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CLIMATE VARIABILITY, REAL EXCHANGE RATE AND AGRICULTURAL TRADE IN MOROCCO: AN ARDL BOUNDS TESTING APPROACH (1963-2023).

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Abstract

Morocco's agriculture faces two structural vulnerabilities at once: extreme climate sensitivity and deep trade dependence. Cereal cultivation is overwhelmingly rainfed, and the country's agricultural trade coverage ratio, the value of agricultural exports divided by that of agricultural imports, has fallen from a surplus of 1.47 in 1970 to a deficit ratio of 0.54 in 2023. Whether this deterioration is associated with climate variability, and over what horizon, has not been established on long historical data. This paper estimates the long-run relationship between precipitation, temperature, the real exchange rate and this coverage ratio over 1963-2023, using annual data drawn entirely from primary sources: FAOSTAT, the ERA5 reanalysis and the World Bank. Domestic agricultural output is excluded from the baseline specification because the estimand of interest is the total effect of climate: since climate is expected to act on the ratio through production, conditioning on production would identify only the residual direct effect. The autoregressive distributed lag bounds testing procedure of Pesaran, Shin and Smith (2001) is applied, with lag order selected by the Schwarz criterion on a pre-declared grid and inference conducted on Newey-West standard errors. Unit root tests place precipitation at order zero and the remaining series at order one, none at order two. Two sets of estimates are reported, of different evidential status. On the full sample the bounds test gives an F statistic of 4.22, which exceeds the upper critical value at the 10% level alone: this is evidence of a long-run association, retained here as a historical benchmark. Parameter constancy is rejected on that sample, with a break dated 1973 on which three independent procedures agree. On the post-break regime, taken here as the preferred specification, the bounds test gives F = 8.52, above the upper critical value at the 1% level, so the evidence of cointegration is strong. The error correction term is -0.343 and significant at the 1% level, implying a half-life of 1.6 years, and the long-run precipitation elasticity is 1.12, significant at the 1% level: a 10% shortfall in rainfall is associated with a durable deterioration of the coverage ratio of about 11%. That elasticity remains positive and significant at the 5% level for every regime starting between 1971 and 1976. Temperature shows no statistically identifiable independent effect within the linear specification. Climate adaptation and water-efficiency policies could generate a measurable trade benefit by reducing the sensitivity of agricultural trade to rainfall.

Keywords: Climate variability; Agricultural trade coverage ratio; ARDL bounds test; Error correction; Real exchange rate; Morocco; Food sovereignty.

1. Introduction

Morocco's agricultural sector stands at the intersection of two structural vulnerabilities: extreme climate sensitivity and deep trade dependence. Cereal cultivation is overwhelmingly rainfed, conducted on the bour lands (Bouras et al., 2020), so that agricultural output fluctuates sharply with annual precipitation cycles. The consequences are visible in the trade accounts. Morocco's agricultural trade coverage ratio, agricultural export value divided by agricultural import value, stood at 1.47 in 1970, a comfortable surplus. It had fallen to 0.54 by 2023 (FAO, 2024). In the severe drought years of 1981 and 1995 it collapsed to 0.39 and 0.43 respectively, and the historical minimum of 0.35 was recorded in 1984.

Beyond the immediate macroeconomic cost, the interaction between climate variability and agricultural trade raises a question about Morocco's food sovereignty. The country meets about half of its wheat consumption through imports, but the share swings with the harvest: 34% in 2018, 68% in 2020, 69% in the drought year of 2022 (FAO, 2024). That volatility is what the present paper seeks to price. The exposure was compounded that same year by war in the Black Sea: Russia and Ukraine together supplied 23% of world wheat exports in 2021; their combined shipments fell by 29% the following year, Ukraine's alone by 42% (FAO, 2024). The reversal is recent enough to fall within the sample used here: Morocco ran an agricultural trade surplus in every year up to 1973 and a deficit in every year since, a structural break that no study of the country has yet examined jointly with its climatic determinants over the full period.

The policy stakes are concrete. If climate variability durably erodes the agricultural trade position, then adaptation spending on irrigation and water efficiency is not merely a food security measure but a trade policy instrument, and its return can be quantified. If instead the coverage ratio is governed chiefly by relative prices, then exchange rate management and export diversification deserve the greater share of public effort. The two readings imply different budgets. The Green Generation 2030 strategy commits substantial public resources to irrigation expansion on food security grounds alone; if the trade benefit of that spending can be measured, the case for it rests on firmer ground. The two instruments are not equivalent in reach or in availability: exchange rate management is constrained by the monetary regime, while water efficiency is a domestic choice whose horizon is measured in decades rather than in budget cycles.

Despite the significance of this nexus, the quantitative literature on Morocco remains sparse. Existing studies either analyse climate impacts on domestic production without connecting them to trade outcomes, or examine trade balance determinants without incorporating climate variables. No study has yet modelled the transmission from climate variability to Morocco's agricultural trade coverage ratio within a unified long-run econometric framework over a long historical period.

This study addresses that gap. The research question is stated simply: does climate variability bear a measurable and persistent long-run relation to Morocco's agricultural trade coverage ratio, and how does it rank against the exchange rate channel? We estimate an autoregressive distributed lag model on annual data covering 1963-2023, with the agricultural trade coverage ratio as the dependent variable and precipitation, temperature and the real exchange rate as determinants. All series are drawn from primary sources and the estimation is fully reproducible from the estimation scripts. The specification excludes domestic agricultural output, a choice explained in Section 3 and tested in Section 5.4; the robustness of the estimates is displayed across the whole lag grid rather than for the retained model alone. Because the introduction asserts a regime change in the early 1970s, that assertion is itself tested rather than assumed: Section 5.6 dates the break with three procedures that do not impose it in advance, finds that parameter constancy is rejected, and re-estimates the model on the post-break regime. That regime is the one Morocco has occupied for half a century, and it is where the relationship is cleanest. Three contributions follow: a long historical series assembled entirely from primary sources and reproducible from the estimation scripts, a specification aligned with the mechanism it claims to measure rather than with convention, and an explicit treatment of the regime change that every account of Moroccan agricultural trade mentions and none has dated.

The subject of this research is the long-run relationship between climate variability and Morocco's agricultural trade position, measured by the coverage ratio of agricultural exports to agricultural imports. Its objective is twofold: to establish whether that relationship exists over a long historical sample and to weigh the climatic channel against the real exchange rate channel, so that adaptation policy and exchange rate management can be discussed on a common metric. The paper is organised as follows. Section 2 reviews the relevant literature and states where the present work departs from it. Section 3 synthesises the theoretical, methodological and empirical framework and justifies the exclusion of domestic agricultural output. Section 4 presents the data, their primary sources and the econometric methodology. Section 5 reports the empirical results, from the unit root tests to the structural break analysis. Section 6 discusses them, and Section 7 concludes with the policy implications.

2. Literature review

2.1. Climate variability and agricultural output

That climate variability is a primary determinant of agricultural output in semi-arid regions is well established. Lobell, Schlenker and Costa-Roberts (2011) estimated that warming trends since 1980 reduced global wheat yields by approximately 5.5% and maize yields by 3.8%, and Ortiz-Bobea et al. (2021) found that anthropogenic climate change has slowed global agricultural total factor productivity growth by 21% since 1961.

For Morocco the evidence is unusually concentrated. Achli et al. (2025) systematically reviewed 135 peer-reviewed and grey sources published between 1990 and 2024 on the drivers of Moroccan crop yields, and identified precipitation as the primary driver, ahead of irrigation, fertilisation, water stress and temperature. Bouras et al. (2020) confirm the mechanism at province level: over 2000-2017, remotely sensed vegetation and soil moisture indices around the heading stage in March and April correlate with cereal yield at up to 0.94, which places the transmission from rainfall to output in the spring window rather than in the annual average.

The temperature channel behaves differently. Bouras et al. (2019) simulated irrigated cereal yields in the Tensift basin under RCP4.5 and RCP8.5 and found that rising temperature shortens the wheat development cycle by up to fifty days, with optimal yields falling by 7 to 30% when the fertilising effect of CO_2 is excluded and rising modestly when it is included. The sign of the temperature effect is conditional on assumptions that a linear reduced-form model cannot represent. It is worth bearing in mind when reading the estimates below.

A related literature has established that Moroccan cereal outcomes are predictable well before harvest. Lehmann et al. (2020) extract climate precursors from geopotential height and sea surface temperature fields and forecast wheat yield variability from December onward, explaining about half the out-of-sample variance. Bouras et al. (2021) reach comparable accuracy by combining weather data, the North Atlantic Oscillation and satellite drought indices, and state their motivation explicitly: a country that is not self-sufficient needs to anticipate its import requirements as early as possible. That motivation is the premise of the present paper, which estimates the trade cost attached to those requirements.

2.2. Climate variability, trade dependence and food security

The link from production shortfalls to trade outcomes has been studied mostly at the level of food security rather than of the trade balance. Affoh et al. (2022) estimate a pooled mean group panel ARDL on 25 sub-Saharan African countries over 1985-2018 and find that rainfall has a significantly positive long-run effect on food availability, accessibility and utilisation, while temperature is harmful to availability and accessibility. Their design is close to ours and their result on rainfall points in the same direction, though the dependent variable differs.

That trade mediates the relationship between local water endowments and food outcomes is now well documented. D'Odorico et al. (2014) show that the volume of food calories traded internationally more than doubled between 1986 and 2009 and that a growing number of countries depend on imports rather than on domestic resources, which transfers the constraint from land and water to purchasing capacity. For the MENA region specifically, Droogers et al. (2012) project total water demand rising to 393 km³ per year by 2050 against a supply falling by 12%, so that the regional shortage grows to 199 km³ per year. Schilling et al. (2020) assess the vulnerability of five North African countries and conclude that all are exposed to strong warming and high drought risk, with water scarcity aggravated by population growth and capable of acting as an indirect driver of social instability.

Trade policy responses can themselves amplify the instability they seek to contain: Anderson and Nelgen (2012) document how the volatility of trade barriers contributes to world agricultural price instability. Cashin, Cespedes and Sahay (2014) note that post-shock currency depreciation raises the local-currency cost of food imports, straining both the trade balance and the subsidy budget.

What this literature does not provide is an estimate of how much, and for how long, a rainfall shortfall moves a national agricultural trade position. That is the gap the present paper addresses for Morocco.

2.3. The ARDL approach in agricultural economics

The bounds testing approach of Pesaran, Shin and Smith (2001) has become the standard tool for long-run analysis in agricultural economics when samples are moderate and integration orders mixed. Its advantages are applicability to variables that are I(0) or I(1) without prior classification, acceptable performance in small samples, and the joint estimation of short-run dynamics and long-run equilibrium within a single specification.

Applications to the climate-agriculture nexus are numerous. Chandio et al. (2020) apply the framework to China, Warsame et al. (2021) to crop production in Somalia, Ahsan et al. (2020) to Pakistani cereal production over 1971-2014, and Nasrullah et al. (2021) to rice in South Korea, where rainfall carries an adverse sign that the authors attribute to irrigation infrastructure rather than to water scarcity. For Morocco, Soumbara and El Ghini (2023) estimate a nonlinear ARDL and identify asymmetric effects of climate variability on the food production index between 1961 and 2020.

None of these studies takes the agricultural trade coverage ratio as the dependent variable, and none covers Morocco over a period long enough to include the structural shift from agricultural surplus to deficit that occurred in the early 1970s. The present paper does both.

Each element of the specification estimated below is drawn from this literature rather than chosen for convenience. The dependent variable, the agricultural trade coverage ratio, follows the trade-outcome framing of Affoh et al. (2022) and Nasrullah et al. (2021), who relate climatic conditions to national agricultural trade positions. Precipitation enters as the primary climatic regressor because the Moroccan yield literature identifies it as the dominant constraint on rainfed cereal production: Bouras et al. (2020, 2021) obtain most of their predictive power from rainfall and drought indices, and Balaghi et al. (2008) from rainfall combined with vegetation indices. Temperature is retained because Bouras et al. (2019) and the regional evidence of Zittis et al. (2022)

make warming a candidate determinant, even though the linear form used here may not capture it. The real exchange rate follows the expenditure-switching tradition and its application to food trade in developing economies. The relative weight of the climatic and the price channel is not assumed here: it is what Section 5 estimates, and Section 6 reports that the pooled and post-break samples do not agree on it.

3. Synthesis of the theoretical, methodological and empirical framework

On the theoretical side, the analysis rests on a supply-side transmission mechanism. Climate acts on the coverage ratio through domestic production: a precipitation deficit reduces rainfed cereal output, which simultaneously contracts the exportable surplus and widens compensatory imports, so that the export-to-import ratio deteriorates on both sides at once. A second channel operates through relative prices: a real depreciation lowers the foreign-currency price of Moroccan produce and raises the domestic cost of imports, improving the ratio through competitiveness rather than through volumes.

The mechanism dictates a modelling choice, and it is worth stating plainly. Because climate is posited to act through production, domestic agricultural output is excluded from the baseline specification: the estimand of interest is the total effect of climate, and conditioning on the mediator would leave the precipitation coefficient measuring only the residual direct effect, the part that does not pass through the harvest, which is not the quantity of interest for a paper asking what a drought costs the external accounts. We estimate the total effect and report the specification including agricultural value added as a robustness check in Section 5.4 rather than as the baseline. The exclusion has a second, incidental benefit: the World Bank output series begins only in 1965, so dropping it restores four observations at the start of the sample.

On the methodological side, three features of the data dictate the choice of estimator. The series display mixed integration orders: precipitation is stationary in level while the coverage ratio, temperature and the real exchange rate are stationary in first difference, and none is integrated of order two. This is the configuration the bounds testing approach of Pesaran, Shin and Smith (2001) accommodates and the Johansen framework does not. The sample is moderate, 61 observations, a range in which the bounds procedure retains acceptable power where system methods do not.

Finally, the adjustment of a trade ratio to a rainfall deficit is expected to be gradual, which calls for an error correction representation separating the long-run equilibrium from the speed at which deviations from it are corrected.

On the empirical side, the design delivers a long-run precipitation elasticity of 2.07, significant at the 1% level, a real exchange rate elasticity of 0.90 significant at the 10% level, and an adjustment speed of 24.4% per year implying a half-life of 2.5 years. The bounds test supports a long-run relationship at the 10% level. All are obtained without searching the specification space: the lag order follows a pre-declared criterion and the full grid is reported.

This articulation also fixes the boundaries of what the paper can establish. Because the specification is linear, it estimates an average long-run response and cannot detect a threshold beyond which additional warming reverses its sign. Because the data are national annual aggregates, the estimates average agro-ecological zones whose exposure differs widely, from the irrigated Souss to the rainfed plateaux. And because the dependent variable is a ratio of aggregate values, it conflates volume and price movements. Each boundary follows from a choice made at the design stage, and each is revisited in the concluding section. A fourth boundary emerged from the analysis rather than from the design, and it is the most consequential: the sample spans two trade regimes, an agricultural surplus that lasted until the early 1970s and the deficit that has prevailed since. Pooling them assumes a stability the data do not support, which is why Section 5.6 tests for the break and reports the post-break estimates alongside the pooled ones. The two readings are presented together rather than one being suppressed.

4. Data and methodology

A word on the methodological posture adopted here. This research is conducted within a hypothetico-deductive framework and a post-positivist epistemology: theory states a mechanism, that mechanism implies testable restrictions on observable series, and the data are given the opportunity to reject them. Section 3 posits that climate acts on the coverage ratio through domestic production and that relative prices act through competitiveness; those two propositions are what Sections 5.2 to 5.6 confront with the evidence. The reasoning is therefore deductive in direction and quantitative in method, and the choice of a time-series design over a survey or a case study follows from the object itself: the question concerns an aggregate national relationship observed over six decades, which no cross-sectional instrument can reach. Consistently with that posture, the lag structure is selected on a grid declared in advance rather than on the result it produces, the specification that departs from convention is defended before any estimate is reported, and results that do not support the hypotheses are reported as such.

4.1. Data and variable description

The empirical analysis employs annual data for Morocco. The sample runs from 1963 to 2023, giving 61 usable observations after lag adjustment. All variables enter in natural logarithms, so that coefficients read as elasticities and heteroskedasticity is reduced.

The dependent variable is the agricultural trade coverage ratio, ATB = agricultural export value / agricultural import value, computed from the FAOSTAT aggregate « Crops and livestock products » in current US dollars. It is a coverage ratio rather than a trade balance in the strict sense of exports minus imports, and we use it as an indicator of agricultural trade performance: a value below unity indicates that agricultural imports exceed agricultural exports in value. Morocco recorded surpluses until 1973 and deficits in every year since. Precipitation and temperature are national annual figures derived from the ERA5 reanalysis (Hersbach et al., 2020) accessed through the Open-Meteo historical API, averaged over four points covering the principal cereal-growing regions: Saïs, Chaouia, Doukkala and Gharb. The official exchange rate and the two consumer price indices come from the World Bank (2024). exchange rate is computed in the conventional way, q = e × (CPI_USA / CPI_Morocco), where e is the official rate in dirhams per US dollar. An increase denotes a real depreciation, and so a gain in competitiveness.

Table N°1 sets out the definitions and sources. Table N°2 reports descriptive statistics. Figure N°1 plots the four series in logarithms, with the severe drought years of 1981, 1995 and 2022 marked. Figure N°2 sets the coverage ratio against annual precipitation and makes the association visible at the level of the raw data.

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Table N°1 : Variable description, measurement and sources

Variable	Definition	Unit	Source
ATB	Agricultural export value / agricultural import value	ratio	FAOSTAT, Crops and livestock products
PRECIP	Annual precipitation, cereal-growing regions	mm	ERA5 reanalysis (Open-Meteo)
TEMP	Mean annual temperature, same locations	°C	ERA5 reanalysis (Open-Meteo)
RER	Real exchange rate, e × (CPI_USA / CPI_Morocco)	index	World Bank

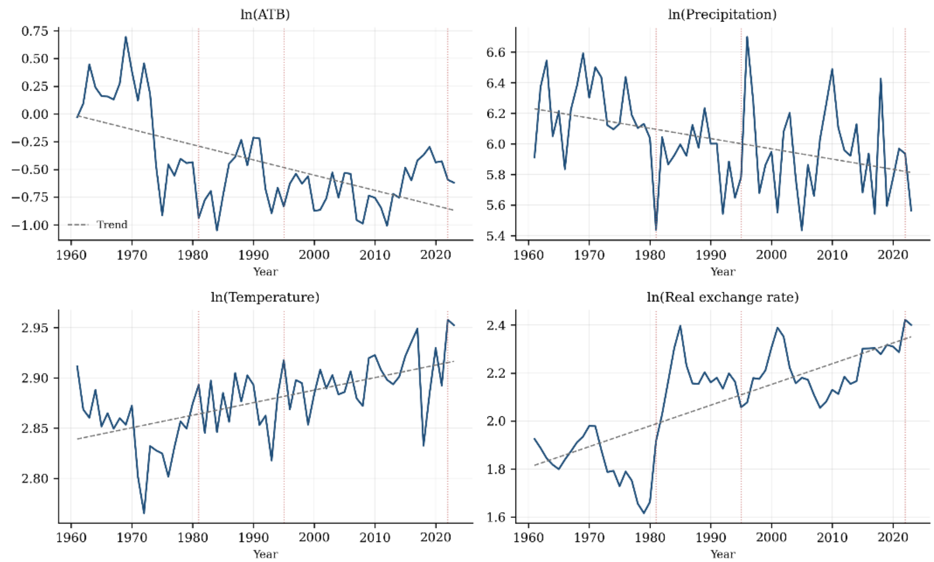
Source: Authors' compilation from primary databases. All variables enter in natural logarithms.

Table N°2 : Descriptive statistics

Variable	Obs.	Mean	Std. dev.	Min.	Max.	Skew.	Kurt.
ATB	61	0.70	0.35	0.35	2.00	1.80	2.97
PRECIP	61	428.71	129.47	229.30	811.67	0.81	0.48
TEMP	61	17.78	0.67	15.89	19.26	-0.21	0.34
RER	61	8.25	1.63	5.03	11.27	-0.22	-0.83

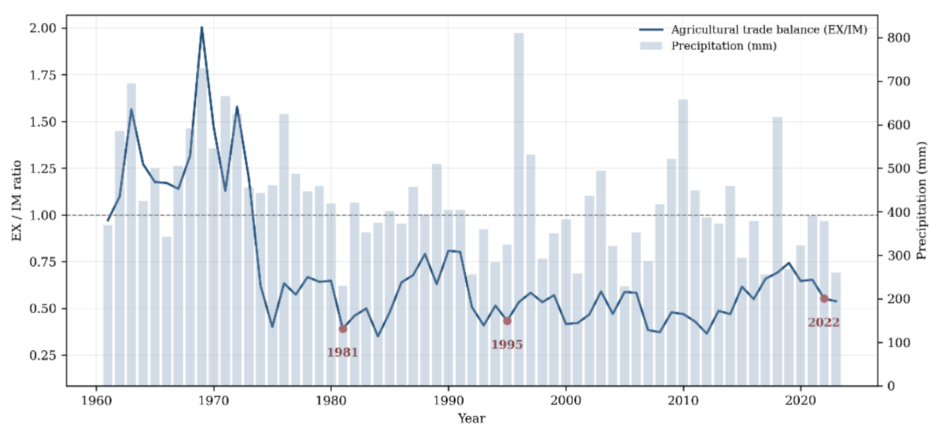
Source: Authors.

Figure N°1 : Time series of the variables in natural logarithms, Morocco. Dashed lines are linear trends; dotted vertical lines mark the severe drought years of 1981, 1995 and 2022.



Source: Authors.

Figure N°2 : Agricultural trade coverage ratio (EX/IM, left axis) and annual precipitation (right axis), Morocco. The dashed horizontal line marks the break-even equilibrium.



Source: Authors.

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4.2. Stationarity analysis

Before estimation we verify that no variable is integrated of order two, which would invalidate the bounds testing approach. Three tests are applied to each series in level and in first difference: the augmented Dickey-Fuller test, the Phillips-Perron test and the KPSS test, all with a constant and automatic lag selection. Table N°3 reports the outcome. Precipitation is stationary in level under both ADF and Phillips-Perron. The coverage ratio and the real exchange rate are stationary only in first difference. Temperature is the one ambiguous case: Phillips-Perron rejects the unit root in level while the augmented Dickey-Fuller test does not, a divergence that typically reflects the different treatment of short-run serial correlation. We retain the more conservative classification, I(1), which is also the one the bounds procedure is designed to accommodate; nothing in what follows depends on the choice, since the procedure requires only that no series be integrated of order two. None is. Mixed I(0) and I(1) orders are the setting the bounds procedure was built for.

Table N°3 : Unit root tests

Variable	ADF level	ADF diff.	PP level	PP diff.	KPSS level	Order
ATB	0.133	0.000	0.184	0.000	0.012	I(1)
PRECIP	0.000	0.000	0.000	0.000	0.012	I(0)
TEMP	0.505	0.000	0.000	0.000	0.010	I(1)
RER	0.353	0.000	0.751	0.000	0.010	I(1)

Source: Authors. Entries are p-values. ADF and PP: null of a unit root. KPSS: null of stationarity, with p-values bounded below at 0.01 and above at 0.10 by the tabulated critical values. All tests include a constant, with automatic lag selection.

4.3. The ARDL bounds testing framework

The conditional error correction representation is estimated in the form

$$\Delta \ln(ATB)_t = \alpha + \rho \cdot \ln(ATB)_{t-1} + \theta_1 \cdot \ln(PRECIP)_{t-1} + \theta_2 \cdot \ln(TEMP)_{t-1} + \theta_3 \cdot \ln(RER)_{t-1} + \Sigma_i \gamma_i \cdot \Delta \ln(ATB)_{t-i} + \Sigma_j \delta_j \cdot \Delta X_{j,t-j} + \varepsilon_t$$

where ρ is the error correction coefficient and the long-run elasticities are recovered as $-\theta_j/\rho$. The bounds test examines the joint nullity of ρ and the three θ_j against the critical values of Pesaran, Shin and Smith (2001, Table CI, Case III) for k = 3 regressors, complemented by the t test on ρ against the values of Banerjee, Dolado and Mestre (1998).

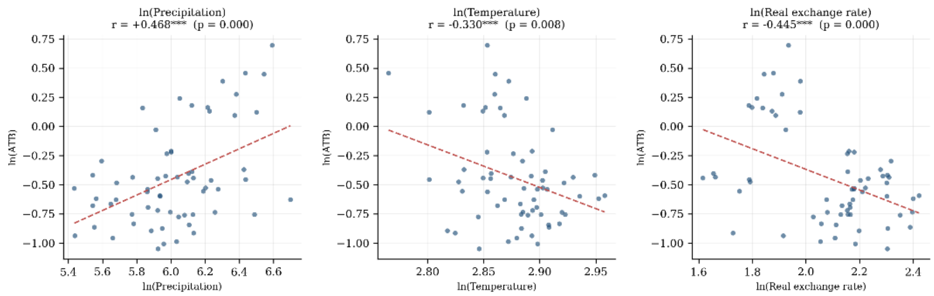
The lag order is selected by the Schwarz information criterion over a grid declared in advance, with p from 1 to 3 lags on the dependent variable and q from 0 to 2 on the regressors, that is nine specifications. The Schwarz criterion (Schwarz, 1978) is preferred to Akaike because it is consistent and penalises parameters more heavily, which matters at 61 observations. The criterion retains p = 1 and q = 0 for each of the three regressors, that is ARDL(1, 0, 0, 0) in full notation. Results for all nine specifications are reported in Table N°6 so that the reader can judge the sensitivity of the estimates rather than take the selected model on trust. Because the ARCH test at one lag is rejected at the margin on the retained model (p = 0.049), inference is conducted throughout on Newey-West standard errors robust to heteroskedasticity and autocorrelation.

5. Empirical results

5.1. Bivariate relationships

Before turning to the conditional estimates, Figure N°3 plots the coverage ratio against each determinant, with the unconditional correlation reported in each panel. These associations are descriptive only: in a multivariate setting where the determinants are themselves correlated, the conditional effects reported below differ, sometimes markedly.

Figure N°3 : Bivariate relationships between the log agricultural trade coverage ratio and each determinant. Dashed lines are OLS fits. *** p < 0.01, ** p < 0.05, * p < 0.10, ns = not significant.



Source: Authors.

5.2. Bounds test for cointegration

Table N°4 reports the bounds test. The computed F statistic is 4.22. At the 10% level the critical values for k = 3 regressors are 2.72 for the I(0) bound and 3.77 for the I(1) bound; the statistic exceeds the upper bound, so the null of no long-run relationship is rejected. At the 5% level, where the upper bound is 4.35, the statistic falls inside the inconclusive band. The t statistic on the error correction term, -2.84, lies between the I(0) and I(1) bounds at the 10% level and falls just short of the I(0) bound at the 5%; on its own it is inconclusive. The evidence supports a long-run relationship at the 10% level and no more; we report it at that strength.

Table N°4 : Bounds test for cointegration

Statistic	Value	10% I(0)	10% I(1)	5% I(0)	5% I(1)	Conclusion
F (joint)	4.22	2.72	3.77	3.23	4.35	Rejected at 10%; inconclusive at 5%
t (on ρ)	-2.84	-2.53	-3.46	-2.86	-3.78	Inconclusive at 10%

Source: Authors. k = 3 regressors. F bounds from Pesaran, Shin and Smith (2001), Table CI, Case III; t bounds from Banerjee, Dolado and Mestre (1998).

5.3. Error correction and long-run elasticities

The error correction term is unambiguous. Table N°5 gives an estimate of -0.2443 with a p-value of 0.0045, significant at the 1% level. The coefficient is negative, as convergence requires, and its magnitude implies that 24.4% of any deviation from long-run equilibrium is eliminated within one year, giving a half-life of 2.5 years. Deviations induced by a drought are absorbed over two to three years, not within the agricultural season. This is consistent with the structural rigidity of Moroccan supply chains: an export base of fresh produce, citrus and olive oil cannot be expanded quickly enough to offset a cereal deficit, and import contracts are typically medium-term.

The long-run elasticities appear in the last column of Table N°5 and in Figure N°4. The precipitation elasticity is 2.066, significant at the 1% level. A 10% shortfall in annual rainfall is associated with a durable deterioration of the coverage ratio of approximately 21%. This is the central result of the paper, and it is economically large: the elasticity is roughly twice unity, so the coverage ratio responds far more than proportionally to rainfall. The mechanism is the one set out in Section 3, operating on both sides of the ratio at once, since a poor harvest simultaneously reduces the exportable surplus and raises compensatory imports. Because domestic output is excluded from the specification, this coefficient measures the total effect of rainfall, direct and mediated together.

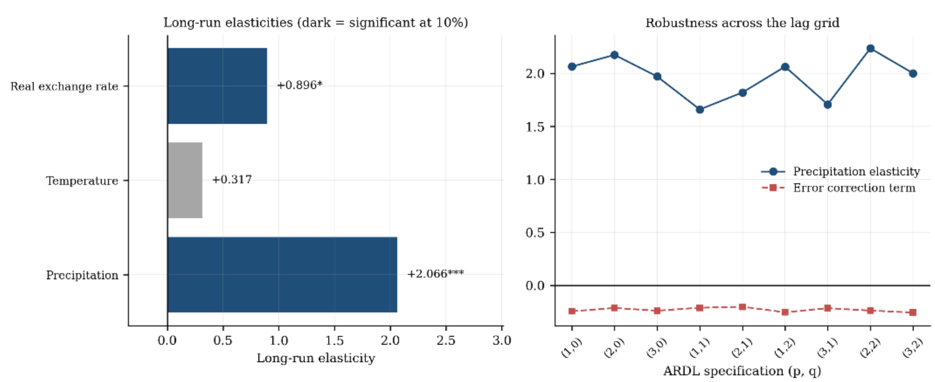
The real exchange rate carries an elasticity of 0.896, significant at the 10% level. A real depreciation improves the coverage ratio, as the expenditure-switching mechanism predicts, and the order of magnitude is close to unity. The channel is present but secondary. Rainfall moves the ratio roughly twice as much, and its coefficient is estimated with far greater precision. Temperature is not identified, with an elasticity of 0.32 and a p-value of 0.935. Over 61 observations the series is collinear with precipitation, and the historical warming range in Morocco, on the order of two degrees, is too narrow for a linear specification to isolate an independent effect. Section 6 returns to this point.

Table N°5 : Error correction term and long-run elasticities

Variable	Coefficient	Std. error	t	p-value	Sig.	Long-run elasticity
ρ (error correction term)	-0.2443	0.0861	-2.84	0.0045	***	—
Precipitation	0.5047	0.1448	3.49	0.0005	***	2.066
Temperature	0.0774	0.9435	0.08	0.9346		0.317
Real exchange rate	0.2190	0.1320	1.66	0.0971	*	0.896

*Source: Authors. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Long-run elasticities computed as $-\theta/\rho$. Newey-West standard errors. Selected specification: ARDL(1, 0, 0, 0), 61 observations, 1963-2023. Half-life of a shock: 2.5 years.*

Figure N°4 : Long-run elasticities in the selected specification (left) and stability of the precipitation elasticity and the error correction term across the nine specifications of the lag grid (right).



Source: Authors.

5.4. Robustness

Table N°6 reports the same quantities across all nine specifications of the lag grid. The error correction term ranges from -0.256 to -0.201 and the precipitation elasticity from 1.66 to 2.24, always positive and always the largest coefficient in the model. Neither result depends on the specification retained. The real exchange rate elasticity is less stable, ranging from -0.49 to 1.06, which is consistent with its weaker significance in the retained model. The two claims should be kept apart: the sign and magnitude of the precipitation elasticity are robust across the lag grid, whereas the evidence of cointegration is strongest for the SIC-selected specification and inconclusive elsewhere. The F statistic exceeds the 10% upper bound in the retained model alone.

Table N°6 : Robustness across the lag grid

p	q	Obs.	AIC	SIC	F	ECT	Precipitation	Real exch. rate
1	0	61	-4.5	14.5	4.22	-0.244	2.066	0.896
2	0	60	-5.2	15.7	3.81	-0.213	2.176	1.056
3	0	59	-2.4	20.5	3.76	-0.239	1.972	0.888
1	1	61	-3.7	21.7	2.16	-0.211	1.661	-0.093
2	1	60	-2.1	25.2	2.22	-0.201	1.821	0.193
1	2	60	-3.1	28.3	3.03	-0.254	2.065	-0.407
3	1	59	1.2	30.3	2.11	-0.215	1.709	0.183
2	2	60	-1.4	32.1	2.93	-0.237	2.238	-0.377
3	2	59	1.5	36.8	2.78	-0.256	2.003	-0.493

Source: Authors. Specifications ordered by the Schwarz criterion. The first row is the retained model.

A second robustness exercise re-introduces domestic agricultural value added, the variable that Section 3 argued should be excluded because it mediates the climate effect. The comparison is informative. With four regressors the sample shortens by four years, the World Bank series beginning only in 1965. The F statistic falls to 2.71, inside the inconclusive band for k = 4, and the precipitation elasticity drops from 2.07 to 1.49. Agricultural value added itself is not identified, with an elasticity of -0.031 and a p-value of 0.933. That is the pattern a mediator produces when it is included: part of the climate effect is absorbed by a variable that carries nothing of its own. The exclusion is a modelling decision derived from the theory, not a search for a favourable outcome, and the discarded specification is reported here so that the reader can weigh it.

5.5. Residual diagnostics

Table N°7 reports the residual diagnostics for the retained model, and Figure N°5 displays them. Residuals are normally distributed (Jarque-Bera, p = 0.572) and free of serial correlation (Breusch-Godfrey at one and two lags, p = 0.563 and 0.539; Ljung-Box at four lags, p = 0.411; Durbin-Watson 1.92). The functional form is not rejected (Ramsey RESET, p = 0.520) and the cumulative sum of recursive residuals stays within the 5% bands throughout. That last result should be read with care: CUSUM is built to detect a drift in the mean of the recursive residuals and has little power against a shift that leaves that mean broadly unchanged, so it is not evidence of coefficient constancy. Section 5.6 tests the coefficients directly and reaches the opposite conclusion. Two heteroskedasticity tests sit close to the conventional threshold: the ARCH test at one lag rejects at the margin (p = 0.049) while the same test at two lags does not (p = 0.110), and Breusch-Pagan is borderline (p = 0.080). This is why inference is conducted on Newey-West standard errors throughout; the ordinary least squares standard errors would in fact be slightly smaller.

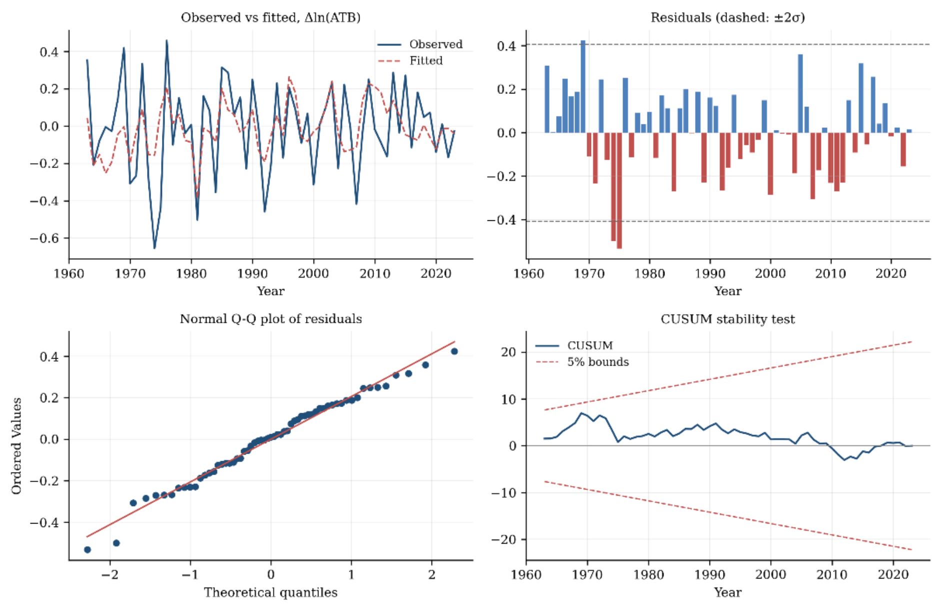
Table N°7 : Residual diagnostic tests

Test	**p-value**	**Conclusion**
Jarque-Bera (normality)	0.572	Normal
Breusch-Godfrey LM(1)	0.563	No serial correlation
Breusch-Godfrey LM(2)	0.539	No serial correlation
Ljung-Box Q(4)	0.411	No serial correlation
ARCH LM(1)	0.049	Rejected at 5%
ARCH LM(2)	0.110	Homoskedastic
Breusch-Pagan	0.080	Homoskedastic
Ramsey RESET	0.520	Functional form not rejected
Durbin-Watson	1.92	No first-order autocorrelation

Test	p-value	Conclusion
CUSUM	—	Parameters stable

Source: Authors. $R^2 = 0.299$, adjusted $R^2 = 0.191$.

Figure N°5 : Residual diagnostics: observed versus fitted first differences (top left), residuals with ±2σ bands (top right), normal Q-Q plot (bottom left) and CUSUM stability test with 5% bands (bottom right).



Source: Authors.

5.6. Structural break

Section 1 asserted that Morocco moved from agricultural trade surplus to deficit in the early 1970s. That assertion should be tested rather than stated, both because a break invalidates estimates that pool the two regimes and because its date is informative in itself. Three tests are applied, none of which imposes the date in advance, and Table N°8 collects their results.

The Gregory and Hansen (1996) procedure searches for the break that most favours cointegration and compares the resulting ADF statistic to critical values that account for the search. Under the level-shift model the statistic is -5.09 against a 10% critical value of -5.02, so the null of no

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cointegration is rejected, and the break is dated 1971. The models allowing a trend or a full regime shift do not reject; we read this as a matter of power rather than of substance, since the regime-shift model estimates twice as many parameters on the same sample, and since the direct test reported below finds the slopes to differ across regimes.

The Zivot and Andrews (1992) test asks a different question: whether each series is stationary once an endogenous break is allowed. For the coverage ratio the statistic is -5.88 with a p-value of 0.001 and a break dated 1973. The series is stationary around a level shift. That is why the augmented Dickey-Fuller test of Section 4.2 classified it as I(1): an unmodelled shift is easily mistaken for a unit root.

The third test bears directly on the estimated model. The Quandt-Andrews sup-Wald statistic for parameter constancy in the error correction equation reaches 5.44, above the 1% critical value of 4.53, with the most likely break in 1973. Parameter constancy is rejected. This contrasts with the CUSUM test of Section 5.5, which found no instability; the divergence is expected, since CUSUM has low power against shifts that leave the mean of the recursive residuals largely unchanged, whereas the sup-Wald statistic tests the coefficients directly.

Three procedures, three break dates within two years of one another: 1971, 1973 and 1973. The reversal the introduction described is real, it is econometrically detectable, and it coincides with the first oil shock and the accompanying reorientation of Moroccan trade. The two tests bearing on the estimated model both select 1973, which is the date used in what follows.

Table N°8 : Structural break tests

Test	Model	Statistic	Critical value	Break	Conclusion
Gregory-Hansen (ADF*)	Level shift (C)	-5.09	-5.02 (10%)	1971	Cointegration with break
Gregory-Hansen (ADF*)	Level and trend (C/T)	-5.06	-5.33 (10%)	1972	No rejection
Gregory-Hansen (ADF*)	Regime shift (C/S)	-5.08	-5.75 (10%)	1972	No rejection
Zivot-Andrews	ln(ATB), intercept	-5.88	p = 0.001	1973	Stationary around break
Quandt-Andrews (sup-F)	Error correction model	5.44	4.53 (1%)	1973	Constancy rejected

Source: Authors. Gregory-Hansen critical values from Gregory and Hansen (1996), Table 1, m = 3 regressors; Quandt-Andrews from Andrews (1993), 15% trimming. Break dates are estimated, not imposed.

Two responses are possible, and they do not agree. Adding a level dummy for the post-1973 period to the full-sample model raises the F statistic to 12.81 and the adjustment speed to -0.667, and the dummy is itself highly significant (p = 0.000); but the precipitation elasticity falls to 0.21 and ceases to be significant (p = 0.137).

Which response is right depends on whether the break shifts only the intercept of the relationship or its slopes as well, and the question is testable. Interacting the post-1973 dummy with every level term and testing their joint nullity gives a Wald statistic of 68.6, with a p-value below 0.001: the slopes change, decisively. The interaction on precipitation alone is significant at the 10% level (p

= 0.060), and the adjustment coefficient shifts from -1.52 before the break to -0.62 after. A level dummy is the wrong instrument, since it imposes on the slopes a constancy the data reject. Estimating on the post-break regime alone is the appropriate response, and it gives a cleaner picture.

Table N°9 reports that estimation. On 48 observations covering 1976-2023, the bounds test yields an F statistic of 8.52, above the upper critical value at the 1% level, so a long-run relationship is established without ambiguity. The error correction term is -0.3432 and significant at the 1% level, implying a half-life of 1.6 years, appreciably faster than the 2.5 years estimated on the pooled sample. The precipitation elasticity is 1.12 and significant at the 1% level. Every residual diagnostic is satisfied, including the ARCH test that was rejected at the margin on the pooled sample (p = 0.437 here).

Table N°9 : Error correction model estimated on the post-1973 regime

Variable	Coefficient	Std. error	t	p-value	Sig.	Long-run elasticity
ρ (error correction term)	-0.3432	0.1024	-3.35	0.0008	***	—
Precipitation	0.3832	0.1264	3.03	0.0024	***	1.117
Temperature	-0.3604	1.0688	-0.34	0.7359		-1.050
Real exchange rate	0.1709	0.1212	1.41	0.1585		0.498

Source: Authors. Newey-West standard errors. ARDL(1, 0, 0, 0), 48 observations, 1976-2023. Bounds test F = 8.52, above the 1% upper critical value of 5.61. Half-life of a shock: 1.6 years. R^2 = 0.435, adjusted R^2 = 0.319.

We regard this as the preferred specification. Constancy is rejected on the full sample, so the pooled estimates of Sections 5.2 to 5.5 average two regimes that the data say are different; the post-break estimates describe the regime Morocco has actually been in for fifty years. The pooled results are retained as a conservative benchmark, and the two readings agree on what matters: rainfall moves the coverage ratio more than proportionally, and the adjustment takes years rather than seasons. They differ on magnitude, 1.12 against 2.07, and on the speed of adjustment. The exchange rate is not identified in the post-break regime, which weakens the competitiveness channel reported in Section 5.3.

One caution applies. The break date is estimated from the same data used for the subsequent estimation, so the post-break inference is optimistic in a way that conventional standard errors do not capture. The result should be read as the relationship holding within the modern regime, not as a sharper measurement of the same quantity.

That caution can be answered in part. If the finding rested on the particular year the search happened to select, moving the start of the regime by a year either way would displace it. Table N°10 and Figure N°6 report the model re-estimated on every regime beginning between 1971 and 1976, holding the specification search unchanged.

The verdict does not move. The bounds test rejects the null of no long-run relationship at the 1% level for all 6 starting dates, with F ranging from 5.97 to 9.64 against an upper critical value of 5.61. The precipitation elasticity is positive and significant at the 5% level in every case. Its point estimates run from 0.57 to 1.34 with a standard deviation of 0.24, and 5 of the 6 lie within a few tenths of unity. The adjustment coefficient stays between -0.52 and -0.29 throughout.

Table N°10 : Sensitivity of the post-break estimates to the start of the regime

First year	Obs.	Lag order	Bounds F	ECT	Precipitation elasticity	p-value
1971-2023	51	ARDL(1,0,0,0)	9.64	-0.5180	0.571	0.0325**
1972-2023	48	ARDL(3,0,0,0)	6.47	-0.3452	1.169	0.0012***
1973-2023	48	ARDL(2,0,0,0)	5.97	-0.2925	1.344	0.0023***
1974-2023 (retained)	48	ARDL(1,0,0,0)	8.52	-0.3432	1.117	0.0024***

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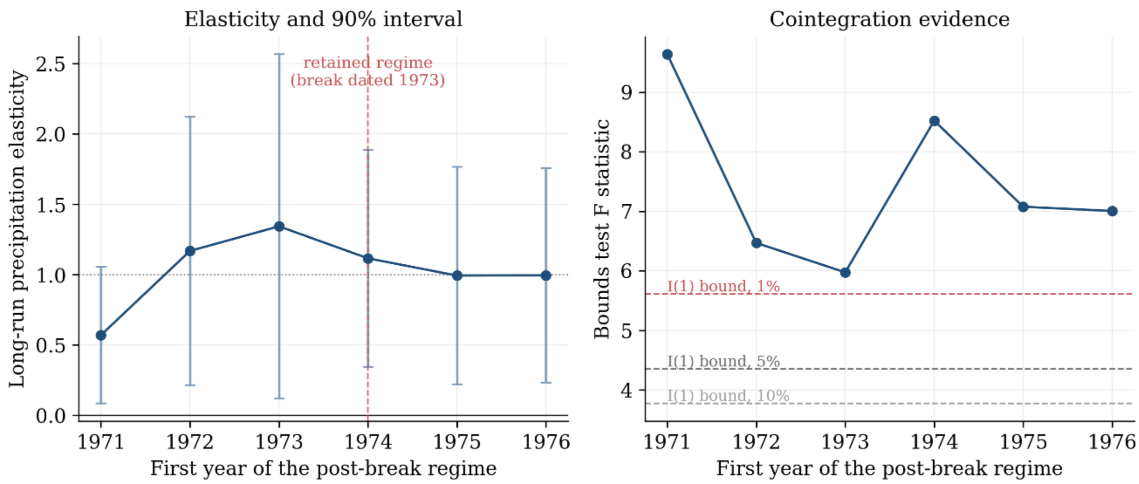
First year	Obs.	Lag order	Bounds F	ECT	Precipitation elasticity	p-value
1975-2023	47	ARDL(1,0,0,0)	7.08	-0.3403	0.994	0.0071***
1976-2023	46	ARDL(1,0,0,0)	7.01	-0.3433	0.995	0.0074***

*Source: Authors. Each row re-estimates the error correction model of Table N°9 on a regime starting in the stated year, with the lag order reselected by the Schwarz criterion and Newey-West standard errors. The upper critical value of the bounds test is 5.61 at the 1% level for k = 3 regressors. *** p < 0.01, ** p < 0.05, * p < 0.10.*

The lowest estimate, 0.57, comes from the earliest start date, which still includes two years that the break tests assign to the previous regime; the widest interval comes from 1973, where the Schwarz criterion selects a longer lag structure on a sample of the same size. Neither pattern suggests the retained date is favourable. The estimate reported in Table N°9, 1.12, sits close to the middle of the range rather than at its top. What the exercise establishes is narrow but useful: the rainfall elasticity of the coverage ratio in the modern regime is of the order of unity, and that order of magnitude does not depend on resolving the break date to the year.

Figure N°6 : Sensitivity of the long-run precipitation elasticity to alternative break dates. Left: point estimate with 90% interval, computed by the delta method. Right: bounds test F statistic against the I(1) upper critical values.



Source: Authors.

6. Discussion

Three findings emerge, and they do not carry equal weight. They are stated for the post-break regime, which Section 5.6 retains as the preferred specification, with the pooled estimates given alongside as a historical benchmark.

The first is the magnitude of the precipitation effect. In the post-break regime the long-run elasticity is 1.12: a 10% shortfall in rainfall is associated with a durable deterioration of the coverage ratio of about 11%. On the pooled sample the elasticity is 2.07, roughly twice as large, which is what fitting a single relationship across two regimes the data reject as identical would be expected to produce; we read the pooled figure as an upper bound rather than as a measurement. On either reading rainfall dominates the other determinants considered here, and the ordering does not depend on resolving the break date, since the elasticity stays positive and significant at the 5% level for every regime beginning between 1971 and 1976.

The second is the speed of adjustment. In the post-break regime 34.3% of a deviation from equilibrium is corrected within a year, a half-life of 1.6 years; on the pooled sample adjustment is slower, 24.4% and 2.5 years. Under either estimate a rainfall deficit is absorbed over several seasons rather than within the following one. For policy this matters more than the elasticity itself: a drought does not produce a one-year import bill but a multi-year deterioration of the external position, and buffer instruments must be sized accordingly.

The third is the ranking of the two channels, and here the two samples disagree in a way worth stating plainly. On the pooled sample a competitiveness channel is present: the real exchange rate elasticity is close to unity and significant at the 10% level, so a real depreciation of 10% is associated with an improvement of about 9%, against 21% for an equivalent gain in rainfall. In the post-break regime that channel is not identified at conventional levels. Exchange rate management is therefore treated here as a possible secondary margin rather than an established one, and on neither reading is it a substitute for adaptation: it acts on the smaller margin, and a country managing a pegged currency cannot reach for it freely.

No independent temperature effect is statistically identifiable within the linear specification, which calls for comment, since it contrasts with the crop-climate modelling literature. Two explanations fit our estimates. Morocco's mean annual temperature over the cereal-growing regions rose by about 1.4 degrees across the period on a fitted linear trend, a range within which yield responses are documented to be modest for the crops that dominate Moroccan exports, and which lies well below the thresholds at which crop models predict sharp declines. Bouras et al. (2019), simulating Tensift cereal yields, find that warming shortens the development cycle substantially while its net yield effect depends on whether CO_2 fertilisation is counted, which is the kind of conditionality a linear reduced form cannot represent. Temperature is also strongly correlated with precipitation in a semi-arid setting, so a linear specification on 61 observations cannot separate the two.

The regional warming context is not in question. Zittis et al. (2022) report that the Eastern Mediterranean and Middle East has warmed at about 0.45°C per decade, faster than other inhabited regions, and project the trend to continue. Our own reconstruction over Morocco's cereal-growing regions gives a slower rate, close to 0.22°C per decade, which places the country at the western and more temperate margin of that hotspot and helps explain why a linear temperature term carries little information over this sample.

Read together, these results shift the terms of the Moroccan food sovereignty debate, which is conducted almost entirely on the production side: how much wheat the country grows and what share of consumption it covers. Our estimates indicate that the climate exposure of the trade position is both larger and more persistent than the production framing suggests, and that the exchange rate channel offsets only a fraction of it. Adaptation spending on irrigation and water efficiency could generate a measurable trade benefit by reducing the sensitivity of agricultural trade to rainfall, and the Green Generation 2030 strategy can be argued on that ground as well as on food security.

Three instruments follow. Water efficiency and demand management act on the channel estimated here, and their return can now be compared with alternatives on a common metric. Strategic cereal reserves sized on the multi-year persistence documented above, rather than on a single season, would buffer the ratio through the adjustment period. And early warning based on seasonal precipitation forecasts would allow import procurement to be brought forward, the adjustment path being slow enough for anticipation to be worth something.

The feasibility of the third instrument is already established. Lehmann et al. (2020) obtain useful Moroccan wheat yield forecasts as early as December, and Bouras et al. (2021) reach comparable accuracy from satellite drought indices and regional climate indices. Fragaszy et al. (2020), working with stakeholders across Morocco, Tunisia, Lebanon and Jordan, document both the demand for such systems and the institutional obstacles to acting on their output. The binding constraint on anticipatory procurement is organisational rather than scientific.

6.1. An illustrative counterfactual scenario

The elasticity estimated above describes the past. It can be used to give an order of magnitude for the future, provided the exercise is labelled for what it is: a counterfactual arithmetic, not a projection and not a forecast. No CMIP6 output enters the model at any point, and the calculation assumes that an elasticity estimated on observed variability carries over unchanged to a climate the sample does not contain.

Applying the post-break elasticity of 1.12 mechanically to the 20 to 30% precipitation decline that the SSP5-8.5 scenario associates with Morocco by 2050 gives a long-run deterioration of the coverage ratio of roughly 22 to 33 percent. Starting from the 2023 ratio of 0.54, that would place it between 0.42 and 0.36, against a historical minimum of 0.35 recorded in 1984.

Two reservations bound the exercise. The first is the uncertainty of the elasticity itself: its 90 percent interval in the post-break regime runs from 0.35 to 1.89, so the range above is a point calculation drawn from an interval. The second concerns the rainfall path. Nouaceur et al. (2016) analyse observed series across the central Maghreb and report that the severe drying of the 1970s and 1980s gave way to a gradual return towards wetter conditions from the early 2000s in Algeria and Tunisia and from 2008 in Morocco, a trend they find inconsistent with the drying signal of the climate models. If that reversal persists, the deterioration would be smaller than the arithmetic suggests. The elasticity is symmetric and applies in both directions: it measures the sensitivity of the coverage ratio to rainfall, not the trajectory of rainfall itself.

7. Conclusion

This paper estimates the long-run relationship between climate variability and Morocco's agricultural trade coverage ratio over 1963-2023, on data drawn entirely from primary sources and reproducible from the estimation scripts.

The results come in two layers, and their evidential status differs. On the post-break regime, retained here as the preferred specification, the bounds test establishes a long-run relationship at the 1% level (F = 8.52); the precipitation elasticity is 1.12 and significant at the 1% level, so a 10% shortfall in rainfall is associated with a durable deterioration of the coverage ratio of about 11%; 34.3% of a deviation is corrected within a year, a half-life of 1.6 years; and every residual diagnostic is satisfied. That elasticity remains positive and significant at the 5% level for every regime beginning between 1971 and 1976, so it does not rest on the particular break year the search selected. On the full sample, retained as a historical benchmark, the evidence is weaker: the bounds test rejects at the 10% level only (F = 4.22), the precipitation elasticity is 2.07, the real exchange rate carries an elasticity of 0.90 significant at the 10% level, the half-life is 2.5 years, and the ARCH test at one lag rejects at the margin, which is why inference is conducted on Newey-West standard errors throughout. Parameter constancy is rejected on that sample, with a break that three independent procedures place in 1973 or within two years of it, so the pooled estimates average two regimes the data say are different.

For climate policy, the sensitivity of the trade position to rainfall gives irrigation and water-efficiency investment an economic justification beyond food security, and one that can be quantified. For trade policy, the multi-year persistence of shocks argues for strategic reserves sized on the adjustment period rather than the season, and for early warning systems allowing procurement to be brought forward. For macroeconomic policy the message is cautious: the exchange rate carries a secondary stabilisation margin on the pooled sample, roughly half the size of the climate channel, but it is not identified in the post-break regime we prefer, and should not be relied upon during drought episodes.

Four limitations should be acknowledged. On the pooled sample the long-run relationship is supported at the 10% level only, and the post-break estimate that strengthens it rests on a break date read from the same data, so its precision is overstated by conventional standard errors. National annual aggregates mask regional heterogeneity across agro-ecological zones whose exposure differs widely. The linear framework cannot capture threshold effects, which is the most likely reason temperature is not identified. And the dependent variable, being a ratio of values, conflates volume and price movements, so that an improvement may reflect either larger export volumes or more favourable terms of trade.

Each limitation points to an extension. Disaggregation by sub-sector would separate cereals from fresh produce and livestock, whose climate sensitivities differ. A non-linear threshold or smooth transition specification would test for the temperature effect the linear model cannot detect. Decomposing the ratio into volume and unit value would identify which side of the ratio drives the response. Dating the break on an independent criterion, rather than on the series itself, would remove the circularity noted above. And integrating CMIP6 projections under alternative scenarios would turn the elasticity estimated here into a trajectory to 2050.

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