $\beta_k > 0$ indicates that an increase in the variable X_k leads to an increase in the risk of default and a decrease in the bank's survival time. More precisely, an increase of one unit of the explanatory variable X_k leads to a percentage increase in the failure rate of about $100 \times [\exp(\beta_k) - 1]$. The coefficients β_k thus represent the semi-elasticity of the failure rate at a variation de X_k.

A parametric survival model is one in which survival time is assumed to follow a known distribution whose probability density function can be expressed in terms of unknown parameters. In this approach, all parts of the model are specified, both the hazard function and the effect of any covariates. Parametric survival models therefore require precise assumptions about the distribution of the lifetime T. The literature offers a plethora of distribution choices: Normal, Log-normal, Weibull, generalized Weibull, Gamma, Logistics, Log-logistics, and Gompertz etc.

In the present study, a non-parametric approach was first used to estimate and describe the survival function of WAEMU banks; the Kaplan–Meier estimator was adopted for the same, considering Evrensel (2008) and Pappas et al. (2017). To avoid errors specifying the distribution of the variable T, the Cox proportional hazards model was used to estimate the effects of the explanatory variables on bank survival (Pappas et al., 2017; Evzen and Ichiro, 2019). Parametric models were deployed to control the robustness of the semi-parametric approach estimates (Evrensel, 2008; Mare, 2015; Lin and Yang, 2016).

B. Variables

In a survival analysis, the dependent variable is the failure time, that is, the length of time an institution has been or is in operation. For active banks, this is the difference between the current year and the year of establishment. For failed banks, this is the difference between the last year for which financial statements are available and the year of establishment. Bank failure was captured by a dummy variable equal to 1 in the year the failure occurred and 0 for the years in which the bank survived. Otherwise, it was equal to 0 for the surviving banks for all sample years. A bank is considered to be in default when it undergoes liquidation or when its license has been withdrawn by the banking supervisor. Bank dissolution, liquidation, mergers and acquisition/absorption are also considered bankruptcies (Heffernan, 2005). Furthermore, banks under temporary administrations are also assumed to be failing. Specifically, they are considered banks that would have gone bankrupt without the intervention of the banking supervisor or public authorities. Provisional administration occurs when a bank has serious management difficulties with negative equity capital. Notably, banks that temporarily do not meet the capitalization standard are subject to special monitoring but are not considered to be banks under provisional administration.

The explanatory variables for the present study were chosen based on the reviewed literature, and they consisted of a combination of external or macroeconomic variables, which take into account the economic environments of banks, and internal or microbank variables, which are reflected in the financial statements of banks or are related to the structure of the banking market. The variables selected in this study are summarized in Table 1 below with their expected signs on the risk of bank failure.

The banking variables were chosen based on the CAMELS prudential rating system (capital, asset quality, management, earnings, liquidity, and sensitivity to market risk). Capital ratio, the variable of interest in this study, is measured as effective capital over total assets (EC). The objective of a capital ratio requirement is to ensure that bank shareholders maintain a minimum level of equity to meet the risks incurred in the event of bankruptcy. EC is composed of Tier 1 capital and supplementary capital. Furthermore, total assets are calculated based on unweighted risks in the absence of detailed information on the various assets in the portfolio. This variable was expected to have a negative coefficient, considering that the risk of default decreases as the capital ratio improves. Liquidity (LQD), which represents the ratio of total short-term deposits to total loans, was introduced as a variable to account for its effect on banks' activities. A negative sign was expected for the coefficient of this variable (Beck et al., 2013).

The ratio of net loans to total assets (NL) was also considered in this study. Lending is the main, albeit risky, activity of WAEMU banks. Thus, banks have some expertise in monitoring the associated risks. Assuming a rigorous selection of loan applicants, an increase in this ratio would have a positive impact on bank survival. Otherwise, an increase in this ratio would increase the risk of deterioration of the bank's portfolio. This ratio also captures the degree of diversification of a bank's revenue sources, with a high ratio indicating a low degree of diversification and vice versa. The expected sign of the coefficient for this variable is ambiguous in theory. The study also aimed to capture the effect of credit risk by introducing the bank portfolio deterioration rate (PDR), which is the ratio of gross non-performing loans to total gross loans, to the model. A positive sign was expected for the coefficient of this variable, considering that an increase in non-performing loans would reduce the longevity of a bank (Gonzalez-Hermosillo et al., 1997; Caprio and Klingebiel, 2003).

The share of general expenses in the total expenses (GE) was also taken into account in this study. A low share of general expenses can indicate good management of expenses, which contributes to increasing the bank's profitability and thus ensuring the sustainability of its activities. On the other hand, banks with high overheads may be tempted to choose riskier assets that they believe can be better monitored, which contributes to a higher risk of default. However, a high share of general expenses in the overall costs can have a positive effect on bank survival insofar as these expenses can boost banks' productivity and thus their profitability (Naceur, 2003). Moreover, in the process of maximizing profits, banks tend to incur additional operating expenses, which explains the direct variation between general bank expenses and the return on assets (Bashir, 2000). The effect of this variable on default risk was found to be theoretically uncertain.

Table 1: Main dependent variables in the study

Variable	**Definition**	**Signe**
	Internal or micro-bank variables	
Capital ratio	Effective capital as a percentage of total assets	-
Customer loans	Total customer loans as a percentage of total assets	?
General expenses	Share of general expenses in total expenses	?
ROE	Return on equity	-
Foreign	Dummy variable equal to 1 if the bank is a foreign bank	?
Public	Dummy variable equal to 1 if the bank is a state bank	?
Banking group	Dummy variable equal to 1 if the bank belongs to a group	-
New capital requirement of 2007	Dummy variable equal to 1 starting from 2007	?
Size	Logarithm of total assets	?
Liquidity	Total short-term liabilities over total loans	-
	External or macroeconomic variables	
HHI	Herfindahl-Hirschman Market Concentration Index	-
Market share	Market share of the bank	-
Real GDP per capita	Real Gross Domestic Product in logarithm	-
GDP growth	Gross Domestic Product growth rate	-
Inflation	Country inflation rate	+
Institutional quality	Average of six institutional factors	-
Portfolio quality[3]	Non-performing loans as a percentage of total loans	+

[3] Technically, this is a microbank variable. However, it was taken at the aggregate level of each country due to the unavailability of such data in the banks' published balance sheets.

Source: author

Drawing from the literature, profitability indicators were also included in the study estimations (Powo, 2000; Dabos and Escudero, 2004). According to microeconomic theory, an inefficient firm cannot remain in the market in the long run. ROE was used as a variable in this study, representing return on equity. This variable was chosen instead of ROA (return on assets) because the latter involves total assets and net income—measures that are sensitive to macroeconomic conditions—and is thus more volatile than ROE. Market share (MS) was also taken into account (Bikker and Haaf, 2000; Cihak and Hesse, 2010) in the estimations, following the idea that a bank's life expectancy decreases as its market share shrinks. The market share of a bank was calculated based on the bank's total assets. Negative coefficients were expected for these variables. Furthermore, the market structure was accounted for in the estimations through the Herfindahl–Hirschman concentration index (HHI). The HHI index presents the sum of squares of market shares of the banks in a country. Notably, Ouedraogo (2012) showed that banking concentration increases with bank profitability in the WAEMU zone. A positive sign was expected for the coefficient of this variable.

Four dummy variables (GRP, PUB, FOR, and REG2007) were introduced to control the ownership structures of the WAEMU banks. The dummy variable GRP was assigned the value of 1 for banks belonging to banking groups and 0 otherwise. The dummy variable PUB took the value of 1 if the government-owned more than 50% of a bank's capital and 0 if a bank was privately owned. The dummy variable FOR was assigned the value of 1 if more than 50% of a bank's capital was held by foreigners and 0 otherwise. Based on past empirical studies, foreign ownership, and private ownership were expected to reduce the risk of bankruptcy, and public ownership was expected to be a risk factor for bankruptcy (Iannotta et al., 2007; Nicolo and Loukoianova, 2007; Laeven and Levine, 2009; Tanimoune, 2009). In addition, the present study attempted to capture the changes induced in the regulatory environment by bank equity increases in the years from 2007-2017. To this end, the dummy variable (REG2007) was included in the model. It was assigned the value of 1 for the years starting from 2007. Furthermore, to take bank size into account, the logarithm of the bank's total assets (SIZE) was added to the model. As indicated by Beck et al. (2013) and Heid et al. (2004), the size of a bank's assets can influence funding decisions and default risks. Large banks may benefit from implicit insurance because they are perceived as "too big to fail," which increases the risk of their assets. Large banks also benefit from economies of scale that favor their profitability. The sign of the coefficient for the SIZE variable is ambiguous in theory.

Demirgüç-Kunt and Detragiache (1998) showed that economic slowdowns (low GDP growth and high inflation) negatively affect bank stability. Accordingly, these macroeconomic variables were included in the model in order to account for the state of the economy: the inflation rate (INF), GDP growth rate (GDPG) and the gross domestic product per capita (GDPC) in log. Indeed, price stability is an objective of many central banks, including the WAEMU central bank. Even though high inflation has adverse effects, the effects of moderate inflation are mixed (Cordeiro, 2002; Athanasoglou et al., 2008; Kamgna et al., 2009). Thus, the impact of the inflation rate on the risk of bank failure depends on the level of inflation. An upward trend in GDP should improve bank survival, since increased production increases business opportunities, income, and, consequently, the ability of economic agents to meet their commitments. However, during periods of growth, banks may choose riskier assets and thus be exposed to a higher risk of default. Nonetheless, this study considered the GDP growth rate and GDP per capita as contributing factors to the survival of WAEMU banks.

Institution quality was deemed a non-negligible factor that contributes to the WAEMU countries' economic environments. This variable was measured by a synthetic index (INST) that represents the average of six sub-indices: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. The scores for these sub-indices ranged from -2.5 to 2.5; the value of 2.5 was added to define the index over positive values. A negative sign was expected for this variable based on the assumption that any improvement in these institutional factors would reduce the probability of bank failure (Gbenou, 2018).

C. Data and estimation strategy

The use of survival analysis presents an unavoidable problem—data censoring. It takes many forms and occurs for different reasons. The most fundamental distinction is between left and right censoring. Consider the case of the analysis of the survival times of banks. If a bank is operational at the time of collecting data from financial statements, the duration or survival time is right censored because the observation ends before the event (bank failure) occurs. Since survival time is defined as the actual number of years a bank has been in business, left censoring was avoided in this study. However, right censoring was real for the banks considered in the present study and was explicitly taken into account using the partial maximum likelihood method in the Cox proportional hazards model.

The annual microbank data were taken from the financial statements published on the WAEMU Central Bank web page. Hand-collected data is richer than the data from Bankscope and Bankfocus (see Kanga, Murinde, and Soumare, 2020). Financial statements were obtained for all 147 commercial banks in the eight WAEMU[4] countries for the period from 2003 to 2017. Macroeconomic data were obtained from two databases. Real GDP and consumer price index (CPI) data were obtained from the World Bank's World Development Indicators (WDI) database. Variables for the quality of institutions were taken from the World Bank's Worldwide Governance Indicators (WGI) database.

5. Findings

The results from a descriptive analysis of the main explanatory variables are first presented, and then the unconditional survival function of WAEMU banks is described. Following this, the results of the economic estimates are discussed.

A. Descriptive statistics

The results of the statistical analysis are given in Tables 4–6 in Appendix A. They suggest that failing banks can be distinguished from survivors by their characteristic ratios. The defaulting banks in this study were found to have negative capital ratios, at an average of -0.86% compared to 10.53% for stable banks. This difference was statistically significant at the 1% level. This result illustrates the importance of equity capital in WAEMU banks' survival. Defaulting banks differ from surviving banks in their negative profitability, total assets, and liquidity ratio. As shown in Table 4, return on equity (ROE) was negative on average for the failing banks (-0.22%) during the study period. The market shares and balance sheet sizes of the healthy banks were relatively higher.

The unconditional survival functions of the WAEMU banks were obtained using the Kaplan–Meier estimator. A graphical comparison of the survival functions by bank category is presented in Appendix A, Graph 2. Specifically, the probabilities resulting from the econometric tests of equality of survival functions (the Wilcoxon test) are reported in this graph. Notably, it shows that the survival of private banks was better than that of public banks 10 years after the study period commenced. However, this difference was not significant ($p = 0.20$) when considering the entire study period. Belonging to a banking group did not make a difference to bank survival (Graph 2A). At a significance level of 9%, foreign banks had a higher probability of survival than domestic banks (Graph 2C). On Graph 2D, the shape of the survival curve for large banks differs fundamentally from that of smaller banks. This significant difference at 1% risk reflects the risk borne by smaller banks, which had a lower chance of survival than large banks. This result is in line with that of the descriptive analysis of the market shares of healthy and failing banks (Tables 4 and 6). Graph 3 of Appendix A presents the survival functions of WAEMU banks at a 95% confidence interval, showing that the survival rates of the WAEMU banks after five, 10, and 20 years were 99%, 86%, and 77%, respectively.

B. Estimation results

The econometric estimates of equation (2), which were based on the partial maximum likelihood method, are presented in Table 2. The variables were progressively introduced into the model to evaluate their contributions based on variable type (Columns [1] and [2]). Column [1] presents the estimates obtained when the microbank variables were retained. Following this, macroeconomic conditions were considered; Column [2] thus presents the coefficients of the model's estimates with all variables in place. Furthermore, the statistical findings of the Wald test revealed a higher overall goodness of fit when macroeconomic conditions were taken into account. The coefficients of the individual variables in the study showed the expected signs. However, not all variables were statistically significant at conventional levels.

Overall, some of the variables of interest in the study, namely capitalization ratio, foreign ownership, and the new capital requirements of 2007, were significant at least at a 5% level in all regressions (Table 2). The negative coefficients associated

[4] The West African Economic and Monetary Union (WAEMU) zone includes Benin, Burkina Faso, Cote d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo.

with the capital ratio indicate that it positively influenced the survival of WAEMU banks during the study period. In other words, the more capitalized a bank was, the more the risk of default was mitigated. Column [2] suggests that a one-unit increase in the capital ratio (EC) led to a 1.63% ($100 \times [\exp(-0.0163) - 1]$) reduction in the probability of default. This result corroborates the descriptive analyses of the capital ratios of surviving banks and failing banks (Table 4 in the Appendix), which are in line with Powo's (2007) and Dannon and Lobez's (2014) empirical results indicating that regulatory capital ratios contributed to lowering WAEMU banks' default risks during the 1980–1995 and 2000–2010 periods, respectively.

Market share and bank size foster bank survival. Commercial banks that capture substantial market shares have higher probabilities of survival. As given in Column [2], a one-point increase in market share increased the probability of survival by 14.37%. The coefficient of the market concentration index was found to be positive but not significant. These results suggest that banks in countries with relatively competitive banking sectors have a lower chance of survival, as competition tends to reduce market shares.

Portfolio quality was found to be a significant determinant of bank survival. The coefficient on this variable was significantly positive in all regressions at the 1% level. This result suggests that the life expectancy of a bank depends on its ability to screen loan applications using adequate tools. Indeed, in the absence of real guarantees, the defaulted loan downgrades induced the accumulation of loan loss provisions that eroded bank capital during the study period. The coefficient (0.1082) indicates that a one-point increase in this variable increased the probability of bankruptcy by an average of around 10.25%. The ratio of net lending to total assets (NL) was found to be significant at 1%, with a negative sign in all estimates. This result aligns with the previously stated expectations and with the findings of Powo (2000) and Dannon and Lobez (2014). The higher this ratio is, the more the risk of default is limited.

Furthermore, ownership structure was found to influence the survival of the WAEMU banks. The coefficient of the dummy FOR variable was negative and significant at 1% in all regressions. This indicates that foreign banks survived longer than domestic banks. In addition, the significantly positive coefficient of the dummy variable capturing the capital increase of banks in 2007 suggests that an increase in social capital negatively affected bank survival. This result can be explained by the pre-reform takeovers of fragile banks that found it difficult to raise additional capital due to their profitability levels and the deteriorated quality of their loan portfolios. Moreover, the capital increase may have been accompanied by excessive risk-taking by banks, having a long-term negative impact on their performance and thus their survival. Graphs 1A and 1B corroborate this analysis.

Table 2: Results of the Cox semi-parametric survival model estimates

Variables	**[1]**	**[2]**
Capital ratio (EC)	-0.0158***	-0.0165***
	(0.004)	(0.004)
Size of the bank	-0.6520***	-0.3245
	(0.213)	(0.237)
Customer loans (NL)	-0.0243**	-0.0318***
	(0.010)	(0.011)
Return on equity (ROE)	-0.1189	-0.1310
	(0.236)	(0.216)
Share of general expenses (GE)	-0.0152	-0.0247
	(0.014)	(0.015)
Market share (MS)	-0.0383	-0.1552***
	(0.031)	(0.059)
Liquidity (LQD)	-0.3120	-0.1522
	(0.446)	(0.502)
Banking group dummy (GRP)	-0.6389	-0.5820
	(0.459)	(0.482)
Public bank dummy (PUB)	-0.5099	-0.7770*
	(0.451)	(0.416)
Foreign bank dummy (FOR)	-0.8946**	-1.0621**
	(0.439)	(0.429)
Capital requirement of 2007	4.1272***	4.1270***
	(0.938)	(0.920)
Portfolio quality (PDR)		0.1082**
		(0.048)
Log of GDP per capita		-0.2734
		(0.360)
GDP growth rate		0.0684
		(0.088)
Inflation rate		0.0526
		(0.093)
Institutional quality		-4.1924
		(2.894)
HHI Market Concentration		0.0005
		(0.001)
Wald Chi2	156.69	172.04
Prob > Chi2	0.0000	0.0000
Observations	1,384	1,384

Source: author's estimate using Stata software, robust standard errors in parentheses. *** p<0,01, ** p<0,05, * p<0,1.

Concerning the effects of macroeconomic variables, the corresponding coefficients were found to be non-significant. Indeed, the effects of institution quality and GDP per capita were negative but not significant. Similarly, inflation would have been detrimental to banking activity during the study period but only marginally. Furthermore, the GDP growth was positive but non-significant. These results can be explained by the macroeconomic frameworks of the zone's countries, which were characterized by sustained GDP growth and controlled inflation. However, the results require further investigation with other analytical approaches.

C. Robustness checks

The present study's results were subjected to three types of robustness tests before any implications were drawn. First, Equation (2) was re-estimated by lagging all the exogenous variables by one, two, and three periods to identify the variables that could predict the probability of a bank's failure or survival over a time frame of up to three years. The results are given in Table 3 below.

Table 3: Results of the Cox semi-parametric survival model estimates

Variables	**[1]** All variables lagged by one period	**[2]** All variables lagged by two period	**[3]** All variables lagged by three period
Capital ratio (EC)	-0.0277***	-0.0289***	-0.0228**
	(0.008)	(0.008)	(0.011)
Size of the bank	-1.0360***	-0.8459***	-1.0270***
	(0.230)	(0.198)	(0.272)
Portfolio quality (PDR)	-10.6285**	-0.9862	-0.7917
	(4.471)	(4.405)	(4.407)
Customer loans (NL)	-0.0216	-0.0121	0.0111
	(0.014)	(0.014)	(0.014)
Return on equity (ROE)	-0.0376	-0.3125*	-0.6308***
	(0.220)	(0.169)	(0.220)
Share of general expenses (GE)	-0.0136	-0.0148	0.0163
	(0.011)	(0.016)	(0.014)
Market share (MS)	-0.0166	-0.0372	0.0246
	(0.037)	(0.046)	(0.038)
Liquidity (LQD)	-0.9653**	-0.7823**	-1.7757***
	(0.407)	(0.324)	(0.687)
Banking group dummy (GRP)	-0.9128*	-1.0618**	-0.7801*
	(0.466)	(0.522)	(0.450)
Public bank dummy (PUB)	-0.6927	-0.7469	-0.9558
	(0.720)	(0.675)	(0.631)
Foreign bank dummy (FOR)	-0.7377	-0.7237	-1.1771**
	(0.472)	(0.500)	(0.474)
Capital requirement of 2007	1.5091	1.7069*	1.5482*
	(1.038)	(1.032)	(0.888)
Log of GDP per capita	-0.1294	0.0254	-0.0647
	(0.452)	(0.438)	(0.466)
GDP growth rate	-0.0433	0.2007*	0.0308
	(0.102)	(0.118)	(0.098)
Inflation rate	-0.0939	0.0675	-0.1983**
	(0.075)	(0.097)	(0.090)
Institutional quality	-1.5303	-0.5502	1.9996
	(3.519)	(3.105)	(3.192)
HHI Market Concentration	-0.0004	0.0003	-0.0004
	(0.001)	(0.001)	(0.001)
Wald Chi2	126.38	136.74	199.69
Prob > Chi2	0.0000	0.0000	0.0000

Observations	1,245	1,118	991

Source: author's estimate using Stata software, robust standard errors in parentheses. *** p<0,01, ** p<0,05, * p<0,1.

The results show, with statistical significance ranging from 5% to 1%, that capital ratio, liquidity, and bank size explain the probability of survival or default for a maximum of three years ahead of time. The ROE coefficient was also found to be significant for the two- and three-year time frames, and the portfolio deterioration ratio was determined to have the capacity to predict bankruptcies one year in advance. Graph 1B shows the extreme capital ratio values among the banks considered. The effects of these outliers were eliminated by winsorizing this variable to 1% and 99% (Graph 4, Appendix A). The results of the new estimates (Appendix B, Table 8, column [1]) were qualitatively similar to the basic results.

Second, the robustness of the results of the survival analysis approach was tested. Since the estimates obtained were based on the Cox proportional hazards model, following a semi-parametric approach, the following question arose: Are the conclusions of the econometric analysis valid when a parametric approach is used? To answer this, the estimates were replicated under the assumption that a bank's of banks follows a specific distribution (Evrensel, 2008; Mare, 2015 and Lin and Yang, 2016). Subsequently, three distributions were tested, namely the exponential, Weibull, and Gompertz distributions. The results of the estimates obtained using the parametric approach are presented in Appendix B, Table 8. They are in line with those obtained with the Cox model and indicate that capital ratio and market share positively influenced bank survival during the study period, while loan portfolio deteriorations increased the banks' risk of default. Overall, the various sensitivity tests indicated that the main results were unaffected by the choice of analytical approach.

Finally, a binary choice model was used as an alternative analysis approach to survival analysis. Accordingly, a panel logit model was used to check the robustness of the results, drawing from Powo (2000), Angora (2006) and Lin and Yang (2016). The results are reported in Table 8, column [5]. These results are qualitatively in line with those obtained from the survival analysis.

D. Discussion and implication of results

Since 2018, the monetary and banking authorities of WAEMU countries have been engaged in a convergence toward the Basel II and III standards. Equity capital plays a central role in this process. These new standards define a set of capital ratios based on the quality of the components of capital (Tier 1, Common Equity Tier 1, and Equity Capital) and the various buffers (conservation, countercyclical, systemic, and leverage ratio). Concerning the conduct of banking supervision policy in this new context, the present study's results indicate the crucial role played by capital in WAEMU banks' survival and the need for their supervision by regulators. Considering that capital ratios predict the probability of survival over a timeframe of one to three years, they are key indicators for the supervision of individual banks, implementation of an early warning system, and deployment of stress tests.

The new capital standards enacted in 2018 required a gradual evolution of the capital ratio levels by 2022. This gradual increase could provide additional leverage for the soundness of the banking system. The implementation of these new capital standards should ultimately have a positive effect on the survival of banks. However, it is important to note that capital regulations are not sufficient to safeguard the survival of banks. The risk-taking behaviors of profit-seeking banks are crucial in determining their failure or survival. Furthermore, the results showed that the rate of portfolio deterioration plays a major role in the survival of banks. Defaulting banks are those that accumulate non-performing loans. In terms of regulatory policies for banking activities, this result implies that particular attention must be paid to portfolio quality in the context of individual bank supervision. To this end, the prudential framework that has been in force since 2018 could help identify a portfolio deterioration ratio with a maximum level to be respected by banks. Specific weighting could thus be applied to the assets of banks with deteriorated loan portfolios. The aim of this instruction was to encourage banks to rigorously monitor the quality of their portfolios to minimize default risks. In addition, the regulator could encourage the use of modern risk selection tools, such as information-sharing systems, to facilitate the sharing of and access to information based on the backgrounds of loan applicants. This measure facilitates the selection of loan applications by banks and should ultimately reduce their portfolio deterioration rates. Recent studies (Baah et al., 2016, 2017) have shown that the establishment of information-sharing systems has contributed to significantly reducing credit risks in 15 African countries.

Moreover, based on the results of the descriptive and econometric analyses in the present study, the increase in bank capital from 2007 did not have any positive impact on the capitalization or survival of banks. The capital increase would have favored the absorption of fragile banks and greater risk-taking behaviors, as evidenced by the faster evolution of assets than equity after 2007. These results suggest that greater importance should be given to the other pillars of Basel II and III for regulating the banks in the WAEMU zone, particularly bank governance, and risk-taking. Notably, the baseline estimates indicated that foreign and public ownership would be favorable for the survival of banks in the WAEMU zone. However, these results were not significant after the robustness tests.

Finally, the results also revealed the significance of market share. On the one hand, these results suggest that WAEMU regulators need to pay more attention to small or newly established banks with limited market shares. On the other hand, they imply that the process of issuing new licenses should take into account the level of competition in the banking sector, as newly established banks have limited market shares and are, therefore, vulnerable. Since the WAEMU region consists of developing countries, an increase in the number of banks would enable the deepening of the financial system and boost the funding of economies. However, regulators will have to balance the funding of economies and the stability of the banking system, since a relatively high number of new banks would imply high probabilities of default in light of their low market shares.

6. Conclusion

The WAEMU monetary authorities have initiated the revision of prudential rules applicable to banks in the zone to bring them into line with the new Basel II and III standards, which came into force on January 1, 2018. The aim is to promote the resilience of the sector, encourage banks to return to their fundamentals, strengthen good governance of banking institutions, and limit the systemic risk borne by fragile banks and banking groups. In this context, the new minimum capital requirements are a cornerstone of the architecture of the new framework. Although WAEMU banks were more or less spared by the 2007 financial crisis, empirical studies agree that the major banking crisis experienced by this zone in the 1980s is intrinsically linked to the poor management of banks and the deterioration of the macroeconomic framework. At this early stage of convergence towards international standards, this paper has questioned the role of capital in the survival of banks in the region. What role does regulatory capital play in the survival of WAEMU banks? Do capital ownership and the recent social bank's capital increase matter? These questions are important not only to avoid the reoccurrence of banking crises in WAEMU but also given the substantial costs of these crises in a context where the banking system of the zone is the major provider of financing to the economies.

Based on bank failures observed in the region from 2003 to 2017, the paper attempted to provide answers to these questions using non-parametric, semi-parametric, and parametric duration models estimated by the partial maximum likelihood method. The study showed that banking variables are the main determinants of the survival of WAEMU banks over the study period marked by sustained growth and low inflation. Capital plays a key role in the survival of banks by significantly reducing the probability of failure. Estimates revealed that they can predict banking difficulties over a time horizon ranging from one to three years. Market share and the rate of portfolio deterioration are the other variables revealed to be significant in explaining the survival of WAEMU banks. The increase in bank capital starting in 2007 would have favored the absorption of fragile banks and encouraged risk-taking.

The robustness of the results was tested using alternative approaches. The results highlight the need for an effective capital adequacy framework for banks. The results argue for better management of banking institutions concerning capital management and risk-taking. In addition, the estimates showed that low market share is an indicator of banks' vulnerability. In this respect, the study recommends special supervision of small and newly established banks with small market shares. The study recommends that these parameters be taken into account in the issuance of new licenses to avoid a highly competitive banking sector that is not conducive to the stability and survival of banks.

Bibliographical reference

Abou-El-Sood, H. (2015), 'Are regulatory capital adequacy ratios good indicators of bank failure? Evidence from US banks', *International Review of Financial Analysis*, vol. 48, issue C, pp. 292-302.

Angora A. (2006), 'Les déterminants des crises bancaires dans les pays de l'Union Monétaire Ouest Africaine (UMOA) : une approche empirique', Laboratoire d'Analyse et de Prospective Économiques (LAPE), Université de Limoges (France).

Athanasoglou P., Brissimis S., Delis M. (2008), 'Bank-specific, industry specific and macroeconomic determinants of bank profitability', *Journal of International Financial Markets, Institutions and Money*, vol. 18 (2), pp. 121-136.

Baah A. K, Agboyor E. K., Fiador V. O., Osei K. A. (2016), 'Does Information Sharing Promote or Detract from Bank Returns: Evidence from Ghana', *African Development Review*, vol. 28 (3), pp. 332-343.

Baah A. K, Agboyor E. K., Ansa-Adu K., Gyeke-Dako A. (2017), 'Bank credit risk and credit information sharing in Africa: Does credit information sharing institutions and context matter?', *Research in International Business and Finance*, vol. 42(C), pp. 1123-1136.

Bashir A. (2000), 'Assessing the Performance of Islamic Banks: Some Evidence from the Middle East 1993-1998', Papier présenté à la 8ième Conférence de l'Economic Research Forum (ERF), Amman, Jordanie, novembre.

BCEAO (Banque centrale des États de l'Afrique de l'Ouest), divers rapports et instructions de la Commission bancaire, www.bceao.int/.

BCEAO (2017), 'Dispositif prudentiel applicable aux établissements de crédit et aux compagnies financières de l'Union Monétaire Ouest Africaine'.

Beck T., De Jonghe O., Schepens G. (2013), 'Bank Competition and Stability: Cross-Country Heterogeneity', *Journal of Financial Intermediation*, vol. 22 (2), pp. 218-244.

Ben Naceur S. (2003), 'The determinants of the Tunisian banking industry profitability: panel evidence', Conférence Annuelle ERF.

Bichsel R., Blum J. (2004), 'The Relationship between Risk and Capital in Swiss Commercial Banks: a Panel Study', *Applied Financial Economics*, vol. 14, pp. 591-597.

Bikker J. A., Haaf K. (2002), 'Competition, Concentration and Their Relationship: An Empirical Analysis of the Banking Industry', *Journal of Banking and Finance*, vol. 26 (11), pp. 2191-2214.

Blum J. M. (1999), 'Do capital adequacy requirements reduce risks in banking?' *Journal of Banking and Finance*, vol. 23 (5), pp. 755-771.

Boyd J. H., Graham S. L. (1986), 'Risk, Regulation and Holding Company Expansion', Federal Reserve Bank of Minneapolis, *Quarterly Review*, issue Spr, pp. 2-17.

Camara B. (2010), 'Réglementation prudentielle et risque bancaire : incidence de la structure et du niveau du capital réglementaire', thèse soutenue publiquement le 7 décembre 2010 pour obtenir le grade de docteur de l'université de Limoges en sciences économiques, 221 p.

Caprio G., Klingebiel D. (2003), 'Episodes of systemic borderline crises', In: Klingebiel, D., Ed., The World Bank, Washington DC.

Cihak M., Hesse H. (2010), 'Islamic Banks and Financial Stability: An Empirical Analysis', *Journal of Financial Services Research*, 38 2-3, pp. 95-113.

Cordeiro J. (2002), 'Different Monetary Systems: Costs and Benefits to Whom?' Universidad Central de Venezuela (UCV), Caracas (Venezuela).

Cox D. R. (1972), 'Regression Models and Life-Tables', *Journal of the Royal Statistical Society Series B- (Methodological)*, vol. 34 (2), pp. 187-220.

Dabos M., Sosa Escudero W. (2004), 'Explaining and Predicting Bank Failure Using Duration Models: The Case of Argentina after the Mexican Crisis', *Revista de Analisis Economico*, vol. 19 (1), pp. 31-49.

Dagher J., Ariccia G, Laeven L, Ratnovsky L and Tong H. (2020), 'Bank capital: a seawall Approach', *International Journal of Central Banking*, vol. 16 (2), pp. 249-291.

Dannon P., Lobez F. (2014), 'La régulation bancaire dans l'Union économique et monétaire ouest-africaine est-elle efficace ?', *Revue d'Economie Financière*, 2014/4(N°116).

Delaite, M-F. (2012), 'Les fonds propres bancaires au cœur de la crise financière', *Mondes en développement* (4), N°160, pp. 117-132.

Delis M. D., Staikouras P. K. (2011), 'Supervisory Effectiveness and Bank Risk', *Review of Finance, vol. 15,* pp. 511-543.

Demirgüç-Knut A., Detragiache E. (1998), 'The determinants of banking crises in developing and developed countries', *IMF Staff Papers*, 45(1), pp. 81-109.

Evrensel, A. Y. (2008), 'Banking crisis and financial structure: A survival-time analysis', *International Review of Economics & Finance*, 17 (4), pp. 589-602.

Evzen, K. and Ichiro, I. (2019), 'Bank survival in Central and Eastern Europe', IOS Working Papers, No. 382, Leibniz-Institut für Ost- und Südosteuropaforschung (IOS), Regensburg.

Freixas, X. & Rochet, J.C. (2008), 'Microeconomics of banking', Second Edition, Cambridge, MA, MIT Press.

Gbenou, K. D. A. (2018), 'Modélisation de la prévision du stress financier du système bancaire des pays de l'UEMOA: Evidence empirique du rôle des facteurs institutionnels', *African Development Review*, 30(3), pp. 264-277.

Gonzalez-Hermosillo B., Pazarbasioglu C., Billings R. (1997), 'Determinants of Banking System Fragility: A Case Study of Mexico', *IMF Fund Staff Papers*, 44 (3), pp. 295-314.

Goyeau D., Tarazi A. (1992), 'Évaluation du risque de défaillance bancaire en Europe', *Revue d'économie politique*, N° 102, pp. 249-280.

Heffernan, S. A. (2005), 'Modern banking', Chichester, West Sussex, England; Hoboken, NJ: John Wiley & Sons.

Heid F., Porath D., Stolz S. (2004), 'Does Capital Regulation Matter for Bank Behavior? Evidence for German Savings Banks' Discussion Paper Series 2: Banking and Financial Studies 2004, 03, Deutsche Bundesbank.

Hellmann, T. F., Murdock K. C., and Stiglitz J. E. (2000), 'Liberalization, Moral Hazard in Banking, and Prudential Regulation: Are Capital Requirements Enough', *American Economic Review,* 90 (1): 147-165.

Hosmer D. W., Lemeshow S. (1999), 'Applied Survival Analysis: Regression Modelling of Time to Event Data', Canada: John Wiley & Sons, Ltd.

Iannotta G., Nocera G., Sironi A. (2007), 'Ownership Structure, Risk and Performance in the European Banking Industry', *Journal of Banking and Finance*, vol. 31, pp. 2127-2149.

Jeitschko T. D., Jeung S. D. (2004), 'The Effect of Capitalization on Banks' Risk Under Regulation and Managerial Moral Hazard: A Theoretical and Empirical Investigation'. Available at SSRN: https://ssrn.com/abstract=629414.

Kamgna S. Y, Tinang Nzesseu J., Tsombou Kinfak C. (2009), 'Macro prudential Indicators for CEMAC Banking System', *MPRA Working Paper*, N°16555.

Kanga D. Murinde V. and Soumaré, I. (2020), 'Capital, risk and profitability of WAEMU banks: does bank ownership matter?', *Journal of Banking and Finance*, vol. 114, 105814.

Kaplan E. L., Meier P. (1958), 'Nonparametric Estimation from Incomplete Observations', *Journal of the American Statistical Association*, 53 (282), pp. 457-481.

Kim, D. & Santomero, A. M. (1988), 'Risk in banking and capital regulation', *Journal of Finance*, vol. 43, pp. 1219–1233.

Koehn M., Santomero A. M. (1980), 'Regulation of bank capital and portfolio risk', Journal of Finance, vol. 35, pp. 1235–1244.

Kose J., John T. A. and Senbet L.W. (1991), 'Risk-shifting incentives of depository institutions: A new perspective on federal deposit insurance reform', *Journal of Banking and Finance*, vol. 15, pp. 895-915.

Kose J., Saunders A. and Senbet L.W. (2000), 'A theory of Bank Regulation and Management Compensation', *The Review of Financial Studies*, vol. 13 (1), pp. 95-125.

Laeven L., Levine R. (2009), 'Bank Governance, Regulation and Risk Taking', *Journal of Financial Economics*, vol. 93, pp. 259-275.

Laeven, L., and Valencia F. (2018), 'Systemic Banking Crises Revisited', IMF Working Paper No. 18/206.

Lane W. R., Looney S. W., Wansley J. W. (1986), 'An Application of the Cox Proportional Hazards Model to Bank Failure', *Journal of Banking and Finance*, vol. 10(4), pp. 511-31.

Lapetit L., Nys E., Rous P., Tarazi A. (2008), 'Bank Income Structure and Risk: an empirical Analysis of European Banks', *Journal of Banking and Finance*, vol. 32 (8) pp. 1452-1467.

Lee C. M. C. Wang, Y. and Zhong, Q. (2019), 'Loan Portfolio Risk and Capital Adequacy: A New Approach to Evaluating the Riskiness of Banks', Stanford University, Working Paper No 3818.

Lin C. C. and Yang S. L. (2016), 'Bank fundamentals, economic conditions, and bank failures in East Asian countries', *Economic Modelling*, vol. 52, issue PB, 960-966.

Mare D.S. (2015), 'Contribution of macroeconomic factors to the prediction of small bank failures', *Journal of International Financial Markets, Institutions and Money*, Vol 39, pp. 25-39.

McKinnon R.I. (1973), 'Money and capital in economic development', the Brooking Institution, Washington.

Mishkin F. (2007), 'Monnaie, banque et marches financiers', nouveaux horizons, 8ième édition.

Morrison A. D., White L. (2005), ‘Crises and Capital Requirements in Banking’, *American Economic Review*, vol. 95 (5), pp. 1548-1572.

Ndiaye M. (2014), ‘Prévention du risque de défaillance des banques de l’UEMOA : impact des fonds propres sur le risque de défaillance’, Papier présenté au colloque l’AETA, novembre 2014.

Nicolo G. D., Loukoianova E. (2007), ‘Bank Ownership, Market Sructure and Risk’, *IMF Working Paper*, N° WP/07/215.

Repullo, R. (2004), ‘Capital Requirements, Market Power, and Risk-taking in Banking’, *Journal of Financial Intermediation,* 13 (2): pp. 156-182.

Saadaoui Z. (2010), ‘Capitalisation et prise de risque des banques dans les pays émergents’, *Brussels Economic Review*, vol. 53 (3/4).

Shaw E.S. (1973), ‘Financial deepening in economic development’, New-York 1973, Oxford University Press.

Sheldon G. (1995), ‘A limit-risk capital adequacy rule: An alternative approach to capital adequacy regulation for banks with an empirical application to Switzerland’, *Swiss Journal of Economics and Statistics*, vol. 131 (IV), pp. 773-805.

Shrive R. E., Dahl D (1992), ‘The Relationship between Risk and Capital in Commercial Banks’, *Journal of Banking and Finance*, vol. 16, pp. 439-457.

Shumway T (2001), ‘Forecasting Bankruptcy More Accurately: A Simple Hazard Model’, *The Journal of Business*, 74(1), pp. 101-124.

Tanimoune N. A. (2009), ‘Performances bancaires dans l’Union Economique et Monétaire Ouest Africaine : les effets « taille » et « structure actionnariale » sont-ils pertinents ?’ *Revue Economique et Monétaire de la BCEAO*, N° 5, juin 2009.

Ouedraogo S. (2012), ‘Concentration bancaire, profitabilité et développement financier bancaire dans l’UEMOA’, *Revue Economique et Monétaire de la BCEAO*, N° 12, décembre 2012.

Plantin, G. (2015), ‘Shadow Banking and Bank Capital Regulation’, *Review of Financial Studies,* 28 (1): 146-175.

Plihon D., Couppey-Soubeyran J., Saidane D. (2006), ‘Les banques acteurs de la globalisation financière’, Paris, La documentation Française.

Powo F. (2000), ‘Les déterminants des faillites bancaires dans les pays en voies de développement: le cas de l’Union Économique et Monétaire Ouest Africaine (UEMOA)’, Université de Montréal.

APPENDIX A

Table 4: number of bank failures in the WAEMU over the period 2003-2017 by country

	2003	2007	2008	2009	2010	2011	2012	2013	2015	2016	2017	TOTAL
BEN	0	0	0	0	2	1	1	0	0	1	1	6
BFA	0	0	1	0	1	0	1	0	0	0	0	3
CIV	0	1	0	0	0	0	2	1	0	1	3	8
GNB	0	0	0	0	0	0	1	0	0	0	1	2
MLI	0	0	0	0	0	0	1	0	1	0	0	2
NER	0	0	1	1	0	0	1	0	0	0	0	3
SEN	0	0	0	0	0	0	2	0	0	1	0	3
TGO	1	0	0	0	0	1	1	0	0	0	4	7
TOTAL	1	1	2	1	3	2	10	1	1	3	9	34

Source: author's calculations from the financial statements of banks and financial institutions published by WAEMU Central Bank. BEN= Benin, BFA= Burkina Faso, CIV= Cote d'Ivoire, GNB= Guinea-Bissau, MLI= Mali, NER= Niger, SEN= Senegal and TGO = Togo.

Table 5: number of bank failures in the WAEMU over the period 2003-2017 by type of bank

	2003	2007	2008	2009	2010	2011	2012	2013	2015	2016	2017	TOTAL
Group	0	0	0	1	1	2	9	0	1	1	2	17
NonGrp	1	1	2	0	2	0	1	1	0	2	7	17
Public	0	0	0	1	0	0	0	1	1	1	4	8
Private	1	1	2	0	3	2	10	0	0	2	5	26
Foreign	0	0	0	0	2	1	9	0	0	1	3	16
National	1	1	2	1	1	1	1	1	1	2	6	18
Small	1	1	1	1	1	1	10	1	0	3	3	23
Large	0	0	1	0	2	1	0	0	1	0	6	11
TOTAL	1	1	2	1	3	2	10	1	1	3	9	34

Source: author's calculations from the financial statements of banks and financial institutions published by WAEMU Central Bank. Small banks are those with total assets of less than CFA Franc 50 billion. Non Grp = non-group bank.

Table 6: descriptive statistics of bank variable

Variables	Mean		
	Healthy Banks	Defaulting banks	Difference
Effective capital as a percentage of total assets (EC)	10.5324	-0.8561	11.3886***
Size of the bank (log of total assets)	11.5762	10.2920	1.2841***
Liquidity (Total short-term liabilities over total loans)	0.5790	0.4663	0.1124***
Total customer loans as a percentage of total assets	53.8088	54.3204	-0.5115

Return on equity (ROE)	0.2731	-0.2170	0.4901***
Share of general expenses in total expenses	40.3706	43.7161	-3.3454***
Market share of the bank calculated with total assets	8.4682	7.4570	1.0111
Number of banks	113	34	

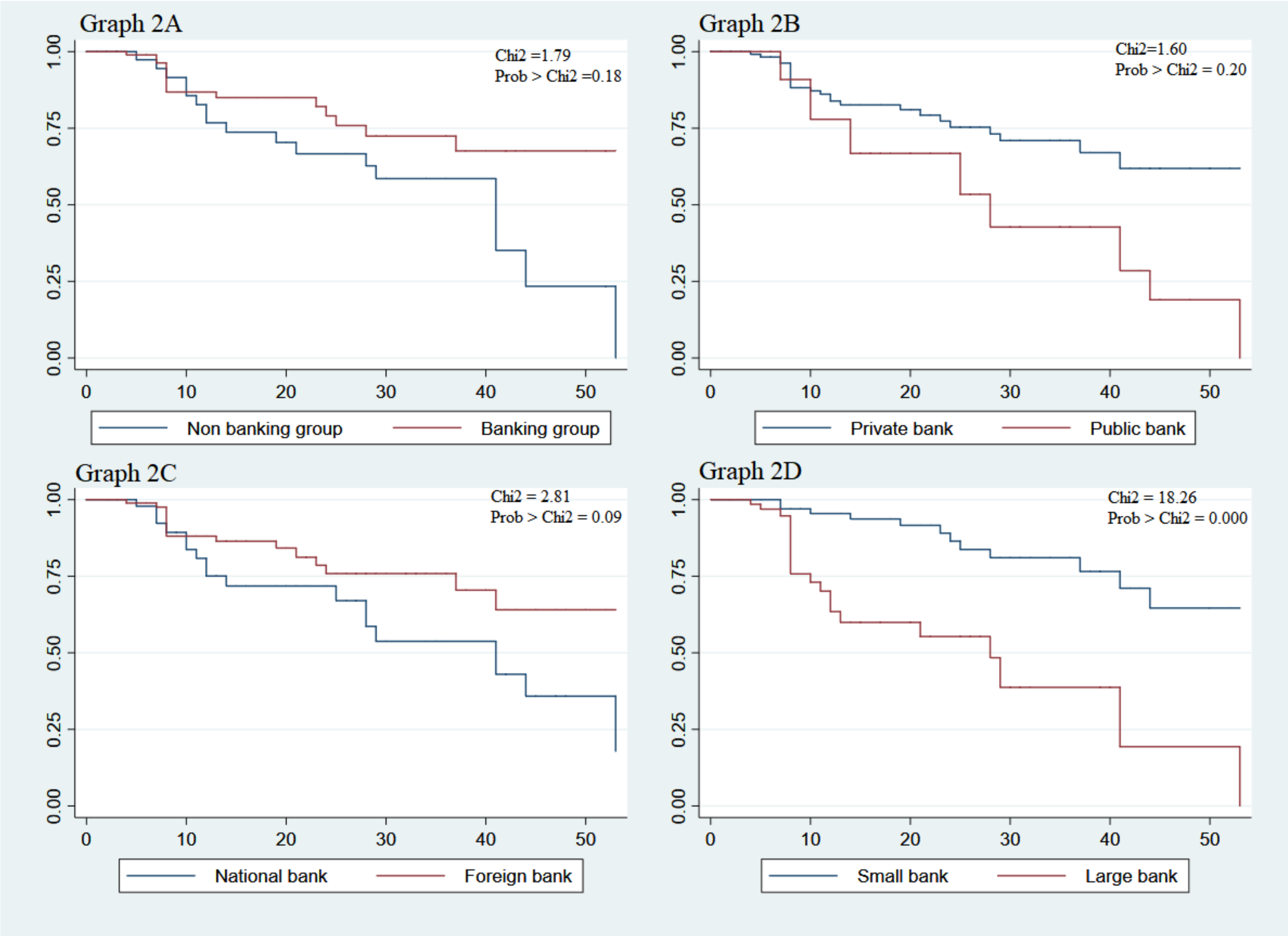
Source: author's calculations from the financial statements of banks and financial institutions published by WAEMU Central Bank. *** p<0,01, ** p<0,05, * p<0,1. Descriptive statistics were calculated over the entire period of operation for each type of bank.

Table 7: Market share of cross-border banks by geographical zone of origin

Geographical zone	**2015**	**2016**	**2017**	**2018**	**2019**
West African Economic and Monetary Union	28.3	26.7	33.3	33.2	33.8
Maghreb zone	36.6	33.3	32.4	30.4	30.2
European union	14.6	14.1	14.4	14.9	14.6
West African Monetary Zone	6.6	6.7	3.0	3.8	3.1
Central African States Economic and Monetary Community	1.2	1.6	1.7	2.0	1.8
Other zones	2.4	2.3	2.3	2.4	2.4
Non-affiliated	13.4	15.4	12.9	13.2	14.1

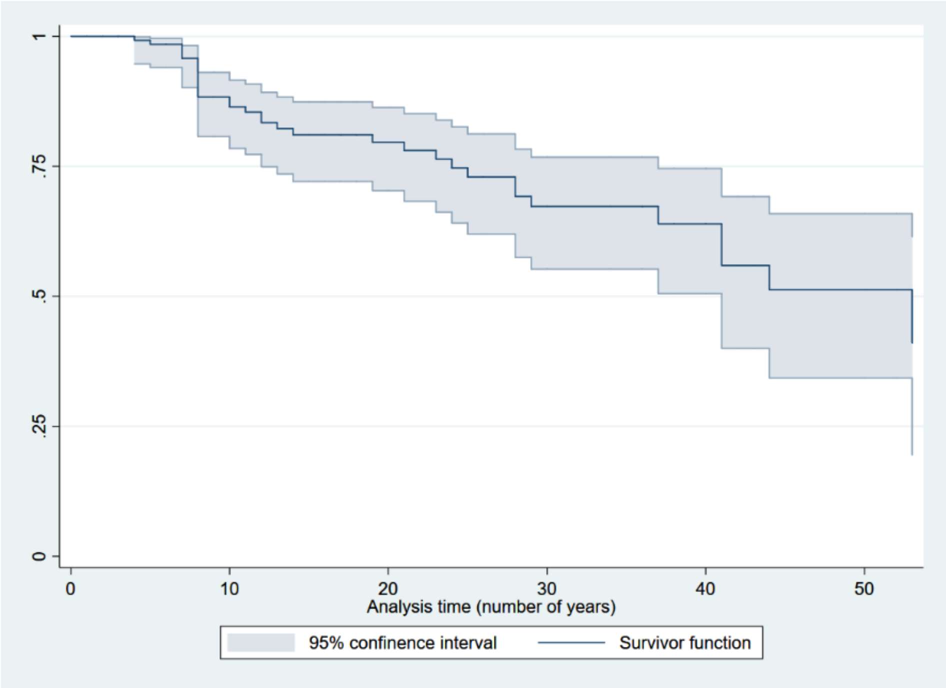
Source: Annual reports of the WAEMU banking commission.

Graph 2: Comparison of survival functions (Kaplan-Meier estimate) by type of bank



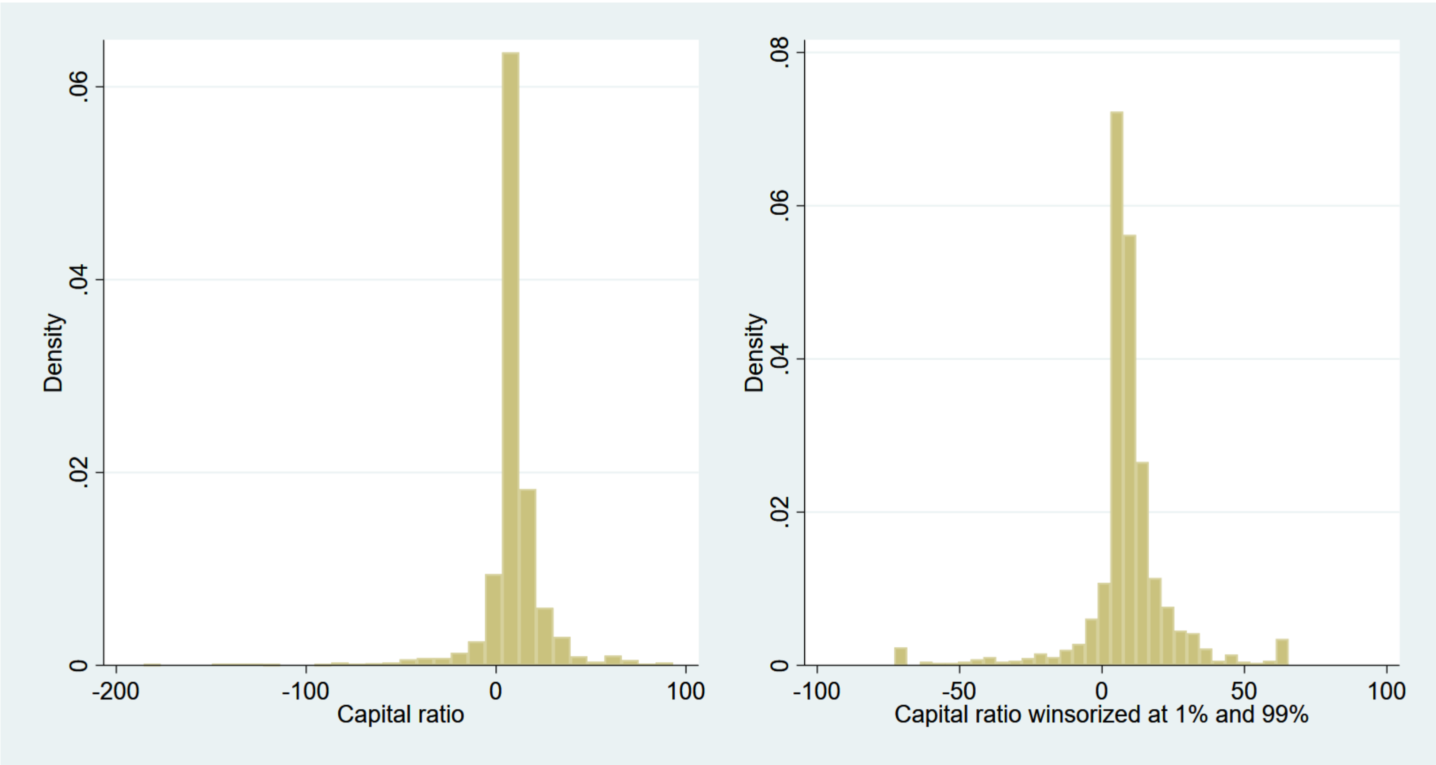
Source: author

Graph 3: Survival function of WAEMU banks from 2003 to 2017 estimated by the Kaplan-Meier method



Source: author

Graph 4: Results of capital ratio winsorizing



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APPENDIX B

Table 8: Results of the robustness tests

Variables	[1] Cox's model (winsorizing data)	[2] Weibull distribution	[3] Gompertz distribution	[4] Exponential distribution	[5] Binary Logit estimation
Capital ratio (EC)	-0.0274***	-0.0152***	-0.0154***	-0.0146***	-0.0319***
	(0.006)	(0.004)	(0.004)	(0.004)	(0.007)
Size of the bank	-0.4806**	-0.3152	-0.2319	-0.1955	-0.5891*
	(0.212)	(0.195)	(0.192)	(0.234)	(0.312)
Portfolio quality (PDR)	0.0906*	0.1047**	0.1070**	0.0873***	0.0944**
	(0.046)	(0.042)	(0.042)	(0.029)	(0.039)
Customer loans (NL)	-0.0349***	-0.0169	-0.0108	-0.0086	-0.0209*
	(0.010)	(0.011)	(0.010)	(0.009)	(0.011)
Return on equity (ROE)	-0.0601	-0.1820	-0.2152	-0.2218	0.0160
	(0.202)	(0.230)	(0.219)	(0.214)	(0.219)
Share of general expenses (GE)	-0.0226	-0.0204	-0.0160	-0.0102	-0.0198
	(0.015)	(0.013)	(0.012)	(0.012)	(0.013)
Market share (MS)	-0.1228**	-0.1461**	-0.1430**	-0.1043*	-0.0613
	(0.051)	(0.064)	(0.063)	(0.054)	(0.060)
Liquidity (LQD)	-0.2051	-0.5598	-0.5993	-0.6876	-1.0470*
	(0.407)	(0.556)	(0.535)	(0.520)	(0.566)
Banking group dummy (GRP)	-0.6816	-0.4490	-0.5129	-0.6482**	-1.0772***
	(0.516)	(0.352)	(0.325)	(0.314)	(0.394)
Public bank dummy (PUB)	-0.9390**	-0.1231	0.0188	0.3693	-0.0955
	(0.454)	(0.407)	(0.402)	(0.410)	(0.484)
Foreign bank dummy (FOR)	-1.1024**	-0.2502	-0.1940	-0.0515	-0.3375
	(0.448)	(0.439)	(0.447)	(0.436)	(0.447)
Capital requirement	4.3731***	3.4077***	3.1954***	3.1940***	1.7082**

of 2007					
	(0.954)	(0.898)	(0.856)	(0.841)	(0.837)
Log of GDP per capita	-0.0510	-0.2000	-0.1713	-0.2152	-0.7833**
	(0.397)	(0.187)	(0.179)	(0.190)	(0.360)
GDP growth rate	0.0837	0.1282*	0.1321*	0.1290*	0.1351
	(0.082)	(0.078)	(0.077)	(0.075)	(0.097)
Inflation rate	0.0361	0.0283	0.0290	0.0329	-0.0284
	(0.093)	(0.095)	(0.097)	(0.090)	(0.096)
Institutional quality	-3.7394	-3.7645	-2.9878	-2.1797	-0.7131
	(2.755)	(3.149)	(2.984)	(2.724)	(3.422)
HHI Market Concentration	0.0004	0.0000	0.0002	0.0002	-0.0005
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Wald Chi2	170.54	369.17	447.50	682.74	181.40
Prob > Chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	1,384	1,384	1,384	1,384	1,401

Source: author's estimate using Stata software, robust standard errors in parentheses. *** p<0,01, ** p<0,05, * p<0,1. Marginal effect estimates were reported for the logit model on an unbalanced panel set.

Impact of Irrigation on Farm Household Diet Quality: Evidence from Ethiopia

Musa Hasen Ahmed

AFRICAN ECONOMIC RESEARCH CONSORTIUM
CONSORTIUM POUR LA RECHERCHE ÉCONOMIQUE EN AFRIQUE

Impact of Irrigation on Farm Household Diet Quality: Evidence from Ethiopia

By

Musa Hasen Ahmed

UNU-MERIT, Maastricht University, the Netherlands

ahmed@merit.unu.edu

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Abstract

Irrigation could theoretically affect farm households' nutritional status in two directions. On the one hand, irrigation may improve nutritional status by boosting farm productivity and household income. On the other hand, it may deter diet quality by shifting farmers' attention from nutrition-rich food to cash crops. This study examines the impact of irrigation schemes on farm households' nutritional status using nationally representative data from Ethiopia. Using the endogenous switching regression model, the study shows that irrigation improves diet quality. In addition, the study also identifies the production of micronutrient-rich crops such as vegetables and fruit and the adoption of productivity-enhancing inputs as the main pathways through which irrigation affects dietary quality. Hence, irrigation can be considered a viable instrument to enhance the diet quality of smallholders, and efforts should be made to tackle constraints that impede the adoption of irrigation technologies.

Keywords: irrigation, nutrition, selection model, impact evaluation, Ethiopia

Sylvanus Kwaku Afesorgbor

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1. Background and Justification of the Study

According to the latest report on the state of food security and nutrition, approximately 10% of the global population is undernourished (FAO et al., 2021). The problem appears to be escalating in Africa, where approximately 21% of the population is undernourished (Global Nutrition Report, 2018). This shows that more effort remains to be made in the region to end hunger, ensure food security, and enhance nutritional status, which are part of the Sustainable Development Goals (SDGs).

Ethiopia is one of the countries in the region where ch[illegible] widespread. Approximately a quarter of the population is estimated to be food insecure. More than half of the population consumes four or fewer food groups out of seven, and starchy staples account for more than 70 percent of the total calorie consumption (WFP & CSA, 2019). Relatedly, per capita vegetable and fruit consumption in the country is 50.2 and 3.5 kg per year, respectively, which are far below the 146 kg recommendation of the WHO. Strikingly, the problem of malnutrition in the country is not sensitive to wealth status, as a quarter of children from the highest wealth quintile also struggle with stunting, and only 16% of children from the wealthiest families are receiving a minimum acceptable diet (Feed the Future, 2019; WFP & CSA, 2019).

Sylvanus Kwaku Afesorgbor

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The country has been working with its partners to establish nutrition-related interventions. For example, the second National Nutrition Program, which was developed in 2015, aims to integrate nutritional needs with the agricultural sectors to end hunger by 2030.[1] Since the vast majority of poor and undernourished people depend on small-scale agriculture to support their livelihoods, improving the performance of the sector can play a vital role in eradicating poverty and malnutrition.

As argued by Haddad et al. (2016), examining the performance of the agricultural sector from the perspective of supporting healthier diets is urgently needed to inform nutrition-sensitive agriculture strategies. Accordingly, numerous studies have explored the linkages between agriculture and nutrition in recent years, mostly in developing countries.[2] Among them, the vast majority (including Tesfaye & Tirivayi, 2020; Hirvonen & Hoddinott, 2017; Jones, 2015; Sibhatu & Qaim, 2018) studied the link between

[1]The document can be accessed at http://extwprlegs1.fao.org/docs/pdf/eth190946.pdf

[2]See Ruel et al. (2018) for a comprehensive review of the relationship between agriculture and nutrition.

farm production diversity and the quality of household diet.[3] Others, such as Carletto et al. (2017) and Ogutu and Qaim (2019), examined the role of commercialization on diet quality and nutritional security.

However, as rigorously reviewed by Shankar et al. (2019), the research base on the nutrition implications of agricultural asset ownership is thin and incomplete. In particular, as observed by Balasubramanya and Stifel (2020), studies that explore the link between irrigation use and rural welfare remain unexpectedly undeveloped. They argued that the great majority of existing studies treat water as a given input or focus on the management aspects of the resource. Nevertheless, since the degree of substitutability between water and other crop inputs is very low, a separate analysis is required to examine the impact of irrigation on the welfare status of farm households.

This being the case, studies that establish an empirical link between irrigation use and nutritional security are scarce. In addition, the few available studies are inconclusive and provide two different lines of arguments. Passarelli et al. (2018), Alaofè et al. (2016), and Bhagowalia et al. (2012) argue that irrigation can improve nutritional status either by allowing farmers to produce (and consume) nutritious foods, including micronutrient-rich vegetables and fruits, or it enables them to purchase nutritious foods due to their income increment through increased output and diversion to high-value crops. Contrary to these arguments, others such as Shively et al. (2012) argue that there could be a potential trade-off, as irrigation would cause a shift in the cropping pattern by moving farmers' attention away from nutrition-rich food to not-so-nutritious cash crops. In line with this, Kafle et al. (2021) and Hagos et al. (2009) showed that cereals and pulses are the most important crops in Ethiopia's rain-fed system, whereas horticultural crops are widely grown in the irrigation system.[4]

Nonetheless, most of the existing studies either argue without empirical support or fail to account for selectivity bias. For instance, Hagos et al. (2017) did not address the issue of selectivity bias. However, irrigation use decisions may not be random. Hence, if, for instance, resource-rich farmers are more likely to use irrigation, as shown by Passarelli et al. (2018) and Kafle et al.

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[3] See Sibhatu and Qaim (2018) for a review of studies that examined the linkage between agricultural production diversity and diet quality.

[4]Hussain and Hanjra (2004) also highlight the role of irrigation in shifting farmers' attention toward a market-oriented production system. Similarly, Hagos et al. (2008) argued that small-scale irrigation is a viable option for promoting a market-oriented production system in Ethiopia, as environmental risks, such as rainfall variability, are among the main reasons that trap farmers in the production of low-risk/low-return food grains. High-value crops, such as horticultural crops, are expected to have the highest long-term economic potential (Hagos et al., 2016). Carletto et al. (2011), Euler et al. (2017), and Meng et al. (2020) show cash crops raise household income and living standards.

(2021), they may have better nutritional status even in the absence of irrigation. Alaofè et al. (2016) relied on a few sample sizes taken from four villages, which limits the generalizability of their findings to other areas.

This study adds to the existing literature by providing information on the impact of irrigation on diet quality using nationally representative data from Ethiopia. There are pertinent reasons to focus on Ethiopia for this study. First, food insecurity and malnutrition are widespread and continue to be among the major public health problems in the country. Second, the government of Ethiopia (GoE) has given due attention to developing the agriculture sector by investing in irrigation infrastructure. In the country, the area of land covered by irrigation exceeded 2.34 million hectares in 2015, and the GoE allocated a substantial amount of the national budget to increase this coverage to 4.14 million hectares by the end of 2020 (NPC 2016).[5] Studying the impacts of irrigation schemes on the welfare status of farming households may contribute to charting sound policies for future irrigation development and to justifying whether irrigation can be considered a viable instrument to enhance nutrition security for Ethiopia and beyond.

> *Sylvanus Kwaku Afesorgbor*
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> ---
> What is the percentage of arable land that is irrigated? This will provide a more interesting view point?

The remaining sections of the paper are organized as follows. Section 2 presents a conceptual framework that indicates the possible pathways through which irrigation can affect nutrition. Section 3 provides information about the data used in this research and the techniques applied to address the objective of the study. Section 4 presents and discusses the results obtained from different models, and the last section presents conclusions and recommendations.

2. Conceptual Framework

Good health is a function of good nutrition, and good nutrition relies on agriculture (Thomas et al., 2015). Accordingly, several studies have been carried out to comprehend the impact of improved agricultural practices and new technologies on nutrition security. Out of them, this section reviews those studies that enable us to construct a conceptual framework that explores the possible pathways by which irrigation can affect nutritional outcomes.

[5] During the period, the total government budget was estimated to be 2.3 trillion Ethiopian Birr (ETB), with ETB 1.3 trillion allocated for capital investment. The infrastructure sector accounted for approximately 48.4 percent of the total capital investment, with 21.6 percent going to irrigation and energy (NPC, 2016). According to the most recent estimates, the country's irrigated agricultural area covers 3.07 million hectares.

Impact of Irrigation on Nutritional Security through Own Production

Irrigation improves the availability and accessibility of food by improving farm productivity, encouraging the adoption of agricultural innovations, enabling portfolio diversification, and increasing cropping seasons per year. For instance, the meta-analyses carried out by Du et al. (2018) and Zheng et al. (2019) documented that irrigation can increase crop yield by 19.3% and 30.5%, respectively. Colli (1992) and Rathore et al. (2017) also highlight the role of irrigation in improving agricultural productivity. However, Makombe et al. (2007) found rain-fed farms in Ethiopia to be more technically efficient than irrigated plots. Gebregziabher et al. (2012) also found a similar result, but they re-estimated separate production frontiers for irrigated and non-irrigated fields and showed that the frontier for irrigated plots is higher than that of rain-fed plots, although the latter are more technically efficient.

Irrigation can also increase food production by boosting farmers' confidence in adopting productivity-enhancing agricultural technologies. Agricultural technologies are usually adopted jointly as complements or supplements. Similarly, irrigation can encourage farmers to adopt productivity-enhancing technologies, such as improved varieties and agrochemicals (Launio et al., 2018; Gebregziabher & Holden, 2011; Abdoulaye and Sanders, 2005). Numerous studies, including Teklewold et al. (2013) and Manda et al. (2016), show that adopting multiple technologies provides a higher yield gain than adopting technologies in isolation.

Irrigation can also empower farmers to produce crops multiple times per year and enables crop diversification by increasing cropping intensity (Buisson & Balasubramanya, 2019). This production diversification helps to improve diet diversity (Thomas et al., 2015; Domènech, 2015; Tesfaye & Tirivayi, 2020). It also gives confidence to farmers to switch from low-risk/low-return subsistence farming to cash crops, including high-value and water-intensive crops (Hussain and Hanjra, 2004; Kafle et al., 2021 and Hagos et al., 2009).

Irrigation can also enable farmers to diversify their portfolios, even by incorporating livestock production, since the accessibility of water supports fodder production and supplies drinking water for livestock. This will, in turn, increase the availability of animal source foods, which significantly improves diet quality (Rawlins et al., 2014).

Impact of Irrigation on Nutritional Security through Market Participation

Improved agricultural productivity, a move to high-value crops, and the potential to produce more than once a year are all expected to boost irrigation users' earnings. Li et al. (2020), Gebregziabher et al. (2009), Garbero & Songsermsawa (2018) and Huang et al. (2005) support this argument. Among them, Gebregziabher et al. (2009) from Ethiopia show that non-irrigating households have less than half the income of irrigating households. This improvement in farm income is expected to boost the ability to access food. For instance, Ogutu et al. (2017) showed that the market participation of smallholder farmers significantly increases the consumption of food purchased without reducing the amount of nutrients consumed from their production. The role of irrigation on diet quality by improving farm income was also discussed by Passarelli et al. (2018).

Impact of Irrigation on Nutritional Security through Gender Empowerment

As fetching water is mainly the responsibility of women and children in most rural areas, the availability of water due to irrigation can reduce the work burden on women (Domènech, 2015). Hence, they can allocate more time for food preparation and sanitation. For example, Ahmed et al. (2017) also showed an inverse association between time spent fetching water and diet quality. Particularly, if women have control over the income and the food generated via irrigation, the chance of improving the diet quality is higher (Upadhyay et al., 2005). However, irrigation may also encourage household members to devote more time to farming or other off-farm income-generating activities, potentially altering their time allocation. As a result, the direction of the effects of this mechanism on diet quality is an empirical question.

Impact of irrigation on nutritional security through health aspects

Better accessibility of water within the household due to irrigation can also result in better hygiene and sanitation practices. As argued by Van Der Hoek et al. (2002), the accessibility of water might be much more important in rural areas than the quality of water for health.

However, to realize all the benefits of irrigation listed above, there must be a regular water supply and proper management. If appropriate management practices are not put in place, they may cause harmful effects on health and the environment. In addition, there must be institutional support, such as extension, credit, and market information, for farmers. Empirical findings (e.g., Wang, 2010; Alcon et al., 2011) also indicated that socioeconomic variables such as family size, off-farm activity, risk preference, education and age of the household head, farm size, and land tenure affect the decision of farmers to use irrigation. Based on the above empirical reviews, Fig.1 outlines the pathway and intermediaries through which irrigation can affect nutrition security.

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It will be important to provide a brief description of the Figure 1. One or two paragraphs describing the pathways will be good.

3. Research Methodology

The Data

This research uses the comprehensive and nationally representative Ethiopian Socioeconomic Survey, which was administered by the Living Standards Measurement Study-Integrated Surveys of the World Bank in 2013/2014. The survey produced rich data at the household, plot, and village levels by covering 433 enumeration areas (EAs) across all regional states of the country.[6] The sample respondents were selected using a two-stage probability sample. In the first stage, EAs were selected using simple random sampling. The location of EAs in the country is indicated in Fig.2. This stage was followed by the selection of households to be interviewed from each EA.[7] This study uses data collected from rural EA.

Indicator of Household Nutrition

This study uses household Diet Diversity Scores (DDS) as an indicator of nutrition status. It is believed that increasing the variety of foods across and wit[illegible] adequate intake of essential nutrients and promotes good h[illegible] shown that diet diversification is positively correlated with nutrient adequacy (both macro-and micronutrients) and dietary quality (Moursi et al., 2008). It also improves health outcomes, including birth weight (Rao et al. 2001) and child anthropometric status (Arimond & Ruel, 2004). A recent study from Ethiopia by Mekonnen et al. (2020) also found DDS to be a strong predictor of nutrient adequacy.

Dietary diversity is usually measured by summing the number of foods or food groups consumed over a reference period, and this period usually ranges from 1 to 7 days. This study calculates DDS based on a 7-day food consumption recalls of 12 food groups of the FAO guideline, which comprise "vegetables; white tubers and roots; cereals; legumes; nuts and seeds; fruits; oils and fats; meat; fish and fish products; milk and dairy products; eggs; sweets and sugars; condiments, spices, and beverages".

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A sentence on how the households were selected will be great. You did indicate that for the first-stage.

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DDS should be defined immediately the term was used, and not in the next paragraph.

[6] The survey did not cover the nonsedentary population of three zones of Afar and six zones of Somali regional states.

[7] Detailed information on sampling procedure, data collection instrument, the types of data collected and related information can be accessed at http://microdata.worldbank.org/index.php/catalog/2783

Method of Data Analysis

Estimating the impact of irrigation on DDS

The relationship between irrigation use and its impact on nutritional status can be modelled, along with a vector of other explanatory variables (X) and their coefficients (ψ), as follows:

$$N_i = X_i\psi + \Omega I_i + \varepsilon_i$$

where N_i stands for the outcome variables, I_i denotes a binary variable indicating whether the farmer uses irrigation or not and ε_i represents the random error term. Hence, the impact of irrigation on the outcome variable would be equal to Ω if users and nonusers were randomly assigned. However, users and nonusers may not be randomly distributed between the two groups. For example, irrigation users and nonusers may differ based on their wealth status (Passarelli et al. 2018 and Kafle et al. 2021), physical and human capital endowments (Koundouri et al. 2006; Hunecke et al. 2017), or risk-taking behavior (Torkamani & Shajari 2008). In this case, the mean value of the outcome indicators of the two groups differed even in the absence of the treatment (i.e., irrigation). Hence, this initial bias has to be solved. As selection bias may arise due to systematic differences in terms of both observable and unobservable characteristics, this study adopted the endogenous switching regression model (ESR) to control for these heterogeneities.

The implementation of the ESR framework involves two stages. In the first stage, the selection equation that shows the decision to use irrigation is modelled. This stage can be specified as follows:

$$I_i^* = X_i\beta + \varepsilon_i \text{ with } I_i = \begin{cases} 1 \; if & I_i^* > 0 \\ 0 & otherwise \end{cases} \quad (2)$$

where I^*_i is the latent variable for the decision to use irrigation, ***I_i*** is its observable counterpart[8], and ***X_i*** are vectors of observed characteristics determining farmers' decisions to use irrigation. ***X_i*** includes household, community, and environmental factors. As environmental factors, drought index and soil fertility indicators are included. The drought index is measured using the standardized precipitation evapotranspiration index (SPEI), and

[8] In this study, a household is considered as an irrigation user if irrigation is used for agricultural activities in one of the plots operated by the farmer. Table 10 provides a list of crop items produced using irrigation

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Must be consistent in the order of arranging the variable and the parameter.

soil fertility is proxied by the availability of soil nutrients.[9] Controlling for soil fertility helps to account for whether farmers residing in areas that are more suitable for irrigation are cultivating higher value crops given better land quality.

In the second stage of the ESR framework, two outcome regression equations faced by the farmers—to use irrigation (Regime 1) and not to use (Regime 2)—conditional on adoption are estimated. The equations can be expressed as:

$$\text{Regime1 (user)}: \quad D_{1i} = \alpha_1 J_{1i} + e_{1i} \quad \text{if} \quad I_i = 1 \qquad (3a)$$

$$\text{Regime 2(nonuser)}: \quad D_{2i} = \alpha_2 J_{2i} + e_{2i} \quad \text{if } I_i = 0 \qquad (3b)$$

where D_i is the outcome variable (diet diversity score) in each regime, $\boldsymbol{J_i}$ represents a vector of exogenous variables expected to affect the outcome variable, and e_i are random errors. The error terms given under this framework are assumed to have a trivariate normal distribution, with zero mean and a nonsingular covariance matrix, which can be expressed as:

$$\text{cov}(e_{1i}, e_{2i}, u_i) = \begin{pmatrix} \sigma^2_{e1} & . & \sigma_{e1u} \\ . & \sigma^2_{e2} & \sigma_{e2u} \\ . & . & \sigma^2_u \end{pmatrix}$$

where σ^2_u represents the variance of the error term in the selection equation (adoption of irrigation, for this case), and σ^2_{e1} and σ^2_{e2} are the variances of the error terms in the outcome functions (DDS equation). Correspondingly, σ_{e1u} and σ_{e2u} represent the covariance of $u_i e_{1i}$ and $u_i e_{2i}$ (Khonje et al. 2015).The expected values of e_{1i} and e_{2i} conditional on the sample selection are given by:

$$E[e_{1i} | I_i = 1] = \sigma_{e1u} \frac{\varphi(\beta x_i)}{\Phi(\beta x_i)} = \sigma_{e1u} \lambda_{1i} \qquad (4)$$

$$E[e_{2i} | I_i = 0] = \sigma_{e2u} \frac{\varphi(\beta x_i)}{1 - \Phi(\beta x_i)} = \sigma_{e2u} \lambda_{2i} \qquad (5)$$

where $\varphi(.)$ stands for the standard normal probability density function, $\Phi(.)$ is the standard normal cumulative density function, and λ_{1i} and λ_{2i} represent the inverse Mills ratio calculated from the selection equation (Asfaw et al., 2012).

[9] SPEI is accessed from https://spei.csic.es/ and availability of soil nutrients is obtained from

https://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/

The average treatment effect on the treated (ATT) and the untreated (ATU) can be estimated from the above framework by comparing the expected values of the outcomes of users and nonusers in actual and counterfactual scenarios. Accordingly, ATT is computed as the difference between the expected outcome of irrigation users and the counterfactual case that they did not use, whereas ATU is computed as the difference between the expected outcome of nonusers and the counterfactual case that is the expected value of the outcome indicator if they decided to use irrigation.

For the endogenous switching models to be identified, it is important to include a selection instrument. Accordingly, '*the slope of the plot'* is chosen as a selection instrument by conducting a falsification test following Di Falco et al. (2011). The test result, which is presented in Table A5, indicates that the selected instrument is a viable instrument as it is strongly correlated with the decision to use irrigation, and it is found not to be correlated with the outcome variable for the nonusers. Because the Ethiopian land tenure law prohibits landholders from selling agricultural land, selection bias is negligible.

Farmers' decision to use irrigation is significantly influenced by the slope of the plot (Pokhrel et al., 2018). Walker (1989) also listed the slope of the field and its uniformity as the most important determinants for using irrigation. As the slope of the plot affects the water distribution, steeper fields require additional energy (and cost) to move water across areas in the plot. Depending on the direction of the water source, irrigation can also induce erosion and affect water use efficiency. Hence, the slope of the plot can affect farmers' decisions to use irrigation. However, the instrumental variable is not irrefutable. It is possible, for example, that slope would affect agricultural production through other avenues, so the findings of the study should be interpreted with this caveat in mind.

3.1.1. Exploring the mechanisms

After evaluating the impacts of irrigation on diet quality, the study explores the impact pathways outlined in the preceding section, depending on data availability. The most common technique for examining impact mechanisms in existing studies is to examine the relationship between the proposed mechanisms and the independent variable. In this strategy, a variable is considered to have some mediation effects if the independent variable substantially predicts the expected mediator. However, Acharya et al. (2016) illustrate that this technique might lead to biased estimates and propose a strategy that treats the problem as a system of equations. In line with this, recent studies, including Pace et al. (2022), Passarelli et al. (2018), and Cockx et al. (2018), explored impact pathways by solving structural equations. As both techniques have their own strengths, this study combines the two approaches. Specifically, the study combines the propensity matching score technique (PSM) with *Stata's 'medsem'* package that solves systems of equations to explore the possible mechanisms.

PSM helps to adjust for initial differences between the two groups by matching each irrigation user to nonusers based on similar observable characteristics (Rosenbaum & Rubin, 1983). Therefore, the first step in PSM is to predict the propensity scores for each observation using characteristics that are not affected by the treatment variable. This stage is followed by imposing the common support region and the identification of an appropriate matching estimator. The fourth step is checking for matching quality, and if the matching quality is satisfied, the average treatment effect on the treated (ATT) can be specified as the mean difference in the outcome indicator of the irrigation users matched with nonusers who are balanced on the propensity scores and fall within the region of common support and can be expressed as:

$$E\left[Y(1) I=1\right] - E\left[Y(0) I=0\right] = \tau_{ATT} + E\left[Y(0) | I=1\right] - E\left[Y(0) | I=0\right] \quad (6)$$

where τ_{ATT} is the treatment effect on the treated, Y is the outcome indicator (DDS), *and I* is a dummy variable that indicates whether the household has used irrigation or not. Both terms on the left-hand side are observable, and ATT can be identified if and only if $E[Y(0) \mid I = 1] - E[Y(0) \mid I = 0] = 0$. when there is no self-selection bias.

The other technique used to identify the mediators is solving the system equations using Stata’s ‘medsem’ package. Under this approach, a variable must fulfil certain preconditions to be considered a mediator (Mehmetoglu 2018; Zhao et al., 2010). After solving the system equation, the independent variable has to have a significant effect on the mediating variable (X -> M) (for our case, irrigation use has to have a statistically significant effect on the production of noncereals, for example). In the second step, the mediating variable has to have a statistically significant effect on the outcome variable (M -> Y). There will be no mediation effect if either of the above two conditions is not fulfilled, and there could be ‘some’ mediation if both are fulfilled. Specifically, to have a ‘complete’ mediation effect, in addition to the above two conditions, Sobel's z-test[10] must be statistically significant, and the

[10]The Sobel z-test determines if an independent variable has an indirect effect on the dependent variable mediated by another variable. To do so, it tests the hypothesis that there is no statistically significant difference between the total effect and the direct effects of the independent variable after accounting for the influence of a potential mediator (Allen, 2017).

coefficient of the independent variable on the dependent variable must be statistically insignificant (X->Y); otherwise, there will be partial mediation. Detailed theoretical and empirical descriptions of the model can be found in Mehmetoglu (2018) and Zhao et al. (2010).

4. Results and Discussions

Descriptive statistical results of the variables used in the models

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The description and summary statistics of the variables used for this study are presented in Table A1 and Table 1. As indicated in Table 1, 75% of the households are headed by a male. The average age of the household head is approximately 46 years, and 38% of them can read and write at least. On average, households own 1.24 hectares of land and 4.7 units of livestock measured in tropical livestock units (TLU). The average family size, measured in terms of adult equivalent, is four. Regarding their access to institutions, 20% of them have accessed credit, and 47% of them live in the village where there is a weekly market. On average, they travel approximately 17 km to reach the nearest major road. The result from a simple ttest implies the difference in terms of some of the characteristics considered in the study as statistically significant. These variables include location dummy, demographic characteristics (sex and family size), wealth status (livestock and land size), and access to the market.

Regarding the outcome variable, the mean DDS is 5.697, which is above the minimum acceptable diet (four or more food groups). However, 26% of the households reported consumption below the minimum acceptable diet. As shown in Table A2, there is also visible heterogeneity between irrigation users and non-users in terms of the consumption of different food groups. Cereal is widely consumed by both groups, with more than 97% of non-users and 99% of users reporting intake. The consumption of beans, beef, and fish is common in non-user households, whereas vegetables, fruits, and dairy products are common in user households. This is in line with Alaofè et al. (2016), who showed that irrigation increases the consumption of vegetables and fruits, and Hagos et al. (2009), who highlighted the prevalence of cereals and pulses in Ethiopia's rain-fed system.

Regarding the share of irrigation users, 12% of households are irrigation users. Rivers and ponds are the main sources of irrigation water, as 68% and 7% of irrigation users cited them as their main source of irrigation water. Among cereal crops, maize and sorghum are the major crops that use irrigation. The most commonly irrigated fruits are bananas, lemons, and oranges, while the corresponding crops from the vegetable groups are kale, onions, and tomatoes. Likewise, coffee and chats are the most important irrigation user cash crops. Tables A3 and A4 summarize crops grown using irrigation and irrigation water sources, respectively.

Econometric Results

Estimating the impact using the Endogenous Switching Regression

The result of the full information maximum likelihood estimates of the endogenous switching model is presented in Table A6. The first column presents the coefficient of the selection equation, and DDS_1 and DDS_0 present DDS equations for irrigation users and nonusers, respectively.[11]Although identifying the coefficients of the equations of DDS for irrigation users and nonusers is not the aim of the paper, the result presented in the table illustrates the presence of heterogeneity in the determinant of the diet diversity score equation of the two groups. This shows that estimating the DDS equation using simple regression analysis by incorporating a dummy variable to indicate irrigation use cannot account for the heterogeneities between the two groups. In addition, the significance of the estimated coefficients of the correlation term *rho* presented in the table implies that the hypothesis of the absence of selectivity bias is rejected. Indeed, the endogenous switching regression model is adapted to control for such types of sample selection bias and to account for heterogeneity that exists between the two groups.

After fitting the ES models, the predicted values of the outcome indicators are used to estimate the average treatment effect of using irrigation on the treated (ATT) and untreated (ATU) groups. The results are presented in Table
2. As presented in the table, irrigation increases DDS by an average of 2.14 units for users. Furthermore, the results also show that if nonusers had adopted irrigation technology, their DDS would have increased by an average of 0.34. This result is consistent with the existing knowledge. For example, Mekonnen et al. (2019) and Baye et al. (2019) show a positive association between households' nutritional status and irrigation in Ghana and Ethiopia.

Mechanisms

Tables 3 and 4 present the results from the analysis of the mechanisms obtained from the PSM and system equation-based models, respectively. The study examines farmers' land allocation decisions, spending on nutritious food items, adoption of commercial inputs, portfolio diversification, and time

[11] The *Stata* command '*movestay*' is used to run the ESR model and a detailed description of the procedure can be found at Lokshin and Sajaia (2004).

spent by female household members fetching water as plausible mechanisms.

The result from the PSM technique shows that irrigation increases the probability of the production of non-cereals and the adoption of commercial inputs. However, the effects on spending on nutritious food items, livestock size, and time spent by female household members fetching water are not statistically significant. As presented in the table, irrigation increases, on average, the probabilities of producing noncereal crops by approximately 19% compared with their non-irrigated counterparts. Similarly, it increases the likelihood of production of either vegetables or fruits by 25 to 29 % compared with their non-user counterparts. Related works by Alaofè et al. (2016) and Naylor et al. (2011) also show that irrigation increases the production and consumption of fruits and vegetables in SSA. Irrigation use also increases the probability of adoption of fertilizer up to nine percent compared with their non-user counterparts. The complementarity between irrigation use and the adoption of commercial inputs, such as inorganic fertilizer, has been documented in previous studies (Gebregziabher & Holden 2011; Abdoulaye & Sanders, 2005). The adoption of such inputs is expected to enhance nutritional status (Teklewold et al., 2019). Sensitivity analysis was conducted for all significant outcome variables, and the results are presented in Tables A7 to A9.

Consistent with the PSM model findings, the result obtained by solving the system equations also identified the production of noncereal crops and the adoption of new technologies as possible mechanisms (Table 4). One of the additional features of this technique is that it also calculates the contributions of the mediators on the total effects by computing the ratio between the indirect and total effects. For example, the result shows that approximately 44% of the effects of irrigation on diet diversity score are mediated by the production of fruits and vegetables, while the share for the adoption of fertilizer is approximately 13%.

Hence, the results from the two models indicate that the main pathway through which irrigation affects diet quality is through improving access to nutritious food items from own production. The importance of own production for household nutrition status is highlighted by Jones et al. (2014), Sibhatu et al. (2015), and Tesfaye and Tirivayi (2020). Even though the income generated from irrigation can serve to improve diet quality by helping farmers purchase essential food items that are not produced at home, income growth alone may not be sufficient to boost diet quality, as the translation from income to diet quality depends heavily upon a series of factors, including women's education and decision-making power (Ogutu & Qaim, 2019;

Holland & Rammohan, 2019). Furthermore, as observed by Von Braun et al. (1989), there could be cases where malnutrition could be endemic in a given society, and households may not be aware of their nutritional problems as long as they live a life comparable to most of their neighborhood. In this case, the additional income generated through irrigation use may often have little or no impact on improving diet quality, since households are less aware of their nutritional problems.

5. Conclusion and Recommendation

This paper analysed the impact of irrigation use on diet quality using nationally representative data from Ethiopia. The study used the ESR model that enables us to control for both observable and unobservable heterogeneities. The results show that irrigation significantly and positively affects diet diversity. This implies that irrigation can be considered a viable instrument to enhance the diet quality and nutritional status of smallholders. Furthermore, the study also shows that irrigation encourages farmers to produce nutritionally rich crops such as vegetables and fruits and adopt productivity-enhancing technologies such as inorganic fertilizer.

The result is interesting for countries like Ethiopia, where malnutrition and micronutrient deficiencies are major public health problems. As a result, developing the agriculture sector by investing in irrigation infrastructure can contribute significantly to reducing malnourishment since the majority of poor and malnourished households rely on agriculture. Therefore, efforts should be made to tackle constraints that are impeding the adoption of irrigation technologies.

The study has the following limitations. First, since DDS is constructed based on the food consumption data collected at the household level using a 7-day recall method, the study could not account for seasonal fluctuations in food supply and intrahousehold food allocation. The consumption data of the LSLM survey were collected between February and April 2014, along with household characteristics and postharvest agriculture questionnaires. The two months fall between harvesting and the start of the next planting season. As a result, the data collection period represents an average between the food surplus season and the period when stocks are depleted. Second, DDS does not require information on quantities of foods consumed, as it relies on the list of items consumed. Last, the study also does not consider the types of irrigation technologies used by farmers.

It is worth affirming the need for further research to know more about the impacts of irrigation on diet quality and nutritional security. In particular, additional research is needed to explore the impacts of irrigation on the production and consumption of micronutrients such as zinc, iron, protein, and vitamins, as deficiencies in these micronutrients are among the major public health problems in most developing countries, including Ethiopia. In addition, the shift in farmers' decisions to produce nutritionally rich food varieties can have an implication on the type and amount of food produced and supplied to the local market. This, in turn, could affect the availability and affordability of nutritious food items for all, including landless laborers and urban dwellers. Hence, exploring the spill-over effects of irrigation on diet quality at the market level could be of interest in the literature.

References

Abdoulaye, T., & Sanders, J. H. (2005). Stages and determinants of fertilizer use in semiarid African agriculture: the Niger experience. *Agricultural economics*, *32*(2), 167-179.

Acharya, A., Blackwell, M., & Sen, M. (2016). Explaining causal findings without bias: Detecting and assessing direct effects. *American Political Science Review*, *110*(3), 512-529.

Alaofè, H., Burney, J., Naylor, R., & Taren, D. (2016). Solar-Powered Drip Irrigation Impacts on Crops Production Diversity and Dietary Diversity in Northern Benin. *Food and Nutrition Bulletin*, *37*(2), 164–175.

Alcon, F., de Miguel, M. D., & Burton, M. (2011). Duration analysis of adoption of drip irrigation technology in southeastern Spain. *Technological Forecasting and Social Change*, *78*(6), 991-1001.

Allen, M. (Ed.). (2017). *The SAGE encyclopedia of communication research methods*. Sage Publications.

Arimond, M., &Ruel, M. T. (2004). Dietary diversity is associated with child nutritional status: evidence from 11 demographic and health surveys. *The Journal of nutrition*, *134*(10), 2579-2585.

Ayele, G. K., Nicholson, C., Collick, A. S., Tilahun, S. A., &Steenhuis, T. S. (2013). Impact of small-scale irrigation schemes on household income and the likelihood of poverty in the Lake Tana basin of Ethiopia.ILRI.

Balasubramanya, S., & Stifel, D. (2020). Water, agriculture & poverty in an era of climate change: Why do we know so little? *Food Policy*, 101905.

Baye, K., Choufani, J., Mekonnen, D., Bryan, E., Ringler, C., Griffiths, J. K., & Davies, E. (2019). *Irrigation and Women's Diet in Ethiopia A Longitudinal Study* (Vol. 1864). Intl Food Policy Res Inst.
Bhagowalia, P., Headey, D., & Kadiyala, S. (2012). *Agriculture, Income, and Nutrition Linkages in India* (Poverty, Health, and Nutrition Division Development Strategy and Governance Division). *IFPRI report*. Retrieved from http://www.ifpri.org/sites/default/files/publications/ifpridp01195.pdf
Buisson, M. C., & Balasubramanya, S. (2019). The effect of irrigation service delivery and training in agronomy on crop choice in Tajikistan. *Land Use Policy*, *81*, 175-184.
Carletto, C., Corral, P., &Guelfi, A. (2017). Agricultural commercialization and nutrition revisited: Empirical evidence from three African countries. *Food Policy*, *67*, 106-118.
Carletto, C., Kilic, T., & Kirk, A. (2011). Nontraditional crops, traditional constraints: The long-term welfare impacts of export crop adoption among Guatemalan smallholders. *Agricultural Economics*, *42*, 61-76.
Cockx, L., Colen, L., & De Weerdt, J. (2018). From corn to popcorn? Urbanization and dietary change: Evidence from rural-urban migrants in Tanzania. *World Development*, *110*, 140-159.
Croppenstedt, A., Demeke, M., &Meschi, M. M. (2003). Technology adoption in the presence of constraints: the case of fertilizer demand in Ethiopia. *Review of Development Economics*, *7*(1), 58-70.
Di Falco, S., Veronesi, M., &Yesuf, M. (2011). Does adaptation to climate change provide food security? A microperspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829-846.
Domènech, L. (2015). *Is Reliable Water Access the Solution to Undernutrition? A Review of the Potential of Irrigation to Solve Nutrition and Gender Gaps in Africa South of the Sahara*. *Environment and Production Technology Division Poverty, Health, and Nutrition Division*. Washington. https://agrilife.org/ilssi/files/2019/12/water-access-and-nutrition.pdf
Du, Y. D., Niu, W. Q., Gu, X. B., Zhang, Q., Cui, B. J., & Zhao, Y. (2018). Crop yield and water use efficiency under aerated irrigation: A meta-analysis. *Agricultural water management*, *210*, 158-164.

FAO, IFAD, UNICEF, WFP and WHO. 2021. The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO. https://doi.org/10.4060/cb4474en
Feed the Future 2019 Global Food Security Strategy Ethiopia Country Plan 2019–2023. Accessed at: https://www.usaid.gov/sites/default/ files/documents/1867/GFSS-Country-Plan-Ethiopia-FINAL-April-2019.

Food and Agriculture Organization of the United Nations. State of Food and Agriculture 2013: Food systems for better nutrition 2013 Rome, Italy Galasso, E., &Wagstaff, A. (2019). The aggregate income losses from childhood stunting and the returns to a nutrition Intervention aimed at reducing stunting. *Economics & Human Biology*.
Garbero, A., &Songsermsawas, T. (2018). Impact of modern irrigation on household production and welfare outcomes, Evidence from the Participatory Small-Scale Irrigation Development Programme (PASIDP) project in Ethiopia, IFAD research series.
Gebregziabher, G., & Holden, S. (2011). Does irrigation enhance and food deficits discourage fertilizer adoption in a risky environment? Evidence from Tigray, Ethiopia. *Journal of Development and Agricultural Economics*, *3*(10), 514-528.
Gebregziabher, G., Namara, R. E., & Holden, S. (2009). Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. *Agricultural water management*, *96*(12), 1837-1843.
Gebregziabher, G., Namara, R. E., & Holden, S. (2012). Technical Efficiency of Irrigated and Rain-Fed Smallholder Agriculture in Tigray, Ethiopia : A Comparative Stochastic Frontier Production Function Analysis, *51*(3), 203–226.
Gebul, M. A. (2021). Trend, Status, and Challenges of Irrigation Development in Ethiopia—A Review. *Sustainability*, *13*(10), 5646.
Global Nutrition Report, 2018. 2018 Global Nutrition Report: Shining a light to spur action on nutrition. Bristol, UK: Development Initiatives
Haddad, L., Hawkes, C., Webb, P., Thomas, S., Beddington, J., Waage, J., & Flynn, D. (2016). A new global research agenda for food. *Nature News*, *540*(7631), 30.
Hagos, F., Haileslassie, A., Getnet, K., Gebregziabher, G., Bogale, A., & Getahun, Y. (2016). Marketing patterns of rainfed and irrigated systems: Do they differ? *LIVES Working Paper*.

Hagos, F., Makombe, G., Namara, R. E., & Awulachew, S. B. (2009). *Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation* (Vol. 128). IWMI.
Hagos, F., Makombe, G., Namara, R., & Awulachew, S. B. (2008). Does access to small scale irrigation promote market-oriented production in Ethiopia.
Hagos, F., Mulugeta, A., Erkossa, T., Langan, S., Lefore, N., & Abebe, Y. (2017). Poverty Profiles and Nutritional Outcomes of Using Spate Irrigation in Ethiopia. *Irrigation and Drainage*, *66*(4), 577–588.
Hanjra, M. A., & Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy*, *35*(5), 365–377.
HDR. (2016). *Ethiopia Humanitarian Requirements Document-2016*. Retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/ethiopia_hrd_2016.pdf
Hirvonen, K., &Hoddinott, J. (2017). Agricultural production and children's diets: Evidence from rural Ethiopia. *Agricultural Economics*, *48*(4), 469-480.
Holland, C., &Rammohan, A. (2019). Rural women’s empowerment and children’s food and nutrition security in Bangladesh. *World Development*, *124*, 104648.
Huang, Q., Rozelle, S., Lohmar, B., Huang, J., & Wang, J. (2006). Irrigation, agricultural performance and poverty reduction in China. *Food Policy*, *31*(1), 30–52.
Hunecke, C., Engler, A., Jara-Rojas, R., & Poortvliet, P. M. (2017). Understanding the role of social capital in adoption decisions: An application to irrigation technology. *Agricultural systems*, *153*, 221-231.
Hussain, I., & Hanjra, M. A. (2004). Irrigation and poverty alleviation: review of the empirical evidence. *Irrigation and drainage*, *53*(1), 1-15.
Jones, A. D. (2015). The production diversity of subsistence farms in the Bolivian Andes is associated with the quality of child feeding practices as measured by a validated summary feeding index. *Public health nutrition*, *18*(2), 329-342.
Jones, A. D., Shrinivas, A., & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data. *Food Policy*, *46*, 1-12.

Kafle, K., Omotilewa, O., Leh, M., & Schmitter, P. (2021). Who is Likely to Benefit from Public and Private Sector Investments in Farmer-led Irrigation Development? Evidence from Ethiopia. *The Journal of Development Studies*, 1-21.
Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World Development*, *66*, 695-706.
Koppmair, S., Kassie, M., & Qaim, M. (2017). Farm production, market access and dietary diversity in Malawi. *Public health nutrition*, *20*(2), 325-335.
Koundouri, P., Nauges, C., & Tzouvelekas, V. (2006). Technology adoption under production uncertainty: theory and application to irrigation technology. *American Journal of Agricultural Economics*, *88*(3), 657-670.
Launio, C. C., Luis, J. S., & Angeles, Y. B. (2018). Factors influencing adoption of selected peanut protection and production technologies in Northern Luzon, Philippines. *Technology in Society*.55, 56-62.
Li, J., Ma, W., Renwick, A., & Zheng, H. (2020). The impact of access to irrigation on rural incomes and diversification: evidence from China. *China Agricultural Economic Review*.
Lokshin, M., &Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *The Stata Journal*, *4*(3), 282-289.
Makombe, G., Kelemework, D., &Aredo, D. (2007). A comparative analysis of rainfed and irrigated agricultural production in Ethiopia. *Irrigation and Drainage Systems*, *21*(1), 35-44.
Makombe, G., Namara, R., Hagos, F., Awulachew, S. B., Ayana, M., &Bossio, D. (2011). *A comparative analysis of the technical efficiency of rain-fed and smallholder irrigation in Ethiopia* (Vol. 143). IWMI.
Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics*, *67*(1), 130-153.
Mehmetoglu, M. (2018). Medsem: A Stata package for statistical mediation analysis. *International Journal of Computational Economics and Econometrics*, *8*(1), 63-78.
Mekonnen, D. K., Choufani, J., Bryan, E., Abizari, A. R., Ringler, C., & Amikuzuno, J. (2019). *Irrigation-nutrition linkages: Evidence from northern Ghana* (Vol. 1887). Intl Food Policy Res Inst.

Mekonnen, D.A., Talsma, E.F., Trijsburg, L., Linderhof, V., Achterbosch, T., Nijhuis, A., Ruben, R. and Brouwer, I.D. (2020). Can household dietary diversity inform about nutrient adequacy? Lessons from a food systems analysis in Ethiopia. *Food Security*, *12*(6), 1367-1383.
Moursi, M. M., Arimond, M., Dewey, K. G., Treche, S., Ruel, M. T., &Delpeuch, F. (2008). Dietary diversity is a good predictor of the micronutrient density of the diet of 6-to 23-month-old children in Madagascar. *The Journal of Nutrition*, *138*(12), 2448-2453.
National Planning Commission. (2016). Federal Democratic Republic of Ethiopia: Growth and Transformation Plan II (GTP II). *Vol. I*. accessed at https://www.greengrowthknowledge.org/sites/default/files/dow nloads/policy-database/ETHIOPIA%29%20Growth%20and%20Transformation %20Plan%20II%2C%20Vol%20I.%20%20%282015%2C16-2019%2C20%29.pdf
Naylor, R., Burney, J. A., & Postel, S. (2011). Smallholder Irrigation and Crop Diversification under Climate Change in sub-Saharan Africa: Evidence and Potential for Simultaneous Food Security, Adaptation, and Mitigation. *AGUFM*, *2011*, B32B-09.
Ogutu, S. O., &Qaim, M. (2019). Commercialization of the small farm sector and multidimensional poverty. *World Development*, *114*, 281-293.
Ogutu, S. O., Gödecke, T., &Qaim, M. (2017). *Agricultural commercialization and nutrition in smallholder farm households* (No. 97). global food Discussion Papers.
Pace, N., Sebastian, A., Daidone, S., Prifti, E., & Davis, B. (2022). Mediation analysis of the impact of the Zimbabwe Harmonized Social Cash Transfer Programme on food security and nutrition. *Food Policy*, *106*, 102190.
Passarelli, S., Mekonnen, D., Bryan, E., & Ringler, C. (2018). Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania. *Food Security*, *10*(4), 981–997.
Pokhrel, B., Paudel, K., &Segarra, E. (2018). Factors Affecting the Choice, Intensity, and Allocation of Irrigation Technologies by US Cotton Farmers. *Water*, *10*(6), 706.
Rao, S., Yajnik, C.S., Kanade, A., Fall, C.H., Margetts, B.M., Jackson, A.A., Shier, R., Joshi, S., Rege, S., Lubree, H. and Desai, B., (2001). Intake of micronutrient-rich foods in rural Indian mothers is associated with the size of their babies at birth: Pune Maternal Nutrition Study. *The Journal of nutrition*, *131*(4), 1217-1224.

Rathore, V.S., Nathawat, N.S., Bhardwaj, S., Sasidharan, R.P., Yadav, B.M., Kumar, M., Santra, P., Yadava, N.D. and Yadav, O.P., (2017). Yield, water and nitrogen use efficiencies of sprinkler irrigated wheat grown under different irrigation and nitrogen levels in an arid region. *Agricultural Water Management*, *187*, 232-245.

Rawlins, R., Pimkina, S., Barrett, C. B., Pedersen, S., &Wydick, B. (2014). Got milk? The impact of Heifer International's livestock donation programs in Rwanda on nutritional outcomes. *Food Policy*, *44*, 202-213.

Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, *70*(1), 41-55.

Ruel, M. T. (2003). Operationalizing dietary diversity: a review of measurement issues and research priorities. *The Journal of nutrition*, *133*(11), 3911S-3926S.

Ruel, M. T., Quisumbing, A. R., &Balagamwala, M. (2018). Nutrition-sensitive agriculture: What have we learned so far? *Global Food Security*, *17*, 128-153.

Shankar, B., Poole, N., & Bird, F. A. (2019). Agricultural inputs and nutrition in South Asia. *Food Policy*, *82*, 28-38.

Shively, G., Sununtnasuk, C., & Brown, M. (2012). *Measuring the Links Between Agriculture and Child Health in Nepal* (Shively, Gerald, and Celeste Sununtnasuk Molly Brown. 2012. Measuring the Links Between Agriculture and Child Health in Nepal.

Sibhatu, K. T., &Qaim, M. (2018). Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy*. 77,1-18

Sibhatu, K. T., Krishna, V. V., &Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proceedings of the National Academy of Sciences*, *112*(34), 10657-10662.

Teklewold, H., Gebrehiwot, T., & Bezabih, M. (2019). Climate smart agricultural practices and gender differentiated nutrition outcome: Empirical evidence from Ethiopia. *World Development*, *122*, 38-53.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics*, *93*, 85-93.

Tesfaye, W., & Tirivayi, N. (2020). Crop diversity, household welfare and consumption smoothing under risk: Evidence from rural Uganda. *World Development*, *125*, 104686.

Thomas, G., Thompson, B., &Traore, M. (2015). *Sustainable Nutrition Security: Restoring the Bridge Between Agriculture and Health* (No. id: 7784).
Torkamani, J., & Shajari, S. (2008). Adoption of new irrigation technology under production risk. *Water Resources Management*, *22*(2), 229-237.
Upadhyay, B., Samad, M., & Giordano, M. (2005). *Livelihoods and Gender Roles in Drip-Irrigation Technology: A Case of NepalIWMI*.
Van der Hoek, W., S. G. Feenstra, &Konradsen. F., (2002). Availability of Irrigation Water for Domestic Use: Impact on Prevalence of Diarrhea and Nutritional Status of Children. *Journal of Health, Population, and Nutrition,* 20 (1), 77–84.
Victora, C.G., Adair, L., Fall, C., Hallal, P.C., Martorell, R., Richter, L., Sachdev,
H.S. and Maternal and Child Undernutrition Study Group. (2008). Maternal and child undernutrition: consequences for adult health and human capital. *The lancet*, *371*(9609), 340-357.
Von Braun, J. (1989). *The importance of nonagricultural income sources for the rural poor in Africa and implications for food and nutrition policy*. Cornell Food and Nutrition Policy Program, Cornell University.
Walker, W. R. (1989). *Guidelines for designing and evaluating surface irrigation systems*. Irrigation and drainage paper 45Food and Agriculture Organization of the United Nations, Rome.
Wang, X. Y. (2010). Irrigation water use efficiency of farmers and its determinants: evidence from a survey in Northwestern China. *Agricultural Sciences in China*, *9*(9), 1326-1337.
WFP and CSA 2019. Comprehensive Food Security and Vulnerability Analysis (CFSVA) Ethiopia 2019. Accessed at: https://docs.wfp.org/api/documents/WFP-0000106754/download/
Zhao, X., Lynch Jr, J. G., & Chen, Q. (2010). Reconsidering Baron and Kenny: Myths and truths about mediation analysis. *Journal of consumer research*, *37*(2), 197-206.
Zheng, H., Ying, H., Yin, Y., Wang, Y., He, G., Bian, Q., Cui, Z. and Yang, Q., (2019). Irrigation leads to greater maize yield at higher water productivity and lower environmental costs: a global meta-analysis. *Agriculture, Ecosystems & Environment*, *273*, 62-69.

Tables

Table 1: Description statistics of variables used in the analysis

Pooled (n=2,879)			Nonuser (n=2,564)	Users (n=315)	Mean Diff
Variables	Mean	Std. Dev.	Mean	Mean	
Sex of the head	0.752	0.432	0.784	0.836	-0.052**
Age of the head	46.242	15.324	46.354	46.587	-0.233
Education HH	0.376	0.484	0.375	0.376	-0.001
Access to credit	0.198	0.401	0.216	0.241	-0.025
Livestock ownership	4.764	5.854	4.428	4.997	-0.570*
Drought index	0.027	0.163	0.031	0.006	0.024**
Distance to road	17.067	22.746	15.731	14.141	1.59
Access to market	0.470	0.499	0.492	0.333	0.159***
Land	1.245	1.386	1.226	1.400	-0.174**
Access to agri extension	0.940	0.237	0.940	0.951	-0.011
Family size	4.034	1.924	4.189	4.570	-0.381***
Wealth index	-0.925	0.964	-1.001	-0.889	-0.112**
Chemical fertilizer	0.472	0.499	0.385	0.457	-0.073**
Poor nutrient	0.036	0.187	0.021	0.025	-0.004
Slop of plots	0.784	0.412	0.791	0.841	-0.050**

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 2: Estimating the impacts of irrigation using endogenous switching regression model

Outcome variables	ATT		ATU	
	coef	se	**coef**	se
DDS	2.149***	0.067	0.339***	0.025

Note: *** p<0.01

Table 3: Impact pathways: propensity score matching (PSM)

Produce Noncereal			Produce fruit or vegetable		Spending on nutritious food		Adoption of fertilizer		Livestock size		time for fetching water by female	
Algorithms	ATT	S.E.	ATT	S.E.	ATT	S.E.	ATT	S.E.	ATT	S.E.	ATT	S.E.
Nearest Neighbor (2)	0.189***	0.026	0.266***	0.039	0.591	6.697	0.09**	0.04	0.545	0.363	0.454	1.368
Nearest Neighbor (3)	0.199***	0.024	0.292***	0.037	1.144	6.602	0.08**	0.038	0.528	0.376	1.298	0.200
Caliper matching												
Radius of 0.01	0.198***	0.018	0.295***	0.035	-2.267	6.637	0.067*	0.035	0.277	0.354	1.272	-0.120
Radius of 0.05	0.19***	0.018	0.289**	0.033	-3.214	6.493	0.067**	0.034	0.206	0.342	1.229	0.040
kernel matching												
Bandwidth of 0.01	0.199***	0.018	0.294***	0.035	-2.771	6.621	0.06*	0.035	0.275	0.353	1.267	-0.080
Bandwidth of 0.05	0.194***	0.017	0.291***	0.033	-1.372	6.429	0.07**	0.034	0.195	0.336	1.208	0.120

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 4:Impact pathways: system equations

Mediators	Pvalue			Decision	Share
	STEP 1 (X -> M)	STEP 2 (M -> Y)	Sobel-test		
Produce Noncereal	0.000	0.004	0.026	Complete mediation	9.8
Produce fruit or vegetable	0.000	0.000	0.000	Complete mediation	44.4
Spending on nutritious items	0.352	0.000	0.352	No mediation	-
Adoption of fertilizer	0.013	0.000	0.024	Complete mediation	13.0
Livestock size (TLU)	0.072	0.000	0.087	No mediation	-
Time for fetching water by female	0.530	0.006	0.541	No mediation	-

Figure 1: Conceptual framework of the linkages between irrigation and nutrition outcomes

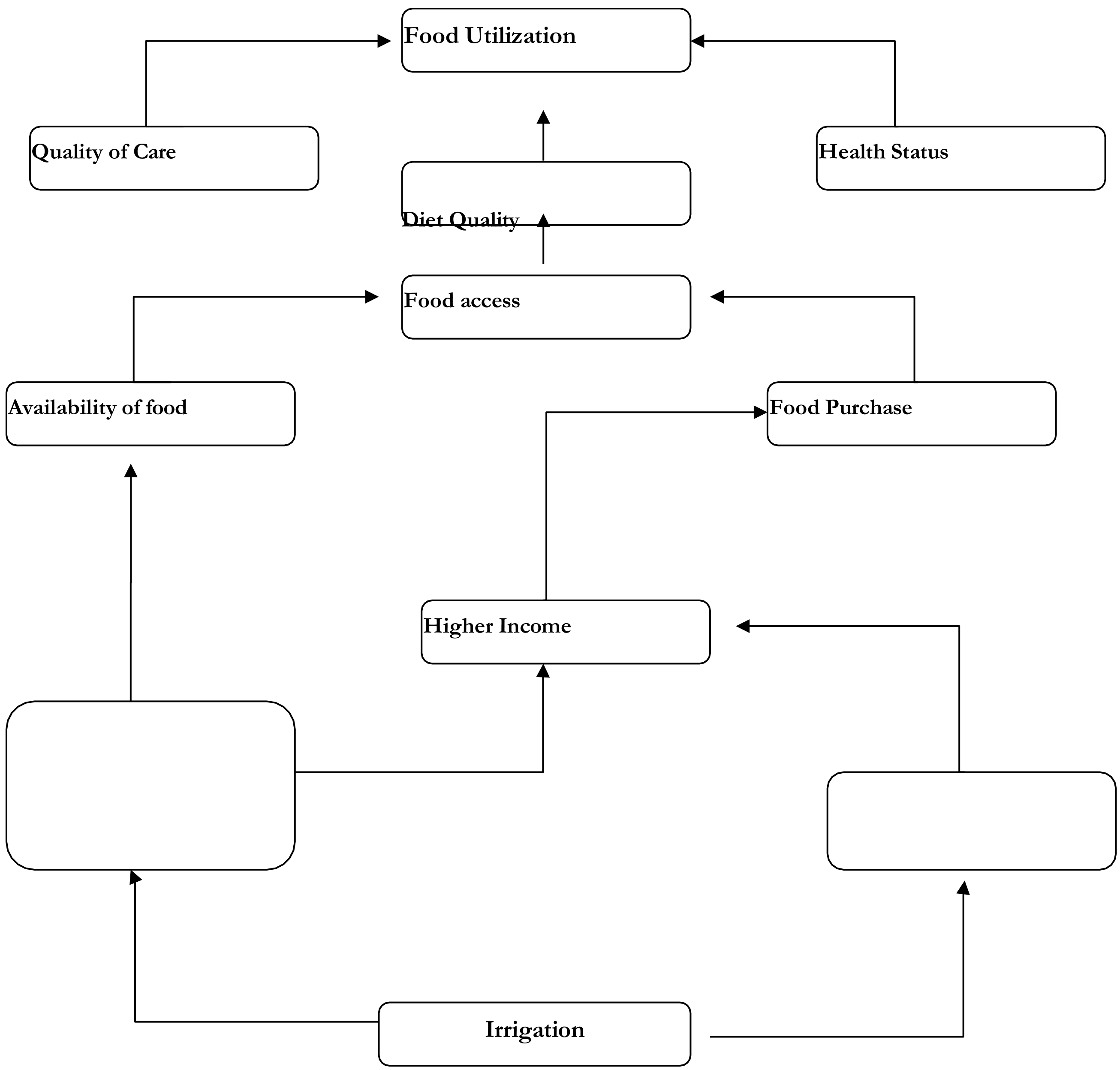
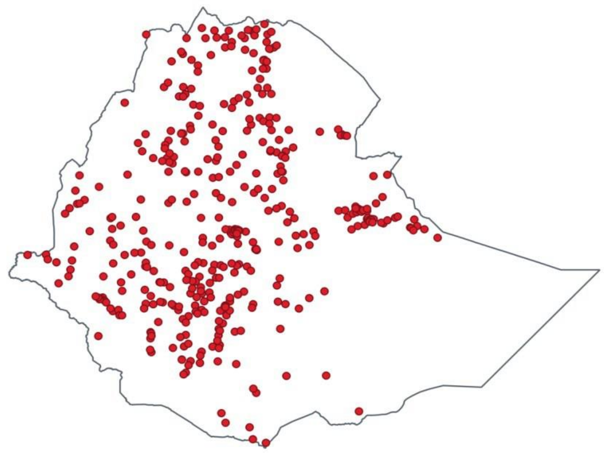


Figure 2: Locations of the enumeration areas in the country



Appendix

Table A 1: Definition and summary of variables used for this study

Variable	Definition
Sex of the head	1 if the household head is male; 0 otherwise. Number of
Age of the head	years the household head lived
Education HH	1 if the household head can read and write; 0 otherwise. 1 if the
Access to credit	household accessed credit; 0 otherwise
Livestock ownership	size of livestock owned in tropical livestock unit
Drought index	1 if village level SPEI index is less than -1; 0 otherwise Distance to
Distance to road	the nearest Major Road in km
Access to market	1 if the household leaves in the community where there is a weekly market; 0 otherwise
Land	size of cultivated land in hectare
Access to Agri extensio	n 1 if the household leaves in the community where there is an extension worker; 0 otherwise
Family size	Number of household members in the adult equivalent
Wealth index	An index computed as the score along the first principal component of a principal component analysis applied to households' assets
Chemical fertilizer	1 if the household uses chemical fertilizer; 0 otherwise
Poor nutrient	1 if the agricultural soil nutrients availability is a severe constraint
Slop of plots	1 if at least one of the plots is flat; 0 otherwise

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Slope

Table A 2: Proportion of households that consumed each food group

Food Group	Nonusers	Users	Mean Diff
Cereals	0.972	0.994	-0.022**
Beans	0.676	0.505	0.171***
Vegetables	0.473	0.502	-0.028
Fruits	0.203	0.257	-0.054**
Meat/poultry	0.206	0.162	0.044*
Egg	0.129	0.121	0.008
Fish	0.018	0.003	0.015*
Oil	0.802	0.838	-0.036
Dairy products	0.386	0.54	-0.154***
condiments	0.96	0.971	-0.012
Roots	0.427	0.39	0.037
Sweet/sugar	0.436	0.616	-0.180***

Note: *** p<0.01, ** p<0.05, * p<0.1

Table A 3: List of crop items produced using irrigation

Crop	Percent	Crop	Percent	Crop	Percent	Crop	Percent
Barley	0.59	Cabbage	0.37	Ground Nuts	0.37	Coffee	6.83
Maize	12.34	Carrot	0.07	Rape Seed	0.07	Cotton	0.07
Millet	0.07	Garlic	0.81	Sesame	0.15	*Enset*	1.91
Oats	0.07	Kale	1.69	Sunflower	0.07	*Gesho*	2.28
Rice	0.07	Lettuce	0.15	Black Pepper	0.07	Sugar Cane	2.87
Sorghum	14.03	Onion	1.1	Red Pepper	0.37	Rue	0.15
Teff	3.31	Green Pepper	0.88	Apples	0.07	*Gishita*	0.07
Wheat	1.4	Potatoes	0.88	Bananas	4.92	Avocados	1.47
Cassava	1.1	Pumpkins	0.51	Lemons	2.87	*Amboshika*	0.29
Chick Peas	0.07	Sweet Potato	2.2	Mandarins	0.44	*Comtatie*	0.22
Haricot Beans	1.47	Tomatoes	1.76	Mangos	4.7	Other Fruits	2.57
Horse Beans	0.29	*Godere*	0.51	Beer Root	0.15	Other Spices	0.07
Oranges	2.87	Lentils	0.07	Guava	1.69	Other Pulses	0.15
Papaya	1.54	Field Peas	0.15	Spinach	0.22	Other Cereal	0.07
Citron	0.15	Cactus	0.29	Chat	13.96		

Table A 4: The source of water used for irrigation

The source of water used for irrigation	Percent
River	68.58
Lake	1.91
Pond	7.22
Harvested Water	1.27
Borehole	7.11
Piped water	0.96
Protected Borehole	0.21
Water Harvested	0.42
from nothing	0.21
Spring	1.06
stand piped water	0.53

Table A 5: Falsification test for instrument

VARIABLES	Irrigation	DDS
The slope of the plots	0.239**	-0.051
	(0.102)	(0.086)
Constant	-1.034**	5.298***
	(0.459)	(0.530)
Other controls	Yes	Yes
Observations	2,557	2,259

Robust standard errors in parentheses; note:*** p<0.01, ** p<0.05

Table A 6: Maximum likelihood estimates of the endogenous switching regression model

VARIABLES	DDS_1	DDS_0	Irrigation
Sex of the head	-0.053	0.092	0.064
	-0.247	-0.098	-0.102
Age of the head	-0.006	-0.032*	0.011
	-0.046	-0.017	-0.016
Education HH	0.670***	0.428***	-0.03
	-0.211	-0.08	-0.078
Access to credit	0.01	-0.025	-0.016
	-0.245	-0.095	-0.09
Livestock ownership	0.029	0.029***	0
	-0.02	-0.007	-0.005
Distance to road	-0.006	-0.004	0.001
	-0.004	-0.002	-0.002
Access to market	0.537**	0.047	-0.200***
	-0.234	-0.075	-0.073
Land	0.109	0.034	0.046*
	-0.084	-0.031	-0.026
Access to Agri extension	-0.061	0.167	0.309*
	-0.468	-0.16	-0.182
Family size	0.102*	0.060***	0.018
	-0.061	-0.023	-0.022
Wealth index	0.396***	0.508***	0.026
	-0.113	-0.043	-0.042
Chemical fertilizer	0.353	0.244***	0.191**
	-0.226	-0.082	-0.082
Poor nutrient	1.461**	0.029	-0.068
	-0.618	-0.222	-0.249
Drought index	-0.143	1.013***	-1.166***
	-0.667	-0.298	-0.445
Slop of plots			0.213**
			-0.102
Region dummies	Yes	Yes	Yes
sigma	0.361***	0.522***	

	-0.03	-0.036	
rho	-0.064	-0.720**	
	-0.322	-0.344	
Constant	4.420***	4.494***	-0.521
	-1.184	-0.602	-0.494
Wald test of indep. eqns.:	$chi^2(1)$ = 4.46Prob > chi2 = 0.0348		

Robust standard errors in parentheses; note:*** p<0.01, ** p<0.05, * p<0.1

Table A 7: Sensitivity analysis for noncereals

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	1	1	1	1
1.25	0	0	1	1	1	1
1.5	0	0	1	1	1	1
1.75	0	0	1	1	1	1
2	0	0	1	1	1	1

Note: "gamma= log odds of differential assignment due to unobserved factors;sig+= upper bound significance level; sig- - lower bound significance level; t-hat+ - upper bound Hodges–Lehmann point estimate;t-hat- - lower bound Hodges–Lehmann point estimate; CI+ - upper bound confidence interval (a=.95); CI- - CI- - lower bound confidence interval (a=.95)

Table A 8: Sensitivity analysis for fruits and vegetables

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	0.5	0.5	0.5	0.5
1.25	0	0	0.5	0.5	0.5	0.5
1.5	0	0	0.5	0.5	0.5	0.5
1.75	0	0	0.5	0.5	0.5	0.5
2	0	0	-4.00E-07	0.5	-4.00E-07	0.5

See the note under Table A7.

Table A 9: Sensitivity analysis for inorganic fertilizer

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	0.5	0.5	0.5	0.5
1.25	0	0	0.5	0.5	0.5	0.5
1.5	0	0	0.5	0.5	0.5	0.5
1.75	0	0	0.5	0.5	0.5	0.5
2	0	0	0.5	0.5	0.5	0.5

See the note under Table A7.

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

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Contact Us
African Economic Research Consortium
Consortium pour la Recherche Economique en Afrique
Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
Tel: +254 (0) 20 273 4150
communications@aercafrica.org