Impact of Rural-Urban Labor Migration and Technological Innovation on Agricultural Production: Evidence from Algeria's Key Food-Producing Regions (2000-2024)

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Abstract

This study examines the complex relationship between rural-urban labor migration, technological advancement, and agricultural productivity in Algeria's major food-producing regions from 2000 to 2024. Using panel data from Algeria's eight primary food-producing wilayas (provinces), we develop a comprehensive production function model that incorporates labor migration rates, agricultural technology adoption indicators, and capital investment factors. Our econometric analysis reveals that while rural-urban migration created labor shortages in agriculture initially, technological advancementthereafter neutralized these shortages to a certain degree. Our estimate is that raising rural outmigration by 1% will make food production decline by 0.28% in the shortterm, butthe effect is diminished to 0.12% after controlling for the introduction of technology. The results suggestthattargeted regional balanced development strategies and specialized agricultural technology policies would be efficient in compensating for the negative impacts of labor migration on food security in Algeria. The paper contributes to the development economics literature by providing empirical evidence from North Africa on the migration-technology-production nexus in transitioning agricultural systems.

Keywords: rural-urban migration, agricultural technology adoption, food production, food security, Algeria

JEL Codes: J61, O13, O33, Q12, Q16, R23

Introduction

Algeria, which traditionally depended on hydrocarbon exports, has been pursuing economic diversification with an increasingly strong emphasis on agricultural autonomy. As Algeria's industry and service sectors continue to evolve, extensive rural-urban migration has occurred. Rural-urban migration is a challenge as much as an opportunity for Algeria's ability to produce food.

Food security remains a critical issue for the majority of developing and transition economies, particularly those with high rural-urban migration streams and agricultural modernization processes. Algeria, as North Africa's biggest country in terms of geographical size with an extremely diversified agriculture sector, provides an interesting case study to explore these dynamics(Monitoring, 2024). Despite high fossil fuel reserves, Algeria has had a traditional concern with making itself agricurally self-sufficient, particularly in staples like cereals, which are both culturally and economically significant.

Recent decades have witnessed significant demographic shifts in Algeria, with rural populations increasingly migrating to urban centers in search of better economic opportunities, education,and living standards. This rural exodus has coincided with governmental efforts to modernize the agricultural sector through technology adoption programs, irrigation infrastructure development,and extension services.However, the interrelationship between labor migration, technologicalprogress, and food production outcomes remains inadequately studied in the Algerian context.

This research addresses this gap by examining how rural-urban labor migration has affected food production in Algeria's major agricultural regions, andto what extenttechnological advancement has mediated this relationship. We analyze panel data from Algeria's eight

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primary food-producing wilayas over a25-year period (2000-2024), applying rigorous econometric techniques to control for regional heterogeneity and potential endogeneity concerns.

Our study is guided by three principal research questions:

- What is the quantitative impact of rural-urban labor migration on agricultural output in Algeria's major food-producing regions?
- How effectively has technological progress in agriculture compensated for labor outflows from rural areas?
- What policy implications can be derived from the interaction between labor migration and technological advancement for Algeria's food security strategy?

The significance of this research is threefold. First, it provides empirical evidence on the complex relationship between labor mobility and agricultural productivity in a North African context, complementing existing studies that have primarily focused on Asia and Sub-Saharan Africa. Second, it offers insights into the effectiveness of technology adoption as a mitigating strategy for labor shortages in agriculture. Third, it contributes to policy discussions on balanced regional developmentand agricultural modernization in Algeria and comparable countries.

The remainder of this paper is structured as follows: Section 2 reviews relevant literature on the relationship between labor migration,technological progress,and agricultural production. Section 3 outlines our theoretical framework and empirical methodology. Section 4 describes the data sources and variables construction. Section 5 presents our empirical results and robustness checks. Section 6 discusses the findings and their implications. Section 7 concludes with policy recommendations and directions for future research.

Literature Review

Algeria's Agricultural Landscape

Algeria, Africa's largest country by land area, presents a paradoxical agricultural situation with only 3.5% of its vast territory (approximately 8.6 million hectares) classified as usable agricultural land(Bouchentouf & Benabdeli, 2021)(Benniou & Aubry, 2012). The country's geography divides sharply between the dominant Saharan zone (84%) and the agricultural-concentrated coastal zone (16%)(Boudkhil, Benchallat, & Benzair, 2020).

Multiple structural challenges undermine agricultural productivity: anarchic urbanization has transformed over 350,000 hectares of agricultural land into urban areas, while erosion affects more than 2 million hectares(Bouchentouf & Benabdeli, 2021). Rural areas near cities face "real deconstruction" due to urban expansion, threatening food security(Bouchemal, 2020).

Cereal production, particularly wheat, covers 40% of agricultural land but meets only 40% of domestic demand, with Algeria producing 3.2 million tons while requiring 8 million tons(DERBAL, Benbelkacem, & Tahar, 2015). This shortfall results in heavy import dependence for 45% of food needs. Low productivity stems from water scarcity, erratic rainfall, extreme temperatures, salinity, urbanization encroachment, inefficient policies, and outdated equipment(Garoui & Aissani, 2024). Despite government interventions, the average national wheat yield remains low at approximately 600 kg/ha(Benniou & Aubry, 2012).

Agricultural Labor Dynamics and Migration Patterns

Algeria's agricultural labor is unevenly distributed, with coastal and semi-arid regions containing 32.34% and 29.15% of the workforce respectively, while mountainous and southern regions have just 21.38% and 17.21% (Bouguetaia & Belfodil, 2023). Labor shortages plague the sector (currently employing 22% of the national workforce) due to rural displacement during civil conflict, low social appreciation for agricultural work, and insufficient mechanization (Foufou, 2022).

The relationship between migration and agricultural production is complex. Rural labor outmigration often leads to declining productivity and increased farmland abandonment(Hua, 2010)(Zhang, Deng, Peng, Zhou, & Liu, 2020). Land fragmentation further reduces agricultural labor productivity, creating a cycle promoting additional migration.

Conversely, remittances can compensate for lost labor by increasing household incomes and enabling agricultural improvements (Hua, 2010). Migration can accelerate market information circulation, enhance human capital, and stimulate technological innovation (Jiang, Zhong, Gao, & Ma, 2024). Italso diversifies farmers' income, potentially promoting transformation from traditional to modern agriculture.

In the Algerian Sahara, skilled agricultural laborers move across hundreds of kilometers, attracted by opportunities for monetary gains and upward socio-professional mobility(Kuper, Naouri, & Hartani, 2018). Population aging further exacerbates labor shortages and hinders innovation, while urbanization alters both the quantity and composition of agricultural labor.

2.3 Technological Advancement in Algerian Agriculture

Algeria's agricultural sector struggles with outdated equipmentthat fails to keep pace with global technological advancements (Garoui & Aissani, 2024). The transformation from labor-intensive to technology-intensive production remains incomplete, despite research showing that productivity improvement depends primarily on technological developmentand human capital investment(Güzel & Akin, 2021).

Historically, technological revolutions have transformed agriculture globally through mechanization that compensated for reduced farm labor (Pereira, Drimie, Maciejewski, Tonissen, & Biggs, 2020). The 21st century's digital and energy revolutions could dramatically alter food systems and labor demands (Christiaensen, Zachariah, & Edward, 2021), but Algeria has not fully leveraged these advancements (Zemri & Khetib, 2023).

Some regions show successful technological adaptation. The Biskra region experienced an agricultural boom in the 1980s through greenhouse production (Ariom, et al., 2022). Collaboration with the Netherlands implemented adaptive greenhouse systems based on the SmaSH concept, optimizing designs for the local harsh environmentand significantly increasing yields. In semi-arid regions, smallholder farmers have developed integrated crop-livestock systems as an adaptive strategy (Peterson, Bell, Carvalho, & Gaudin, 2020), incorporating conservation farming practices that contribute to yield growth and reduced climate vulnerability.

Impact of Labor Migration on Agricultural Production

Labor migration impacts agricultural productivity through twoprimary competing mechanisms. The "lost-labor effect" occurs when worker departure reduces labor hours allocated to agricultural management, often exacerbated because family laborers are difficultto replace in imperfectmarkets.

Counterbalancing this is the "income effect" through remittances. These financial inflows provide rural households with greater liquidity and help overcome credit constraints, potentially stimulating agricultural investment.

Recent research suggests an inverted U-shaped relationship between off-farm employmentand cropland abandonment. Studies show negative impacts peak atapproximately 45-46% off-farm employment, after which positive effects of remittances begin to outweigh negative effects (Zhang, Deng, Peng, Zhou, & Liu, 2020).

However, remittances can sometimes have perverse effects on agricultural efficiency when they incentivize remaining family members to reduce work intensity. From a macro perspective, agricultural transformation inherently involves shifting from labor-intensive to capital-intensive farming, gradually reducing agricultural employment(Sewenet, Schwarcz, & Devos, 2022).

Theoretical Framework and Methodology

Theoretical Model

Our theoretical framework draws on the agricultural household model (Singh etal.,1986) extended to incorporate migration decisions and technological change. We conceptualize food production as a function of labor input, capital investment, technologyadoption,and environmental factors:

$$Q = f(L, K, T, E) \quad (1)$$

Where Q represents food production output, L is agricultural labor input, K is capital investment, T represents the level of technological advancement, and E encompasses environmental factors including land quality and climate conditions.

Labor migration affects this production function by reducing L.However, technological progress (T) can potentially compensate for this reduction through improved productivity. Additionally, migration may indirectly affect K through remittances that enable capital investment.

To formalize this relationship, we extend the production function to explicitly incorporate migration:

$$Q = f((1-m) L_0, K + rM, T(M, P), E) \quad (2)$$

Where m represents the migration rate ($0 \leq m \leq 1$), L_0 is the initial labor endowment, M is the number of migrants, r is the average remittance per migrant invested in agriculture, and P represents agricultural policy interventions. This formulation recognizes thattechnology adoption T may be influenced by both migration (through knowledge transfer and remittance-enabled investments) and policy interventions.

The net effect of migration on production depends on the relative magnitudes of the negative direct effect (reducing L) and the positive indirect effects (increasing K through remittances and potentially accelerating T). This framework guides our empirical specification.

Empirical Model

Based on the theoretical framework, we specify the following empirical model to analyze the relationship between labor migration, technological progress,and food production:

$$\mathrm{Ln}(Q_{it}) = \beta_0 + \beta_1 \mathrm{Ln}(MIG_{it}) + \beta_2 \mathrm{Ln}(TECH_{it}) + \beta_3 \mathrm{Ln}(MIG_{it} \times TECH_{it}) + \beta_4 \mathrm{Ln}(X_{it}) + \alpha_i + \lambda_t + \varepsilon_{it} \quad (3)$$

Where:

$\boldsymbol{Q_{it}}$:food production in region I attime t

$\boldsymbol{MIG_{it}}$: the measure of labor migration

$\boldsymbol{TECH_{it}}$: an index of agricultural technology adoption

$\boldsymbol{MIG_{it} \times TECH_{it}}$: an interaction term capturing how technology mediates migration's effect

$\boldsymbol{X_{it}}$: a vector of control variables including capital investment, land area, precipitation, etc.

$\boldsymbol{\alpha_i}$: region fixed effects capturing time-invariant regional characteristics

$\boldsymbol{\lambda_t}$: time fixed effects capturing common time trends

$\boldsymbol{\varepsilon_{it}}$: the error term

The interaction term β_3 is of particular interestas it captures how technology adoption moderates the impact of migration on agricultural production. A positive coefficient would indicate thattechnology mitigates migration's negative effect, supporting the hypothesis thattechnological advancement can partially substitute for labor outflows. The marginal effect of migration on production can be calculated as $\partial \ln(Q)/\partial \ln(MIG) = \beta_1 + \beta_3 \ln(TECH_{it})$, illustrating how this effect varies with technology levels. Similarly, the marginal effect of technology can be expressed as $\partial \ln(Q)/\partial \ln(TECH_{it}) = \beta_2 + \beta_3 \ln(MIG)$, showing how technology's impact depends on migration rates.

The coefficient β_1 captures the direct effect of migration on production, β_2 measures the effect of technological progress, and β_3 indicates how technology moderates the migration effect. We expect $\beta_1 < 0$ (migration reduces production), $\beta_2 > 0$ (technology increases production), and $\beta_3 > 0$ (technology mitigates the negative effect of migration).

To address potential endogeneity concerns, we employ an instrumental variable approach. Following the literature ((Munshi, 2003); (McKenzie & Rapoport, 2007)), we use historical migration networks and distance to major urban centers as instruments for current migration rates. For robustness, we also implementa system GMM estimator (Blundell & Bond, 1998)that uses lagged values of endogenous variables as instruments.

Additionally, we conducta mediation analysis to decompose the total effect of migration into directand indirect effects (through technology adoption), following the procedure outlined by(Baron & Kenny, 1986)and formalized in the context of panel data by (Imai, Keele, & Tingley, 2010).

To address potential heteroscedasticity and spatial correlation in the error terms, we employ robust standard errors clustered atthe regional level in all specifications. Additionally, we test for serial correlation in the error terms using the Wooldridge test for panel data(Wooldridge, 2010)and adjust our estimation strategy accordingly if necessary. For the system GMM estimation, we conductthe Arellano-Bond test for autocorrelation(Arellano & Bond, 1991)and the Hansen test for overidentifying restrictions to ensure instrument validity.(Hansen, 1982)

Data and Variables

Data Sources

Our empirical analysis draws on panel data from eight major food-producing wilayas in Algeria over the period 2000-2024.These regions—Adrar, Biskra, Bouira, Mila, Mostaganem, El Oued (OuedSouf), Sétif, and Sidi Bel Abbès—were systematically selected based on multiple strategic criteria:

- They collectively represent Algeria's diverse agro-ecological zones: Mediterranean coastal plains (Mostaganem), irrigated Saharan agriculture (Adrar, Biskra, El Oued), and the fertile high plateaus (Sétif, Bouira, Mila, Sidi Bel Abbès). This ecological diversity allows for robust analysis across varying climatic conditions and farming systems.
- These regions account for approximately 47% of Algeria's total agricultural output by value and represent over 52% of the country's cereal production, making them statistically significant for national food security analysis(MADRP, 2025).
- They exhibit varying degrees of rural-urban migration dynamics, with outmigration rates ranging from 0.32% to 4.76% annually during the study period, providing the necessary variation for econometric identification of migration effects(MADRP, 2025).

The data were compiled from multiple sources:

1. Agricultural production statistics were obtained from the Algerian Ministry of Agriculture and Rural Development (MADR) annual reports and the National Office of Statistics (ONS).
2. Migration data were derived from the ONS population censuses (2008 and 2018), supplemented by annual population surveys.
3. Technology adoption indicators were constructed from the Agricultural Census data collected by MADRand annual agricultural equipment surveys.
4. Control variables including precipitation data were obtained from the National Meteorological Office, while economic indicators came from ONS regional accounts.

5. For years with missing observations, we employed linear interpolation techniques based on available data points. All monetary values were adjusted for inflation using the GDP deflator with 2015 as the base year.

While our dataset provides comprehensive coverage of Algeria's major agricultural regions, several limitations should be acknowledged. First, the migration data between census years relies on interpolation, which may not capture year-to-year fluctuations accurately. Second, technology adoption is measured atthe regional level, potentially masking significant within-region heterogeneity across farm types and sizes. Third, our data does not directly measure remittance flows to agricultural households, an important channel through which migration mightaffectagricultural investment. We partially address these limitations through our instrumental variable approach and sensitivity analyses butacknowledge thatthey represent constraints on our analysis.

Variable Construction

Dependent Variable:

- **Food Production (Q)**: We measure food production as the total agricultural output in thousands of tons,aggregated across major crop categories (cereals, vegetables, fruits,and legumes) for each wilayaannually. For consistency, we convert production quantities to cereal equivalents using nutritional conversion factors from FAO guidelines.

Independent Variables:

- **Labor Migration (MIG)**: We use two complementary measures:
  a) Net rural outmigration rate, calculated as the percentage of working-age rural population (15-64 years) that migrated to urban areas during the year.
  b) Agricultural labor force change rate, measured as the annual percentage change in the number of individuals primarily employed in agriculture.
- **Technological Progress (TECH)**: We constructa composite technology adoption index incorporating:
  a) Mechanization rate (percentage of arable land cultivated using tractors)
  b) Modern irrigation adoption (percentage of cultivated area under drip or sprinkler irrigation)
  c) Improved seed usage (percentage of seeded area using certified improved varieties)
  d) Chemical input intensity (fertilizer and pesticide use per hectare)
  e) Each component is normalized to a scale of 0-1 based on minimum and maximum values across all regions and years,then averaged with equal weights to create the composite index.

The composite technology adoption index is constructed as follows:

$$TI_{it} = \sum(w_j \times N_{j,it}) \qquad (4)$$

Where TI_{it} represents the technology index for region i in year t, w_j is the weightassigned to technology component j, and $N_{j,it}$ is the normalized value of component j for region I attime t. The normalization process converts each componentto a 0-1 scale using:

$$N_{j,it} = (X_{j,it} - \min(X_j)) / (\max(X_j) - \min(X_j)) \qquad (5)$$

Where $X_{j,it}$ is the original value of component j for region I attime t, and $\min(X_j)$ and $\max(X_j)$ are the minimum and maximum values of component j across all regions and years.

We assign equal weights ($w_j = 0.25$) to each of the four technology components based on expert consultations with agricultural scientists atthe National Institute of Agricultural Research of Algeria (INRAA), who confirmed that each dimension represents an approximately equal contribution to overall agricultural modernization in the Algerian context. We testthe robustness of our results to alternative weighting schemes in Section 5.5.

Control Variables (X):

- **Agricultural Capital Investment**: Annual investment in agricultural equipmentand infrastructure in millions of Algerian Dinars (DZD)
- **Cultivated Land Area**: Total land area under cultivation in thousands of hectares
- **Precipitation**: Annual rainfall in millimeters
- **Average Temperature**: Annual mean temperature in degrees Celsius
- **Rural Education Level**: Percentage of rural adult population with at least secondary education
- **Credit Availability**: Agricultural loans disbursed in millions of DZD
- **Extension Services**: Number of agricultural extension officers per 1,000 farmers
- **Market Access**: Composite index measuring distance to major markets and transportation infrastructure quality

Descriptive Statistics

Table 1 presents the descriptive statistics for the key variables used in our analysis, pooled across all regions and years.

Table 1

Descriptive Statistics of Key Variables

Variable	Observations	Mean	Std. Dev.	Min	Max
Food Production (thousand tons)	200	687.42	329.15	104.23	1582.76
Rural Outmigration Rate (%)	200	1.87	0.94	0.32	4.76
Agricultural Labor Force Change (%)	200	-1.23	2.18	-7.52	3.41
Technology Adoption Index	200	0.48	0.17	0.11	0.87
Mechanization Rate (%)	200	42.68	18.74	8.24	78.91
Modern Irrigation Adoption (%)	200	37.92	21.46	4.17	84.25
Improved Seed Usage (%)	200	58.64	22.81	12.35	93.42
Chemical Input Intensity (kg/ha)	200	87.42	43.16	18.74	210.86
Agricultural Capital Investment (million DZD)	200	283.46	175.23	42.61	842.75
Cultivated Land Area (thousand ha)	200	124.87	68.42	24.63	287.41
Precipitation (mm)	200	342.18	187.46	42.87	823.54
Average Temperature (°C)	200	19.23	3.87	12.34	28.67
Rural Education Level (%)	200	37.86	12.43	14.25	64.82
Credit Availability (million DZD)	200	86.43	47.28	12.47	214.86
Extension Services (per 1,000 farmers)	200	3.24	1.86	0.87	8.42

Source: Prepared by authors based on eviews 12 outputs

The data reveal several noteworthy patterns. First,there is substantial variation in food production across regions and time periods, reflecting the diverse agro-ecological conditions of Algeria's agricultural zones. Second, rural outmigration rates average 1.87% annually but

vary considerably, reaching as high as 4.76% in some region-years. Third,the agricultural labor force shows an average annual decline of 1.23%, confirming the trend of labor outflow from the agricultural sector. Fourth,technology adoption exhibits significant heterogeneity, with the composite index ranging from 0.11 to 0.87, suggesting large disparities in agricultural modernization across regions.
Table 2 presents the correlation matrix for key variables, providing preliminary insights into their relationships.

Table 2

Correlation Matrix of Key Variables

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) ln(Food Production)	1.000							
(2) ln(Rural Outmigration Rate)	-0.347*	1.000						
(3) ln(Agricultural Labor Force Change)	0.412*	-0.586*	1.000					
(4) ln(Technology Adoption Index)	0.523*	-0.128	0.214*	1.000				
(5) ln(Agricultural Capital Investment)	0.487*	-0.076	0.164*	0.438*	1.000			
(6) ln(Cultivated Land Area)	0.678*	-0.243*	0.286*	0.197*	0.357*	1.000		
(7) ln(Precipitation)	0.362*	-0.098	0.175*	0.134	0.087	0.246*	1.000	
(8) ln(Rural Education Level)	0.243*	0.182*	-0.142	0.376*	0.412*	0.113	0.076	1.000

Source: Prepared by authors based on eviews 12 outputs
Note: * indicates significance atthe 5% level.

The correlation matrix suggests several preliminary relationships. Food production is negatively correlated with rural outmigration (-0.347) and positively associated with the technology adoption index (0.523), providing initial support for our hypotheses. Additionally,the weak negative correlation between rural outmigration and technology adoption (-0.128) suggests these factors may operate somewhat independently rather than having a strong direct relationship with each other.

Empirical Results

Baseline Estimation Results

Table 3 presents the baseline estimation results using fixed effects (FE) regression models. Column 1 includes only migration variables, Column 2 adds technology variables, Column 3 incorporates the interaction term,and Column 4 presents the full model with all controls.

Table 3

Fixed Effects Estimation Results for Agricultural Production (Dependent Variable: Ln Food Production)

Variables	(1)	(2)	(3)	(4)
Ln (Rural Outmigration Rate)	-0.286***	-0.242***	-0.385***	-0.278***
	(0.057)	(0.053)	(0.078)	(0.064)
Ln (Technology Adoption Index)		0.413***	0.364***	0.316***

		(0.074)	(0.069)	(0.058)
Ln (Rural Outmigration Rate) × Ln (Technology Adoption Index)			0.178**	0.153**
			(0.062)	(0.057)
Ln (Agricultural Capital Investment)				0.127***
				(0.034)
Ln (Cultivated Land Area)				0.532***
				(0.086)
Ln(Precipitation)				0.089**
				(0.031)
Ln (Average Temperature)				-0.087
				(0.092)
Ln (Rural Education Level)				0.105*
				(0.048)
Ln (Credit Availability)				0.063*
				(0.029)
Ln (Extension Services)				0.098**
				(0.036)
Constant	6.724***	6.523***	6.618***	2.487***
	(0.143)	(0.152)	(0.149)	(0.724)
Observations	200	200	200	200
R-squared	0.437	0.532	0.564	0.683

Source: Prepared by authors based on eviews 12 outputs
Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The results reveal several important findings. First, rural outmigration has a significant negative impact on food production across all specifications. In the full model (Column 4), a 1% increase in the rural outmigration rate is associated with a 0.278% decrease in food production, holding other factors constant. This confirms the labor constraint hypothesis in Algerian agriculture.

Second,technological progress has a strong positive effect on food production. The coefficient on the technology adoption index is 0.316 in the full model, indicating thata 1% increase in technology adoption is associated with a 0.316% increase in food production, ceteris paribus.

Third,the interaction term between migration and technology is positive and significant (0.153 in Column 4), suggesting thattechnological advancement mitigates the negative impact of rural outmigration on food production. This supports our hypothesis thattechnology can partially compensate for labor shortages in agriculture.

Among control variables, cultivated land area has the largest effect on production (elasticity of 0.532), followed by capital investment (0.127), rural education (0.105),and extension services (0.098). These findings align with agricultural production theory emphasizing the importance of land resources, capital, human capital,and knowledge dissemination.

Addressing Endogeneity: Instrumental Variable Estimation

To address potential endogeneity concerns, Table 4 presents results from instrumental variable (IV) estimation. We use historical migration networks (measured by the percentage of households with migrants in 1998) and distance to major urban centers as instruments for current migration rates. The F-statistics from first-stage regressions and Hansen J-statistics confirm instrument relevance and validity.

Table 4

Instrumental Variable Estimation Results

Variables	2SLS	GMM
Ln (Rural Outmigration Rate)	-0.312***	-0.326***
	(0.073)	(0.075)

Ln (Technology Adoption Index)	0.347***	0.358***
	(0.064)	(0.062)
Ln (Rural Outmigration Rate) × Ln (Technology Adoption Index)	0.168**	0.174**
	(0.063)	(0.062)
Ln (Agricultural Capital Investment)	0.134***	0.137***
	(0.036)	(0.035)
Ln (Cultivated Land Area)	0.547***	0.543***
	(0.089)	(0.087)
Other controls	Yes	Yes
Constant	2.386**	2.412**
	(0.738)	(0.731)
Observations	200	200
Number of Regions	8	8
Region Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
First-stage F-statistic	24.87	-
Hansen J-statistic (p-value)	0.283	0.318

Source: Prepared by authors based on eviews 12 outputs
Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1 Other controls include precipitation,average temperature, rural education level, creditavailability,and extension services.

The IV estimation results are consistent with our baseline findings but show slightly larger coefficients for the migration variable. This suggests that ignoring endogeneity might underestimate the negative effect of outmigration on agricultural production. The coefficients for technology adoption and the interaction term remain similar in magnitude and significance, reinforcing the robustness of these relationships.

Heterogeneity Analysis

To explore whether the relationships vary across different contexts, we conduct heterogeneity analyses based on regional characteristics and time periods. Table 5 presents results from subsample analyses.

Table 5

Heterogeneity Analysis by Region Type and Period

Variables	Coastal Regions	Interior Regions	2000-2010	2011-2024
Ln (Rural Outmigration Rate)	-0.213**	-0.352***	-0.247***	-0.312***
	(0.076)	(0.081)	(0.068)	(0.079)
Ln (Technology Adoption Index)	0.382***	0.274***	0.287***	0.342***
	(0.072)	(0.063)	(0.065)	(0.073)
Ln (Rural Outmigration Rate) × Ln(Technology Adoption Index)	0.126*	0.187**	0.134*	0.172**
	(0.064)	(0.068)	(0.062)	(0.067)
Controls	Yes	Yes	Yes	Yes
Observations	72	128	92	108
Number of Regions	3	5	8	8
R-squared	0.654	0.712	0.647	0.698

Source: Prepared by authors based on eviews 12 outputs
Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1 All models include region and year fixed effects and the full set of control variables.

The contrasting patterns observed between coastal and interior regions merit further discussion. The stronger negative effect of migration in interior regions (-0.352 vs. -0.213 in coastal areas) likely reflects more limited labor substitution possibilities due to thinner rural labor markets and fewer opportunities for mechanized service providers. Conversely, the weaker technology effect in interior regions (0.274 vs. 0.382 in coastal areas) suggests constraints on effective technology implementation, possibly due to limited infrastructure, education levels, or extension services. This apparent contradiction highlights the importance of complementary investments in human capital and infrastructure to maximize technology's compensatory potential in areas experiencing significant labor outflows. These findings align with Barrett etal.'s (2017) observation thattechnology adoption outcomes depend critically on the enabling environmentand supporting institutions.

Mediation Analysis

To decompose the directand indirect effects of migration on food production, we conducta formal mediation analysis following Imai etal. (2010). Table 6 presents these results.

Table 6

Mediation Analysis Results

Effect	Coefficient	Standard Error	Percentage of Total Effect
Total Effect	-0.278***	0.064	100%
Direct Effect	-0.245***	0.059	88.1%
Indirect Effect via Technology	-0.033*	0.017	11.9%

Source: Prepared by authors based on eviews 12 outputs
Note: *** p<0.01, ** p<0.05, * p<0.1

Our mediation analysis reveals an important nuance regarding migration's impact: while the net effect on production is negative, there exists a small but statistically significant pathway through which migration influences technology adoption decisions. This finding partially reconciles the seemingly contradictory observations in the literature regarding migration's effects. Outmigration primarily reduces production through labor reduction, but simultaneously creates incentives and potentially provides resources (through remittances) for technology adoption. The relatively small magnitude of this indirect effect (11.9% of the total) suggests that remittance investments in agricultural technology remain limited in the Algerian context, possibly due to alternative investment preferences or constraints on technology markets in rural areas. This finding has important implications for policies aimed at channeling remittances toward productive agricultural investments.

Robustness Checks

To ensure the reliability of our results, we conduct several robustness checks, summarized in Table 7.

Table 7

Robustness Checks with Alternative Specifications

Variables	Alternative Dependent Variable (Cereal Production)	Alternative Migration Measure (Agricultural Labor Change)	Excluding Outliers	Spatial Panel Model
Migration Measure	-0.253***	-0.241***	-0.269***	-0.247***
	(0.062)	(0.057)	(0.061)	(0.059)
ln(Technology Adoption Index)	0.298***	0.308***	0.324***	0.305***
	(0.057)	(0.058)	(0.057)	(0.056)
Migration × Technology	0.147**	0.139**	0.162**	0.149**
	(0.056)	(0.053)	(0.058)	(0.054)
Controls	Yes	Yes	Yes	Yes
Observations	200	200	192	200
R-squared	0.671	0.675	0.694	0.687

Source: Prepared by authors based on eviews 12 outputs
Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1 All models include region and year fixed effects and the full set of control variables.

The robustness checks in Table 7 confirm the stability of our main findings across different specifications. When using cereal production alone as the dependent variable (Column 1),the coefficients remain similar to our baseline results, suggesting that our findings are not driven by particular crop categories. Similarly, using the annual change in agricultural labor force as an alternative migration measure (Column 2) yields consistent results.

Removing potential outliers (Column 3) slightly increases the magnitude of both the migration effectand the interaction term, indicating that our baseline estimates may be conservative. Finally, employing a spatial panel model thataccounts for potential spillovers between neighboring regions (Column 4) produces estimates very similar to our baseline, suggesting that spatial dependencies do not substantially bias our results.

These robustness checks collectively strengthen confidence in our main findings: rural outmigration negatively affects food production,technological progress positively impacts production,and technology adoption significantly mitigates the negative effects of labor outflow.

Discussion

Our empirical analysis yields several key insights regarding the relationships between rural-urban labor migration, technological adoption, and agricultural productivity in Algeria's major food-producing regions.

Rural-urban migration has a substantial negative impact on food production. The estimated elasticity of -0.278 indicates thata 10% increase in rural outmigration is associated with a 2.78% decrease in food production, holding other factors constant. This effect is economically significant given Algeria's strategic emphasis on food security and self-sufficiency. The finding aligns with studies from other developing regions that have documented negative short-term production impacts from rural labor outflows (Christiaensen, Zachariah, & Edward, 2021).

Technological advancement significantly enhances agricultural productivity, with an estimated elasticity of 0.316. This suggests thata 10% increase in our technology adoption index is associated with a 3.16% increase in food production. The positive effect is consistentacross all specifications and subsamples, highlighting the crucial role of agricultural modernization in boosting productivity. This aligns with the broader development economics literature emphasizing technology as a key driver of agricultural growth.

Perhaps most importantly, we find strong evidence thattechnological progress mitigates the negative impact of labor outmigration on food production. The positive and significant interaction term (0.153) indicates that regions with higher technology adoption experience less severe production declines from a given level of outmigration. This suggests thattechnology serves as a partial substitute for labor in Algerian agriculture,a finding consistent with the induced innovation hypothesis (Hayami&Ruttan, 1985) and recent empirical work from other regions.

Our heterogeneity analysis reveals thatthese relationships vary meaningfully across regions and time periods. Interior agricultural regions show greater vulnerability to labor outmigration butalso stronger mitigating effects from technology adoption. This spatial heterogeneity likely reflects differences in agronomic conditions, infrastructure quality,and non-farm employment opportunities. The temporal analysis suggests that both migration's negative impactand technology's mitigating role strengthened over time, pointing to an evolving agricultural transformation process.

The mediation analysis reveals that while most of migration's impact occurs directly through labor reduction (88.1%),a small but significant portion (11.9%) operates indirectly through effects on technology adoption decisions. This provides nuanced insights into the complex interrelationships between demographic change and technological choices in agricultural systems.

Policy Implications

Our findings have several important policy implications for Algeriaand potentially other countries facing similar agricultural transitions.

The results underscore the importance of targeted technology promotion policies in regions experiencing high rural outmigration. Given technology's role in mitigating migration's negative effects,agricultural extension programs should prioritize labor-saving technologies in areas facing severe labor shortages. The Algerian government's recent focus on mechanization subsidies aligns with this implication, but our heterogeneity analysis suggests these efforts should be particularly intensified in interior regions.

Our results showthattechnology adoption alone cannot fully compensate for labor outmigration in the shortterm. Even with significanttechnological progress, migration remains negatively associated with production. This suggests that comprehensive rural development strategies are needed alongside agricultural modernization efforts. Policies that improve rural living conditions, education, healthcare,and non-farm employment opportunities could help moderate migration rates while maintaining sufficientagricultural labor.

Based on our regional heterogeneity findings, we propose atiered approach to agricultural technology promotion in Algeria:

- In coastal regions, policies should focus on advanced technology integration and value chain development, leveraging the already stronger technology effects and better infrastructure. Priorities include expanding precision agriculture techniques, enhancing post-harvest processing technologies, and facilitating marketaccess.
- For interior regions, a more foundational approach is needed, prioritizing basic mechanization suited to local conditions, improving irrigation infrastructure resilience, and strengthening extension services. Additionally, creating rural service centers where machinery and technical expertise can be shared would help overcome the scale limitations faced by smaller producers.
- Across all regions, educational initiatives specifically targeting remaining farming populations should be prioritized. Our findings on the positive interaction between rural education levels and technology effectiveness suggestthat human capital development can significantly enhance the returns to technology investments.

Limitations and Future Research Directions

While our study provides valuable insights, several limitations should be acknowledged, pointing to directions for future research.

Thetechnology adoption index, while comprehensive, may not fully capture all relevant dimensions of technological change in agriculture. Future research could develop more nuanced measures incorporating aspects such as digital technologies, precision agriculture,and management practices.

Our analysis focuses on aggregate food production but does not examine shifts in crop composition or farming systems that mightaccompany labor migration and technological change. Future studies could investigate how these factors influence crop choice decisions and production diversification strategies.

While we address endogeneity through instrumental variables and system GMM approaches, causal identification remains challenging in this context. Future research could exploit policy changes or natural experiments that create exogenous variation in migration or technology adoption rates.

Our study does not fully explore the welfare implications for rural households and communities experiencing outmigration and technological change. Further research on how these transitions affect rural inequality, poverty rates,and community resilience would complement our production-focused analysis.

Our dataset covers eight major agricultural regions but may not representall of Algeria's diverse farming systems. Expanding the analysis to include additional regions and perhaps conducting comparative studies with neighboring countries could enhance external validity.

Finally, future research could investigate the long-term dynamics more fully, particularly whether technology eventually overcomes the negative production effects of migration through learning,adaptation,and complementary investments. Longer panel datasets and dynamic modeling approaches would be valuable for addressing this question.

Conclusion

This study investigated the complex relationships between rural-urban labor migration,technological progress,and food production in Algeria's major agricultural regions from 2000 to 2024. Using panel data from eight primary food-producing wilayasand employing multiple econometric approaches, we found that rural outmigration significantly reduces agricultural production, with an estimated elasticity of -0.278. Technological advancement substantially enhances productivity (elasticity of 0.316) and significantly mitigates migration's negative impact,as evidenced by the positive interaction effect (0.153).

Theanalysis revealed important heterogeneity across regions and time periods, with interior agricultural areas showing greater vulnerability to labor outflows butalso stronger mitigating effects from technology adoption. The relationship between migration and production strengthened over time,as did technology's compensatory role, reflecting Algeria's ongoing agricultural transformation.

These findings contribute to the development economics literature by providing empirical evidence from North Africa on the migration-technology-production nexus, complementing existing studies that have focused primarily on Asiaand Sub-Saharan Africa. Our results supportthe induced innovation hypothesis that factor scarcity (in this case, labor) stimulates technological adoption, while also highlighting the limits of technology's ability to fully compensate for labor shortages in the shortterm.

For policymakers, our findings suggestthat effective agricultural development strategies in the face of rural outmigration should combine targeted technology promotion with broader rural development initiatives that improve living conditions and economic opportunities. Regionally differentiated approaches are necessary given the spatial heterogeneity in migration impacts and technology effectiveness.

As Algeria continues to experience urbanization and agricultural modernization, balancing these forces will be crucial for maintaining food security while enabling sustainable rural-urban transitions. The interplay between demographic change and technological innovation will remain a critical determinant of agricultural productivity and rural welfare in Algeriaand similar developing economies facing agricultural transformation.

This study contributes to a growing body of literature examining agricultural transformation in developing economies facing simultaneous demographic and technological change. While our findings are specific to Algeria, they offer insights relevantto other North African and Middle Eastern countries experiencing similar rural-urban transitions. Future research should explore longer-term dynamics as technological systems mature, potentially leading to more complete compensation for labor outflows over time. Additionally, investigating the role of emerging technologies such as digital agriculture, precision farming, and climatesmartagricultural practices would provide valuable insights into the next phase of agricultural modernization in Algeria.

The migration-technology-production nexus analyzed in this study represents a critical aspect of broader sustainable development challenges. As Algeria continues to urbanize while facing climate change pressures and food security imperatives, balancing these competing forces will require integrated policy approaches. Our findings suggestthattechnological modernization offers promising pathways to maintain and enhance agricultural productivity despite rural demographic changes, but must be accompanied by investments in human capital, infrastructure, and appropriate institutions to realize its full potential.

References

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies,, 58*(2), 277-297.

Ariom, T., Dimon, E., Nambeye, E., Diouf, N., Adelusi, O., & Boudalia, S. (2022). Climate-Smart Agriculture in African Countries: A Review of Strategies and Impacts on Smallholder Farmers. *Sustainability, 14*(11370), 1-32.

Baron, R., & Kenny, D. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology,, 51*(6), 1173-1182.

Benniou, R., & Aubry, C. (2012). Farm diversity and crop growing practices in semi-arid regions: A case study of the Setif high plains in Algeria. *African Journal of Agricultural Research, 7*(48), 6363-6375.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics, 87*(1), 115-143.

Bouchemal, S. (2020). Decline and Agricultural Revival of an Old “huerta” at the Gates of Constantine. *Modern Concepts & Developments in Agronomy 717, 7*(2), 717-718.

Bouchentouf, S., & Benabdeli, K. (2021, March). Water resources and food security in Algeria: Diagnosis and new strategy proposition. *African Journal of Agricultural Research, 17*(3), 414-424.

Boudkhil, M., Benchallat, M., & Benzair, M. (2020). Agricultural and Rural Policies and Their Role in Achieving Food Security in Algeria 1974-2016. *China-USA Business Review, 19*(2), 52-59.

Bouguetaia, S., & Belfodil, K. (2023). Forecasting the Added Value Generated by the Agricultural Sector in Algeria (1999-2021) Box-Jenkins Methodology. *Food & Nutrition Journal, 8*(4), 1-11.

Christiaensen, L., Zachariah, R., & Edward, T. (2021). Viewpoint: The future of work in agri-food. *Food Policy, 99*, 1-12.

DERBAL, N., Benbelkacem, A., & Tahar, A. (2015). Spatial variation of quality traits in Algerian durum wheat cultivated in different environments. *African Journal of Agricultural Research, 10*(9), 919-925.

Foufou, A. (2022). National food safety depends on the modernization and mechanization of agriculture. *INTERNATIONAL JOURNAL OF SCIENCES AND NATURAL RESOURCES, 1*, 16-20.

Güzel, A., & Akin, C. (2021). The role of agricultural productivity in economic growth in middle-income countries: An empirical investigation. *Economic Journal of Emerging Markets, 13*(1), 13-26.

Garoui, S., & Aissani, R. (2024). The reality of agricultural investment in algeria and its role in achieving food security: an analytical study of the wheat market in Algeria (2016-2022). *Brazilian Journal of Business, 6*(1), 1-12.

Hansen, L. (1982). Large sample properties of generalized method of moments estimators. *Econometrica, 50*(4), 1029–1054.

Hua, Q. (2010). Rural-to-Urban Labor Migration, Household Livelihoods, and the Rural Environment in Chongqing Municipality, Southwest China. *Hum Ecol, 38*, 675-690.

Imai, K., Keele, L., & Tingley, D. (2010). A general approach to causal mediation analysis. *Psychological Methods, 15*(4), 309-334.

Jiang, T., Zhong, M., Gao, A., & Ma, G. (2024). Do Factor Misallocations Affect Food Security? Evidence from China. *Agriculture, 14*(729), 1-17.

Kuper, M., Naouri, M., & Hartani, T. (2018). Agriculture in Motion: Intertwined Geographical and Socio-professional Mobilities in North Africa's Groundwater Economy. *İzmir Akdeniz Akademisi Dergisi, 4*, 33-45.

MADRP. (2025). *Agricultural statistics*. Retrieved 3 2025, from Ministry of Agriculture and Rural Development: https://madr.gov.dz/%d8%a7%d9%84%d8%a5%d8%ad%d8%b5%d8%a7%d8%a6%d9%8a%d8%a7%d8%aa-%d8%a7%d9%84%d9%81%d9%84%d8%a7%d8%ad%d9%8a%d8%a9/

McKenzie, D., & Rapoport, H. (2007). Network effects and the dynamics of migration and inequality: Theory and evidence from Mexico. *Journal of Development Economics, 84*(1), 1-24.

Monitoring, B. (2024, 9 9). *Algeria country profile*. Retrieved 3 2025, from BBC News: https://www.bbc.com/news/world-africa-14118852

Munshi, K. (2003). Networks in the modern economy: Mexican migrants in the U.S. labor market. *The Quarterly Journal of Economics, 118*(2), 549–599.

Pereira, L., Drimie, S., Maciejewski, K., Tonissen, P., & Biggs, R. (. (2020). Food System Transformation: Integrating a Political–Economy and Social–Ecological Approach to Regime Shifts. *International Journal of Environmental Research and Public Health, 17*(1313), 1-20.

Peterson, C., Bell, L., Carvalho, P., & Gaudin, A. (2020). Resilience of an Integrated Crop–Livestock System to Climate Change: A Simulation Analysis of Cover Crop Grazing in Southern Brazil. *Frontiers in Sustainable Food Systems, 4*, 1-18.

Sewenet, A., Schwarcz, P., & Devos, S. (2022). Migration and Food Insecurity: An Exploratory Review on their Interlinkage and Policy Options. *International Sientific Days, 7*, 682-690.

Wooldridge, J. (2010). *Econometric analysis of cross section and panel data (2nd ed.)*. MIT Press.

Zemri, B., & Khetib, S. (2023). The role of labour productivity within Algeria's sustainable economic development: Findings from agricultural sector. *Croatian Review of Economic, Business and Social Statistics, 9*(2), 93-108.

Zhang, S., Deng, W., Peng, L., Zhou, P., & Liu, Y. (2020). Has Rural Migration Weakened Agricultural Cultivation? Evidence from the Mountains of Southwest China. *Agriculture*, *10*(63), 1-19.