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Population Growth, Cereal Yield, Land Availability and Real GDP per Capita in Five Agrarian Economies

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Abstract

This study examines within-country associations among population growth, cereal yield, arable land per person, agricultural land share, and real GDP per capita in Afghanistan, Ethiopia, Niger, Tanzania, and Malawi. Descriptive comparisons use the available World Bank World Development Indicators series, while the principal fixed-effects analysis covers a balanced five-country panel for 2002–2022 (105 country-year observations). The principal two-way fixed-effects model finds no statistically detectable population-growth association with log real GDP per capita (β = 0.0118, 95% CI [−0.0661, 0.0898], p = .766). Log cereal yield is positively associated with GDP per capita in the principal model (β = 0.2864, 95% CI [0.1225, 0.4503], p = .0006), but this association is not statistically significant when country-specific linear trends are included (β = 0.0634, p = .133). The arable-land-per-person coefficient is positive in the principal model (β = 0.9063) but reverses sign under country-specific trends (β = −0.7186, p = .039). Excluding Afghanistan changes the population-growth estimate to −0.1617 (p = .013), indicating substantial country sensitivity. The interaction between population growth and cereal yield is imprecise and statistically insignificant (β = 0.1234, 95% CI [−0.1610, 0.4077], p = .395). These observational estimates are exploratory associations, not causal effects. The descriptive coexistence of declining arable land per person and rising cereal yields in four countries is not evidence that population pressure caused intensification; Niger's yield series differs. The study therefore documents heterogeneous patterns and specification-sensitive associations rather than adjudicating between Malthusian and Boserupian mechanisms.

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1. Introduction

The relationship between population growth and economic development has been one of the central questions in economic thought. Thomas Robert **Malthus (1798)** argued that population has a tendency to increase faster than the means of subsistence, implying that population pressure can eventually reduce living standards through diminishing returns to land and food production. More than a century and a half later, Ester **Boserup (1965)** proposed an alternative mechanism in which population pressure can stimulate agricultural intensification, technological adaptation, and more intensive land use.

These two perspectives need not be mutually exclusive. Population growth can increase pressure on fixed resources while simultaneously creating incentives for

innovation, investment, and intensification. The resulting economic outcome may therefore depend on agricultural productivity, land availability, structural transformation, migration, institutions, and the ability of households and economies to adapt to demographic pressure.

Recent research continues to revisit the conditional nature of these relationships. Historical and cross-country studies have found evidence for Malthusian mechanisms under particular technological and institutional conditions, while research on agricultural intensification indicates that population pressure can induce changes in land use and productivity. Contemporary panel research also suggests that the effect of population growth on economic performance depends on land scarcity, agricultural dependence, structural transformation, technological progress, and migration.

This study contributes to this debate by examining five agrarian developing economies—Afghanistan, Ethiopia, Niger, Tanzania, and Malawi—over a long historical period using a common empirical framework. These countries provide an informative comparative setting because agriculture remains economically important, population dynamics are substantial, and land availability per person has generally declined over time. At the same time, agricultural productivity has changed considerably, providing an opportunity to examine whether declining land availability has been accompanied by productive adaptation.

The central research question is:

Is population growth negatively associated with real GDP per capita after accounting for land availability and agricultural productivity in five agrarian developing economies?

Three related questions are also examined:

1. Is agricultural productivity, measured by cereal yield, positively associated with real GDP per capita?
2. Is arable land per person positively associated with real GDP per capita?
3. Does agricultural productivity moderate the association between population growth and real GDP per capita?

The study makes four contributions. First, it combines demographic, land, agricultural productivity, and economic-development indicators in a common framework. Second, it provides a comparative longitudinal analysis of five agrarian developing economies rather than focusing on a single country. Third, it directly connects the empirical analysis to the Malthusian-Boserupian debate. Fourth, it maintains an explicitly associational interpretation and avoids treating fixed-effects coefficients as causal estimates.

The article is organized into five connected sections: introduction; literature review and theoretical framework; methodology; results and discussion; and conclusion and implications. Data availability, declarations, references, and appendices follow.

2. Literature Review and Theoretical Framework

2.1. The Malthusian Mechanism

The basic Malthusian mechanism emphasizes the interaction between population and agricultural production. Let agricultural output be represented as:

$Y_a = f(L, A)$

where Y_a is agricultural output, L represents land and other agricultural inputs, and A represents agricultural technology and productivity.

If population P increases faster than agricultural production, agricultural output per person may decline:

$Y_a / P \downarrow$

Under sufficiently strong diminishing returns to land, population growth may therefore reduce food availability and living standards.

In modern economies, however, the original Malthusian mechanism may be weakened by technological progress, international trade, migration, structural transformation, human capital accumulation, and declining fertility. The empirical question is therefore not whether Malthusian pressure must always operate, but whether population growth remains negatively associated with economic well-being in agrarian developing economies after accounting for land and agricultural productivity.

2.2. Land Scarcity and Demographic Pressure

A central concept in the Malthusian framework is the amount of productive land available relative to population. The relevant measure is:

L / P

where L is arable land and P is population.

This study uses arable land per person as a measure of demographic-adjusted land availability. A decline in arable land per person indicates that each person is associated with a smaller quantity of arable land.

Arable land per person and GDP per capita share a population denominator. Conceptually, ln(arable land/person) = ln(total arable land) − ln(population), while ln(GDP/person) = ln(total real GDP) − ln(population). Consequently, population changes or population measurement errors can move both ratios together even without an independent land–income mechanism. This

shared component complicates interpretation but does not establish that the estimated coefficient is mechanically generated: the numerators also vary and the regression conditions on other variables and fixed effects. Annual population growth is a distinct demographic regressor, not an independent denominator adjustment that removes this issue. The land coefficient is interpreted as a conditional association, not an exogenous causal effect. A model separating total land and population is not estimated here.

2.3. Agricultural Productivity

Agricultural productivity is represented by cereal yield:

Productivity = Cereal output / Harvested area

Cereal yield measures the quantity of cereal production obtained per hectare of harvested area. Higher yields can allow agricultural production to increase without requiring proportional expansion of cultivated land.

The Boserupian perspective therefore predicts a positive association between productivity and economic performance:

$\beta(\text{cereal}) > 0$

If productivity rises while land per person declines, the economy may be adapting to demographic pressure through intensification.

2.4. The Boserupian Mechanism

Boserup's theory emphasizes that population pressure can stimulate agricultural intensification. The mechanism can be represented conceptually as:

Population pressure → Land scarcity → Intensification and innovation → Higher productivity

This mechanism implies that demographic pressure does not necessarily produce declining living standards. Instead, population growth may create incentives for technological change and more intensive land use.

The empirical results are therefore interpreted by considering both mechanisms simultaneously. A negative population coefficient would be consistent with a Malthusian interpretation, while positive productivity and land-availability coefficients would indicate the importance of productive capacity and resource constraints.

2.5. Related Empirical Literature

The following studies provide evidence on population, land scarcity, intensification and development.

2.6. Malthusian Population Theory

The Malthusian hypothesis has been examined extensively in historical and contemporary settings. **Madsen, Robertson, and Ye (2019)**, for example, revisit long-run economic stagnation and provide historical evidence relevant to Malthusian mechanisms.

Sakanko and Ibrahim (2018) provide econometric evidence from Nigeria and find empirical relationships relevant to Malthusian population theory. **Azam et al. (2020)** further examine Malthusian and related population theories in developing-country settings, emphasizing that population effects should be evaluated within broader economic conditions.

More recent work also emphasizes conditionality rather than a universal population-growth penalty. **Jalles (2026)** develops a two-sector framework incorporating land as a fixed factor, structural transformation, and migration and uses a panel of 152 countries for 1960–2023. The study finds that the effect of natural population growth on per-capita income depends strongly on agricultural dependence and land scarcity, while structural transformation, land-saving technological progress, and migration can mitigate demographic pressure.

Ko et al. (2026) similarly revisit a Neo-Malthusian framework using 128 developing countries over 1960–2022, although their primary outcome is political instability rather than GDP per capita. Their findings reinforce the broader argument that demographic pressure and resource scarcity may have different consequences depending on institutional and economic conditions.

2.7. Population Pressure and Agricultural Intensification

The Boserupian perspective emphasizes adaptation to demographic pressure. **Hadush et al. (2019)**, studying Ethiopia, examine whether population pressure induces farm intensification and provide evidence relevant to the idea that increasing population density can stimulate more intensive agricultural practices.

Willy et al. (2019) examine agricultural intensification at high population densities and show that intensification can generate both economic and environmental consequences. **Binswanger-Mkhize and Savastano (2017)** review agricultural intensification across six African countries and emphasize the importance of productivity-enhancing changes in African agriculture.

Research on land markets also indicates that population pressure can affect economic behavior. **Abay et al. (2021)** examine whether land rental markets respond to increasing population pressures and land scarcity in Sub-Saharan Africa. Such evidence suggests that demographic pressure may alter resource allocation rather than simply produce a mechanical decline in living standards.

Mugizi and Matsumoto (2021) further examine population pressure and soil quality in Sub-Saharan

Africa, illustrating that demographic pressure can have heterogeneous environmental effects.

2.8. Agricultural Productivity, Population, and Development

The relationship between agricultural productivity and broader economic development is central to both Malthusian and Boserupian perspectives. Higher agricultural productivity can support population growth, food security, labor reallocation, and structural transformation.

Chu and Xu (2024) develop a theoretical model connecting population growth, agricultural productivity, the transition from hunting and gathering to agriculture, and subsequent industrialization. Their analysis highlights the importance of agricultural productivity in the long-run evolution of economic systems.

Chatterjee and Vogl (2018) examine fertility and economic growth in developing countries and emphasize the importance of structural economic transformation in understanding the relationship between population and development.

2.9. Research Gap

Although previous research provides substantial evidence on population, land scarcity, agricultural intensification, and economic development, fewer studies combine these dimensions in a common longitudinal framework focused specifically on agrarian developing economies.

The present study addresses this gap by simultaneously considering:

- population growth;
- arable land per person;
- agricultural land share;
- cereal yield;
- real GDP per capita; and
- an interaction between population growth and agricultural productivity.

The comparative focus on Afghanistan, Ethiopia, Niger, Tanzania, and Malawi also provides variation in demographic growth, land availability, agricultural productivity, and economic development.

1. Afghanistan
2. Ethiopia
3. Niger
4. Tanzania
5. Malawi

These five countries constitute the case-based comparative sample already used in the submitted analysis; they are retained rather than selected again in response to the estimates. The prior response describes their agrarian relevance and variation in demographic, land, and productivity patterns as the comparative

The study therefore does not attempt to prove a universal Malthusian or Boserupian law. Instead, it asks whether the observed longitudinal patterns are more consistent with demographic pressure alone or with a combined process of resource pressure and productive adaptation.

3. Methodology

3.1. Data Source

The study uses annual World Bank World Development Indicators (WDI) numerical series archived with the analysis. The supplied export contains year columns from 1960 through 2025. Descriptive endpoint comparisons are restricted to 1961–2023, using the first and last available observation for each indicator within that window; some indicators begin later. The econometric analysis retains the previously used 2002–2022 window: five countries observed for 21 years, giving 105 country-year observations. Inspection of the archived series shows that 2002 is the first year with complete coverage for all variables used across Models 1–6 in all five countries; Afghanistan's agriculture-value-added series is missing in 2000–2001. This common-sample convention includes the supplementary Model 6 and does not imply that every simpler model requires the same start year. The 2022 endpoint is the retained analysis cutoff, not a claim that later complete observations are unavailable: all six variables are also observed for all five countries in 2023. The present revision does not extend the regression period or reselect it on the basis of significance.

No interpolation or statistical imputation was performed. All variables used in Models 1–6 are observed for every retained country-year. The exact original WDI extraction date is not recorded in the materials and is not assigned an unverified date. The replication update uses the supplied frozen numerical export, not a fresh WDI download. The earlier workbook and output files were not supplied in their original binary form for this follow-up; the numerical export and submitted script are retained, together with regenerated outputs and an explicit provenance note.

3.2. Countries

The sample consists of:

motivation. However, the archived materials do not document a quantitative agrarian threshold, a complete eligible-country list, or a reproducible screening rule establishing why these five, rather than other agrarian economies, were chosen. The sample is therefore not presented as random, representative, or the exhaustive set satisfying an objective criterion. This documentary limitation restricts external validity; the results concern these cases and should not be generalized to all agrarian economies.

3.3. Variables

Table 1

Variables and World Bank indicators

Variable	World Bank Indicator	Code	Role
GDP per capita	GDP per capita (constant 2015 US$)	NY.GDP.PCAP.KD	Dependent variable
Population growth	Population growth (annual %)	SP.POP.GROW	Demographic pressure
Arable land per person	Arable land (hectares per person)	AG.LND.ARBL.HA.PC	Land availability
Cereal yield	Cereal yield (kg per hectare)	AG.YLD.CREL.KG	Agricultural productivity
Agricultural land	Agricultural land (% of land area)	AG.LND.AGRI.ZS	Land-use structure
Agriculture value added	Agriculture, forestry, fishing, value added (% of GDP)	NV.AGR.TOTL.ZS	Extended control

3.4. Variable Transformation

The dependent variable is transformed using the natural logarithm:

$LN_GDPPC_{it} = \ln(GDPPC_{it})$

Cereal yield and arable land per person are also expressed in logarithmic form:

$LNCEREAL_{it} = \ln(CerealYield_{it})$

$LNARABLE_{it} = \ln(ArableLandPerPerson_{it})$

Population growth remains in percentage-point units, while agricultural land and agriculture value added remain in percentage units. Population growth is WDI indicator SP.POP.GROW: total annual population growth, not fertility or natural increase alone. Its variation cannot be attributed to a specific migration or demographic event from these series alone.

3.5. Estimation Strategy and Inference

The model sequence and inference settings are set out in Sections 3.6–3.11.

3.6. Baseline Fixed-Effects Model

The baseline model is:

$$\ln(GDPPC_{it}) = \alpha + \beta_1 POPGR_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where:

- i denotes country;
- t denotes year;
- POPGR is population growth;
- μ_i represents country fixed effects;
- λ_t represents year fixed effects; and
- ε_{it} is the error term.

The baseline coefficient β_1 captures the within-country association between population growth and logged GDP per capita after controlling for country-specific time-invariant characteristics and common year effects.

3.7. Principal Model

The principal specification is:

$$\ln(GDPPC_{it}) = \alpha + \beta_1 POPGR_{it} + \beta_2 LNCEREAL_{it} + \beta_3 LNARABLE_{it} + \beta_4 AGLAND_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Model 4 remains the principal descriptive levels specification to preserve continuity with the submitted research question: how income levels covary within countries with demographic, productivity, and land indicators after country and common-year adjustment. It is not retained because its coefficients are more significant, and it is not asserted to identify a long-run equilibrium or causal relationship. The country-trend model instead uses deviations from country-specific linear paths, while first differences emphasize annual changes; these specifications therefore condition on different sources of variation. Their results are reported alongside the levels estimates and constrain every substantive conclusion. No unit-root or cointegration finding is claimed, and the trend sensitivity prevents treating levels associations as established long-run effects.

The expected signs are:

- $\beta_1 < 0$: Malthusian demographic pressure;
- $\beta_2 > 0$: higher agricultural productivity;
- $\beta_3 > 0$: greater arable land availability per person;

- β_4: theoretically ambiguous; agricultural land share is retained as an exploratory control relationship, not a negatively signed confirmatory hypothesis.

3.8. Interaction Model

To assess whether the population-growth association varies with cereal yield, Model 5 includes an interaction between population growth and log cereal yield. For interpretability, log cereal yield is centered at its sample median, corresponding to 1,647.9 kg/ha in the 2002–2022 estimation sample. The marginal association is:

$\partial \ln(GDPPC)/\partial POPGR = \beta_1 + \beta_3[\ln(CEREAL) - \text{median}\{\ln(CEREAL)\}]$.

The coefficient β_1 therefore describes the estimated population-growth association at the median observed cereal yield. The interaction coefficient β_3 tests whether that association varies systematically with cereal yield. The interaction is interpreted as an association, not a causal mechanism.

3.9. Model Sequence

Six fixed-effects specifications are estimated:

- Model 1: Population growth only.
- Model 2: Population growth + arable land per person.
- Model 3: Population growth + cereal yield.
- Model 4: Population growth + arable land per person + cereal yield + agricultural land share.
- Model 5: Model 4 + population-growth × cereal-yield interaction.
- Model 6: Model 4 + agriculture, forestry, and fishing value added.

All models include country and year fixed effects.

3.10. Standard Errors and Inference

The submitted code estimates OLS with country and year indicator variables and statsmodels panel heteroskedasticity-and-autocorrelation-consistent covariance (cov_type="hac-panel"). Observations are sorted by country and year, with country used as the group index. The reproduced levels models, country-trend model, and leave-one-country-out checks use maxlags=2 and a Bartlett kernel; the first-difference model uses maxlags=1. The finite-sample covariance scaling is use_correction="hac", equivalent to N/(N−K), where K counts the fitted design columns, including fixed-effect indicators. The updated script makes these previously implicit defaults explicit. It retains df_correction=True, but use_t=False: reported two-sided p-values use a standard-normal reference distribution and coefficient confidence intervals use the corresponding normal critical value, not a t distribution with four degrees of freedom. The interaction-margin table uses the full coefficient covariance matrix and the submitted 1.96 normal approximation. These settings reproduce the supplied code under statsmodels 0.14.6.

The two-year levels bandwidth is retained from the submitted script as a short-horizon allowance for serial dependence in annual data; the archived materials do not document a data-driven bandwidth selection procedure. The one-year first-difference bandwidth is likewise retained rather than claimed to be optimal. These choices do not demonstrate that longer serial dependence is negligible. Panel HAC here aggregates within-country covariance contributions and does not allow general residual cross-country dependence. Year effects absorb common additive year shocks, but not all common shocks with heterogeneous country loadings. With only five countries and 21 annual observations per country, asymptotic normal inference and the covariance scaling do not establish reliable small-sample coverage. HC1 and country-clustered results remain supplementary diagnostics; inference based on five country clusters is particularly fragile. Statistical significance is treated as exploratory.

3.11. Interpretation

The study is observational and longitudinal. The coefficients should therefore be interpreted as conditional within-country associations, not causal effects.

Potential sources of endogeneity include reverse causality, omitted time-varying variables, measurement error, agricultural shocks, conflict, migration, institutional change, and technological change.

4. Results and Discussion

The descriptive figures below are calculated from the archived WDI numerical series. For each indicator, the starting year is the first available observation from 1961 onward and the endpoint is 2023. Percentage changes are calculated from the exact starting and ending values; they are descriptive comparisons, not estimates of causal effects.

Table 2

Descriptive endpoint comparisons

Country	Arable land per person: start → 2023; change	Cereal yield: 1961 → 2023; change	GDP per capita: first available → 2023; change	Agricultural land share: first available → 2023; change
Afghanistan	1961: 0.830 ha → 0.189 ha; −77.2%	1,115.1 → 2,303.0 kg/ha; +106.5%	2000: $308.32 → $378.07; +22.6%	1961: 57.878% → 58.440%; +1.0%

Country	Arable land per person: start → 2023; change	Cereal yield: 1961 → 2023; change	GDP per capita: first available → 2023; change	Agricultural land share: first available → 2023; change
Ethiopia	1993: 0.186 ha → 0.127 ha; −31.6%	714.6 → 2,656.3 kg/ha; +271.7%	1961: $231.02 → $842.45; +264.7%	1993: 30.540% → 34.078%; +11.6%
Niger	1961: 3.187 ha → 0.677 ha; −78.8%	505.2 → 488.8 kg/ha; −3.2%	1961: $753.98 → $561.96; −25.5%	1961: 24.868% → 36.787%; +47.9%
Tanzania	1961: 0.510 ha → 0.203 ha; −60.3%	805.7 → 1,961.1 kg/ha; +143.4%	1961: $820.26 → $1,092.86; +33.2%	1961: 29.352% → 44.616%; +52.0%
Malawi	1961: 0.350 ha → 0.190 ha; −45.8%	984.5 → 1,856.9 kg/ha; +88.6%	1961: $273.67 → $557.04; +103.5%	1961: 33.941% → 64.171%; +89.1%

Estimation-sample population growth and variation

The following summaries use only the common 2002–2022 regression sample, not the longer endpoint series. Each country contributes 21 observations. Afghanistan has substantially greater annual population-growth variation than the other four countries; this is a descriptive feature, not an event attribution.

Table S1

Population growth in the estimation sample (annual %; SD in percentage points).

Country	N	Mean	SD	Minimum	Maximum
Afghanistan	21	3.3019	1.0599	1.4357	6.1452
Ethiopia	21	2.8106	0.1317	2.6227	3.0440
Malawi	21	2.7303	0.1462	2.4487	2.9564
Niger	21	3.5857	0.1665	3.2517	3.7732
Tanzania	21	2.8997	0.2568	2.4669	3.4073

Table S2

Overall and within-country variation (N = 105).

Variable	Overall SD	Country-demeaned SD	Country-and-year-demeaned SD
ln(real GDP per capita)	0.3259	0.2278	0.1243
Population growth (pp)	0.5906	0.4914	0.4425
ln(cereal yield)	0.5871	0.2305	0.1510
ln(arable land/person)	0.6157	0.1199	0.0645
Agricultural land share (pp)	11.5604	2.2120	1.2350
Agriculture value added (pp)	6.7849	3.3526	2.7516

Notes: All SDs use the sample denominator N−1. Country-demeaned values equal x_it minus its country mean. For this balanced panel, two-way demeaned values equal x_it minus its country mean minus its year mean plus the grand mean. These summaries describe available variation; they are not partialled-out-regressor diagnostics or causal identification tests. Population-growth country-specific SDs in Table S1 use 21−1 observations in the denominator.

4.1. Arable Land per Person

Arable land per person declined in all five countries, although the starting year differs for Ethiopia because the supplied series begins in 1993. The decline ranged from 31.6% in Ethiopia to 78.8% in Niger. These figures indicate a reduction in arable land relative to population, but they do not establish that population growth alone caused the decline; changes in land classification and measurement may also matter.

4.2. Agricultural Land Share

Agricultural land as a percentage of total land area increased markedly in Niger, Tanzania, and Malawi, rose more modestly in Ethiopia over its available period, and was comparatively stable in Afghanistan. This indicator measures physical land use, not agriculture's share of GDP or employment. It should not be used as a direct measure of structural transformation.

4.3. Cereal Yield

Cereal yield increased in Afghanistan, Ethiopia, Tanzania, and Malawi, while Niger's recorded yield decreased slightly from 505.2 to 488.8 kg/ha. Rising yields in four countries alongside falling arable land per person are descriptively consistent with productivity adaptation, but the patterns do not demonstrate that population pressure caused intensification.

4.4. GDP per Capita and Interpretation

GDP-per-capita changes vary substantially across countries and periods. The available series for Afghanistan begins in 2000, whereas the other countries have earlier observations. These endpoint comparisons are not directly comparable as a balanced growth experiment because the starting years differ for some indicators and the countries experienced different economic and political conditions. All descriptive values should be read as observed changes, not causal effects.

4.5. Main Regression Results

The six models were reproduced on the balanced 2002–2022 panel (N = 105), with country and year fixed effects. Parentheses contain panel HAC standard errors with a Bartlett kernel and a two-year lag, HAC finite-sample scaling, and normal-reference inference as specified in Section 3.10. The model-level R^2 statistics include the fixed effects and should not be interpreted as the share explained by the substantive regressors alone.

Table 3

Fixed effects model estimates

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Population growth	0.0324 (0.0420)	−0.0274 (0.0451)	0.0178 (0.0404)	0.0118 (0.0398)	0.0080 (0.0320)	0.0298 (0.0306)
ln(Arable land/person)	—	0.8275** (0.3427)	—	0.9063*** (0.2126)	0.9405*** (0.2089)	1.2949*** (0.2154)
ln(Cereal yield)	—	—	0.3485*** (0.1283)	0.2864*** (0.0836)	—	0.1994*** (0.0692)
ln(Cereal yield), centered at median	—	—	—	—	−0.0535 (0.4172)	—
Agricultural land (% of land area)	—	—	—	−0.0441*** (0.0084)	−0.0409*** (0.0102)	−0.0553*** (0.0091)
Population growth × centered ln(Cereal yield)	—	—	—	—	0.1234 (0.1451)	—
Agriculture, forestry & fishing value added (% GDP)	—	—	—	—	—	−0.0231*** (0.0052)
Observations	105	105	105	105	105	105
R^2	0.856	0.877	0.882	0.917	0.919	0.948
Adjusted R^2	0.811	0.836	0.843	0.886	0.887	0.928
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *** p < 0.01; ** p < 0.05; * p < 0.10. Panel HAC: country groups, Bartlett kernel, maxlags=2, use_correction="hac", use_t=False. Model 5 centers log cereal yield at its sample median (1,647.9 kg/ha), so the population-growth coefficient is the estimated association at that yield. Model 6 is supplementary; agriculture value added as a share of GDP may be endogenous and is not interpreted causally.

4.6. Principal Specification: Model 4

Model 4 is the principal specification. Population growth has a small positive coefficient (β = 0.0118, SE = 0.0398, 95% CI [−0.0661, 0.0898], p = 0.766). Thus, no statistically detectable association between population growth and log real GDP per capita is found in this sample under this specification. The estimate is not evidence that population growth has no economic consequences; the confidence interval remains compatible with both negative and positive associations.

The coefficient on log cereal yield is 0.2864 (SE = 0.0836, 95% CI [0.1225, 0.4503], p = 0.0006), indicating a positive conditional association. Because both GDP per capita and cereal yield are logged, the coefficient can be interpreted as an elasticity within this model: a 1% higher cereal yield is associated with approximately 0.29% higher GDP per capita, conditional on the included variables and fixed effects.

Log arable land per person is positively associated with log GDP per capita (β = 0.9063, SE = 0.2126, 95% CI [0.4897, 1.3229], p < 0.001). This association should be

interpreted cautiously because arable land per person is mechanically related to population and may reflect broader country-year changes.

Agricultural land share has a negative coefficient (β = −0.0441, SE = 0.0084, 95% CI [−0.0606, −0.0277], p < 0.001). The result does not imply that agricultural land itself reduces income. Agricultural land share is a land-use measure, and its negative conditional association may reflect unobserved economic structure or other time-varying factors. It is not a direct measure of agriculture's contribution to GDP or employment.

4.7. Interaction Results

Model 5 tests whether the population-growth association varies with cereal yield. Log cereal yield is centered at its sample median of 1,647.9 kg/ha. The estimated interaction is positive but imprecise (β = 0.1234, SE = 0.1451, 95% CI [−0.1610, 0.4077], p = 0.395). The interval permits both negative and positive moderation, including potentially substantial associations. Failure to reject a zero interaction is not evidence that moderation is absent, nor is this an equivalence test.

To interpret the interaction within the observed data, the estimated marginal association of population growth was calculated at the 25th percentile, median, and 75th percentile of cereal yield. Confidence intervals use the full covariance between the population-growth and interaction coefficients.

Table 4

Population growth association at representative cereal yields

Cereal yield level	Yield (kg/ha)	Estimated population-growth association	95% confidence interval	p-value
25th percentile	1,110.4	−0.0407	[−0.1330, 0.0515]	0.387
Median	1,647.9	0.0080	[−0.0547, 0.0706]	0.803
75th percentile	2,050.8	0.0349	[−0.0757, 0.1456]	0.536

All three confidence intervals include zero. The population-growth associations are not statistically distinguishable from zero at these representative yield levels, but the intervals also permit negative and positive associations. The estimates do not establish a systematic strengthening or weakening with yield, and they do not exclude such moderation. Precision is insufficient to infer absence of moderation.

4.8. Extended Model

Model 6 adds agriculture, forestry, and fishing value added as a percentage of GDP. Population growth remains statistically insignificant (β = 0.0298, p = 0.331). Log cereal yield (β = 0.1994, p = 0.004), log arable land per person (β = 1.2949, p < 0.001), and agricultural land share (β = −0.0553, p < 0.001) retain their respective positive, positive, and negative associations. Agriculture value added share is negatively associated with GDP per capita (β = −0.0231, p < 0.001). Because the value-added share is a compositional economic indicator and may respond to income itself, this extended model is not treated as a causal specification.

4.9. First-Difference Sensitivity

A first-difference model was estimated to examine whether year-to-year changes tell a similar story. The model relates changes in log GDP per capita to changes in population growth, log cereal yield, log arable land per person, and agricultural land share, with country and year effects. It uses 100 observations and panel HAC standard errors with a one-year lag.

The coefficient on the change in population growth is 0.0163 (SE = 0.0175, 95% CI [−0.0180, 0.0506], p = 0.352). The change in log cereal yield is positive (β = 0.0511, SE = 0.0208, 95% CI [0.0103, 0.0919], p = 0.014), while changes in log arable land per person (β = −0.2756, p = 0.167) and agricultural land share (β = −0.0112, p = 0.111) are not statistically significant. This annual-change specification does not reproduce all levels associations. It is reported alongside the levels and country-trend results as a different descriptive perspective, not used to establish a causal effect.

4.10. Serial Dependence and Inference

The lag-one correlation of principal-model residuals was high (pooled within-country pairs = 0.787; country-specific range = 0.255–0.938), as reproduced in the replication output. This motivates allowing within-country serial dependence rather than relying only on HC1. It neither proves that the two-year bandwidth is sufficient nor resolves potential nonstationarity or residual cross-country dependence. The panel HAC settings and normal-reference p-values are reported in Section 3.10. With five countries, uncertainty estimates remain exploratory; country-clustered inference is a fragile supplementary comparison.

4.11. Country-Specific Trends

The principal model was augmented with country-specific linear time trends. In this specification, the population-growth coefficient remained statistically insignificant (β = 0.0298, p = 0.165). The cereal-yield coefficient fell to 0.0634 and was not statistically significant (p = 0.133); the arable-land coefficient became negative (β = −0.7186, p = 0.039), while agricultural land share remained negative (β = −0.0543, p = 0.005). These changes indicate that the positive cereal-yield and arable-land associations in the principal levels model are sensitive to how country-specific trends are treated.

4.12. Leave-One-Country-Out Checks

The principal specification was reproduced five times, each time excluding one country. The population-growth coefficient was statistically insignificant in the full sample and in four exclusion samples. Excluding Afghanistan changed it from 0.0118 (p = 0.766; N = 105) to −0.1617 (p = 0.013; N = 84). Excluding Niger gave 0.0075 (p = 0.858). Afghanistan has substantially greater within-country variation in population growth: its country-demeaned sum of squares accounts for 89.46% of the five-country total; after country and year demeaning its share is 71.62%. These are variation summaries, not a formal decomposition of coefficient influence. Afghanistan's recorded growth is 5.2520% in 2002, 6.1452% in 2003, 2.3561% in 2021, and 1.4357% in 2022; its sample mean is 3.3019% and within-country SD is 1.0599 percentage points. All 21 observations are supplied in Appendix E. This concentration helps describe the sensitivity but does not identify a demographic cause or establish that any particular observation is erroneous. No event-specific explanation or additional year-deletion analysis is claimed.

Table 5

Leave one country out sensitivity

Country excluded	N	Population growth β (p)	ln(Cereal yield) β (p)	ln(Arable land/person) β (p)	Agricultural land share β (p)
Afghanistan	84	−0.1617 (0.013)	0.2933 (<0.001)	0.9103 (<0.001)	−0.0445 (<0.001)
Ethiopia	84	0.0360 (0.332)	0.0892 (0.040)	0.3506 (0.077)	−0.0272 (0.004)
Malawi	84	0.0219 (0.623)	0.5511 (<0.001)	0.6921 (<0.001)	−0.0385 (0.007)
Niger	84	0.0075 (0.858)	0.3098 (0.002)	0.9170 (<0.001)	−0.0444 (<0.001)
Tanzania	84	0.0272 (0.562)	0.2624 (0.011)	1.2538 (<0.001)	−0.0516 (<0.001)

The positive cereal-yield association persists in the leave-one-out checks, although its magnitude varies. The arable-land association is also positive in these checks but becomes statistically weaker when Ethiopia is excluded. Agricultural land share remains negative. These checks indicate partial, not universal, robustness.

4.13. Overall Robustness Assessment

The principal findings should be narrowed accordingly. The absence of a statistically detectable population-growth association is not robust to excluding Afghanistan. The positive cereal-yield association is supported in the principal and first-difference models and most leave-one-out models, but not when country-specific linear trends are included. The arable-land coefficient is positive in the principal and leave-one-out levels models but is not stable in the trend and first-difference checks. Agricultural land share is negative in the levels and trend models but not statistically significant in first differences. The results are best treated as conditional associations that depend partly on model specification.

4.14. Population-Growth Hypothesis

H1 predicted a negative association between population growth and real GDP per capita. In Model 4, the coefficient is positive and statistically insignificant (β = 0.0118, p = 0.766). The hypothesis is not supported in the principal specification. The leave-one-out result excluding Afghanistan shows a negative coefficient (β = −0.1617, p = 0.013), demonstrating that this conclusion is sample-composition sensitive.

4.15. Cereal-Yield Hypothesis

H2 predicted a positive association between cereal yield and real GDP per capita. The principal-model coefficient is positive and statistically significant (β = 0.2864, p = 0.0006). The association is also positive in the first-difference model and most leave-one-out checks, but not statistically significant after adding country-specific linear trends. The hypothesis receives qualified, specification-dependent support.

4.16. Arable-Land Hypothesis

H3 predicted a positive association between arable land per person and GDP per capita. The principal coefficient

is positive and statistically significant (β = 0.9063, p < 0.001), but the association is not stable in the country-trend and first-difference checks. The hypothesis receives qualified associational support, not causal support.

4.17. Productivity-Moderation Hypothesis

H4 concerns whether cereal productivity moderates the population-growth association. The interaction estimate is imprecise (β = 0.1234, 95% CI [−0.1610, 0.4077], p = 0.395), and the intervals for marginal associations at the 25th percentile, median, and 75th percentile of yield include zero. The evidence is inconclusive about moderation: both negative and positive moderation remain compatible with the interval. H4 is not established; absence of moderation is not established either.

4.18. Exploratory Agricultural-Land-Share Association

Agricultural land share is treated as exploratory relationship E1, consistent with the theoretically ambiguous sign specified in Section 3.7. The principal coefficient is negative (β = −0.0441, p < 0.001), and its sign persists with country trends and country exclusions, but the first-difference estimate is not statistically significant. The association concerns physical land-use share. It does not show that agricultural land lowers income or directly identify structural transformation.

4.19. Integrated Discussion

The results offer a qualified perspective on the Malthusian-Boserupian debate. In the principal two-way fixed-effects model, no statistically detectable association between population growth and real GDP per capita is found. This result should not be described as proof that population growth has no economic consequences. The confidence interval is broad, and the coefficient becomes negative and statistically significant when Afghanistan is excluded. Population-growth estimates are therefore sensitive to country composition.

Cereal yield is positively associated with GDP per capita in the principal levels model, the first-difference model, and most leave-one-out checks. This is consistent with the proposition that agricultural productivity and broader economic performance can move together. However, the cereal-yield coefficient becomes statistically insignificant after country-specific linear trends are added. The evidence is thus compatible with a productivity-development association, but it does not establish a stable long-run effect or prove a Boserupian mechanism.

Arable land per person is positively associated with GDP per capita in the principal model, but this relationship is not stable across all sensitivity specifications. The indicator is mechanically related to population and may also capture changes in land measurement, agricultural structure, or other country-year conditions. It should not be interpreted as an independent causal effect of land availability.

The negative coefficient on agricultural land share is likewise descriptive and conditional. The variable measures the share of physical land classified as agricultural; it does not measure agriculture's share of GDP or employment. Structural transformation is one possible explanation for the observed association, but this mechanism is not directly tested by the current model.

The endpoint data show that arable land per person declined in all five countries between each indicator's first available observation and 2023. Cereal yield increased in four countries but declined slightly in Niger. These descriptive patterns are consistent with the coexistence of resource pressure and differing productivity trajectories. They do not demonstrate that population pressure caused yield growth or that all countries adapted successfully.

Taken together, the evidence supports a cautious "pressure-plus-adaptation" framing as a way to organize the research question, not as a proven causal mechanism. The most defensible conclusion is that land availability, cereal yield, and GDP per capita display conditional longitudinal associations in this small panel, while several estimates are sensitive to trend specification and country composition.

5. Conclusion and Implications

The implications are restricted to the descriptive evidence established by this study. No intervention was evaluated, so the analysis does not support causal policy prescriptions or a ranking of investments.

5.1. Agricultural Productivity and Income

The positive cereal-yield association in the principal and first-difference specifications, together with its loss of statistical significance after country-specific trends, identifies a specification-sensitive research relationship. It does not establish the returns to improved seeds, irrigation, fertilizer, extension, roads, storage, or agricultural research.

5.2. Land Availability

Declining recorded arable land per person is a descriptive feature of these country series. It does not separately identify land degradation, soil quality, water scarcity, or the demographic contribution to changes in the ratio. Assessments of these mechanisms require directly measured indicators and appropriate research designs; no land-management intervention is evaluated here.

5.3. Population-Growth Interpretation

The imprecise full-sample estimate and its sensitivity to Afghanistan do not establish either a universal

demographic penalty or the absence of an economically meaningful association. The regressions do not evaluate education, health, reproductive-health services, skills, or employment interventions, and no recommendations about their effectiveness are inferred from these results.

5.4. Physical Land Use and Economic Structure

Agricultural land share measures physical land use, not sectoral GDP or employment. Its negative conditional association cannot justify reducing agricultural land or be read as a direct estimate of economic diversification. Evaluating structural transformation requires separate sectoral measures and an appropriate design; the supplementary agriculture-value-added model does not provide causal identification.

5.5. Country Context and Afghanistan

The leave-one-country-out results show that country composition materially affects the population-growth association. The appropriate implication is to report this sensitivity and investigate country-level measurement and economic trajectories in future work. These regressions do not identify which conflict, migration, institutional, or demographic event explains Afghanistan's influence, and they do not establish country-specific policy effects.

5.6. Limitations and Future Research

Several limitations constrain interpretation. First, the sample contains only five countries and 105 observations, is not representative of all agrarian economies, and lacks a documented reproducible country-screening rule. Second, the study is observational; country and year fixed effects do not eliminate time-varying omitted variables, reverse causality, or measurement error. Panel HAC allows selected within-country serial dependence but not arbitrary residual cross-country dependence; short series, bandwidth choice, and normal-reference asymptotics limit inferential reliability.

Third, GDP per capita and arable land per person share a population denominator, complicating interpretation as explained in Section 2.2. Cereal yield is an incomplete proxy for agricultural productivity. Fourth, the exact original WDI extraction date is not retained. The supplied frozen numerical export and code reproduce the estimates, but byte-for-byte identity with previously submitted binary files cannot be verified from the materials available for this follow-up. No interpolation, imputation, live data refresh, or extension beyond the retained regression cutoff was performed; 2023 is also complete for all six model variables in the supplied export.

Fifth, results are sensitive to specification and country composition: cereal yield loses statistical significance with country trends, the arable-land coefficient reverses sign, and excluding Afghanistan changes the population-growth estimate materially. Sixth, agricultural land share measures physical land use rather than agriculture's GDP or employment share. Finally, the population and economic series alone do not identify which demographic events or measurement conditions explain Afghanistan's sensitivity. These limitations prohibit a universal or causal interpretation.

Future work should use a broader country sample, preserve dated raw-data extracts, include agricultural total factor productivity, land quality, climate and rainfall measures, migration, institutional quality, and sectoral employment and value-added data. Stronger causal claims would require a research design and identification strategy specifically suited to the question.

5.7. Conclusion

This study examined within-country associations among population growth, arable land per person, cereal yield, agricultural land use, and real GDP per capita in Afghanistan, Ethiopia, Niger, Tanzania, and Malawi. Descriptive comparisons show that arable land per person declined in all five countries over the available periods, while cereal yields rose in four and fell slightly in Niger. These descriptive patterns do not show that demographic pressure caused productivity adaptation.

In the principal two-way fixed-effects model, population growth is not statistically distinguishable from zero (β = 0.0118, 95% CI [−0.0661, 0.0898], p = .766). This imprecise estimate does not demonstrate the absence of an economically meaningful relationship. The estimate changes materially when Afghanistan is excluded (β = −0.1617, p = .013). The cereal-yield association is positive in the principal specification but weakens under country-specific trends, while the arable-land-per-person coefficient reverses sign. These sensitivities mean that the associations are not stable across plausible specifications.

The findings do not establish that Malthusian or Boserupian mechanisms dominate. The theories provide context, but the models do not directly estimate whether population pressure induces intensification. With five selected cases, observational data, possible serial and cross-country dependence, shared population denominators, and sensitivity to trends and sample composition, the results are exploratory conditional associations. The interaction uncertainty permits both negative and positive moderation. The implications are therefore limited to these documented patterns and uncertainties, not the effectiveness of interventions.

Data Availability Statement

The analysis uses archived World Bank World Development Indicators numerical series. Indicator

names and codes are listed in Section 3.3 and Appendix A; transformations are given in Section 3.4 and Appendix B. The supplied frozen numerical export and submitted script remain the basis of the analysis; no current WDI refresh is substituted. The updated replication supplement supplies the export, an explicit-settings script, regenerated model outputs, the estimation panel, population-growth and variation summaries, Afghanistan observations, coverage and residual diagnostics, environment details, and a provenance/change log. The original binary workbook and prior binary output files were not available for byte-level comparison; a reconstructed workbook, included only for running the unchanged submitted script, is clearly labelled in the supplement documentation. All seven legacy numerical output tables reproduce under the original and explicit-settings scripts within the stated numerical tolerance. No new regression specification is added. The only numerical-text correction is the first-difference cereal-yield confidence interval, now [0.0103, 0.0919]. The original WDI extraction date is unknown; no missing values were interpolated or imputed.

Conflict of Interest

The author declares no conflict of interest.

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Author Contributions

The author was responsible for conceptualization, data preparation, methodology, analysis, interpretation, writing, and revision of the manuscript.

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Appendix A. World Bank Indicators

Table A1

World Bank indicator codes

Indicator	Code	Unit
Population growth	SP.POP.GROW	Annual %
Agricultural land	AG.LND.AGRI.ZS	% of land area
Arable land per person	AG.LND.ARBL.HA.PC	Hectares per person
Cereal yield	AG.YLD.CREL.KG	kg per hectare
Agriculture value added	NV.AGR.TOTL.ZS	% of GDP
GDP per capita	NY.GDP.PCAP.KD	Constant 2015 US$

Appendix B. Variable Transformations

Original Variable	Transformation
GDP per capita	ln(GDP per capita)
Cereal yield	ln(Cereal yield)
Arable land per person	ln(Arable land per person)
Population growth	Level (%)
Agricultural land	Level (% of land area)
Agriculture value added	Level (% of GDP)

Appendix C. Model Specifications

All levels models include country fixed effects (μ_i) and year fixed effects (λ_t). The dependent variable is ln(real GDP per capita).

Model 1: $\ln(GDPPC_{it}) = \alpha + \beta_1\ POPGR_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Model 2: $\ln(GDPPC_{it}) = \alpha + \beta_1\ POPGR_{it} + \beta_2\ LNARABLE_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Model 3: $\ln(GDPPC_{it}) = \alpha + \beta_1\ POPGR_{it} + \beta_2\ LNCEREAL_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Model 4: $\ln(GDPPC_{it}) = \alpha + \beta_1\ POPGR_{it} + \beta_2\ LNCEREAL_{it} + \beta_3\ LNARABLE_{it} + \beta_4\ AGLAND_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Model 5: $\ln(GDPPC_{it}) = \alpha + \beta_1\ POPGR_{it} + \beta_2\ LNCEREAL_C_{it} + \beta_3(POPGR_{it} \times LNCEREAL_C_{it}) + \beta_4\ LNARABLE_{it} + \beta_5\ AGLAND_{it} + \mu_i + \lambda_t + \varepsilon_{it}$, where LNCEREAL_C is log cereal yield centered at the sample median.

Model 6: $\ln(GDPPC_{it}) = \alpha + \beta_1\ POPGR_{it} + \beta_2\ LNCEREAL_{it} + \beta_3\ LNARABLE_{it} + \beta_4\ AGLAND_{it} + \beta_5\ AGVA_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

All levels models use country-group panel HAC, Bartlett kernel, maxlags=2, use_correction="hac", df_correction=True, and use_t=False (normal-reference inference). The first-difference model uses the same settings except maxlags=1. Country and year effects are included as stated in the model formulas. The principal levels model is descriptive; country-trend and first-difference results constrain its interpretation.

Appendix D. Summary of Hypothesis Tests

Table D1

Summary of hypotheses and exploratory relationship

Hypothesis	Expected relationship	Principal result	Conclusion
H1	Population growth → GDP per capita (−)	β = 0.0118, p = 0.766	Not supported; sensitive to excluding Afghanistan

Hypothesis	Expected relationship	Principal result	Conclusion
H2	Cereal yield → GDP per capita (+)	β = 0.2864, p = 0.0006	Qualified support; not robust to country-specific trends
H3	Arable land/person → GDP per capita (+)	β = 0.9063, p < 0.001	Qualified associational support; sensitivity across specifications
H4	Cereal yield moderates population-growth association	β interaction = 0.1234, p = 0.395	Inconclusive; interval permits negative and positive moderation
E1 (exploratory)	Agricultural land share ↔ GDP per capita (ambiguous sign)	β = −0.0441, p < 0.001	Negative conditional association in levels; not statistically significant in first differences

Appendix E. Afghanistan observations in the estimation sample

All observations are retained in the principal model. Selected high and low population-growth years are discussed in Section 4.12 without an unsupported event attribution. The leave-one-country-out analysis removes all 21 Afghanistan observations, not just selected years.

Table E1

Afghanistan observations in the estimation sample

Population growth (annual %)	Real GDP per capita (2015 US$)
5.2520	338.14
6.1452	346.07
3.5758	338.64
3.5192	363.64
4.0927	367.76
1.8926	410.76
2.1865	417.65
3.6464	488.83
2.9347	542.87
3.6915	525.43
4.0479	568.93
3.4182	580.60
3.6325	575.15
3.1200	565.57
2.5357	563.87
2.8083	562.77
2.9108	553.13
2.9844	557.86
3.1536	527.83
2.3561	408.63
1.4357	377.67