



Adoption of Advanced Varieties to Enhance the Introduction of Bioeconomy Solutions

A dynamic optimization model of West African cocoa and palm oil

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Motivation: The Bioeconomy

The bioeconomy will enhance outputs from renewable resources — land, water, forests, and seas.



Land



Water



Forests



Seas

The challenge

Achieve sustainable intensification — producing more from the same land — to free land for other activities and enhance rural incomes.

This paper's example

Cocoa in West Africa: high-yield practices, a cocoa area cap, and diversification into palm oil.

The Case: West African Cocoa

~60%

of world cocoa supply comes from West Africa (Ghana + Ivory Coast)

$\approx 2\times$

yield gain possible from best management practices (BMP)

Low

BMP adoption today — incomes stagnant, yields flat



Why governments hesitate

If all farmers become more productive at once, the supply surge could depress world cocoa prices and erode the very revenue gains the policy was meant to deliver.

The Proposed Policy Package

Three coordinated components address productivity, oversupply risk, and land reuse together.



1. Adopt high-yield practices

Promote BMP cocoa — improved density, fertilization, shade, pruning, and pest control — roughly doubling yields per hectare.



2. Cap total cocoa area

A binding land ceiling: productivity gains cannot expand the cocoa footprint, blocking the feared supply surge at its source.



3. Diversify into palm oil

Land freed as low-yield stands retire flows into oil palm, generating new income streams and a hedge against cocoa price risk.

Why Palm Oil as the Diversification Crop?



Agroecological fit

Grows in the same humid tropical belt as cocoa — no relocation needed



Existing sector

Established mills and smallholder experience lower fixed and learning costs



Faster maturity

Productive in 3–4 years (vs. 5–6 for cocoa), with lower yield variability



Natural hedge

Palm prices move independently of cocoa, reducing national price risk



CSSV-immune

Palm is immune to cocoa swollen shoot virus, making conversion of infected land sensible



Domestic demand

Palm oil is West Africa's main cooking oil, with demand growing through urbanization

The Model

A dynamic partial equilibrium model of cocoa and palm oil, solved as a planner's problem.

Structure

- Regions: Ghana, Ivory Coast + Rest of World
- Crops: traditional cocoa, BMP cocoa, palm oil
- Age-structured tree cohorts (ages 1–30) with planting, removal & replanting choices
- Endogenous world prices via global market clearing (cocoa demand elasticity $\epsilon = -0.35$)
- 120-year horizon; results for years 1–60; 4% discount rate

Key features

- Binding cocoa area ceiling in both countries
- Infrastructure constraints: seedling nurseries limit BMP planting; milling capacity limits palm output
- Capacity grows $\leq 10\%$ /year — an S-curve on construction speed
- Terms-of-trade feedback: West Africa's 60% share means its output moves world prices
- Compared against business-as-usual: one-for-one replanting, no BMP

Result 1: The Land-Use Transition

Under optimal adoption, the planner replaces virtually all traditional cocoa with BMP within 2–3 decades.

Ghana

- Holds cocoa area near the ceiling; gains mainly from BMP yield increases
- Palm area grows from 0.4M to ~1M hectares

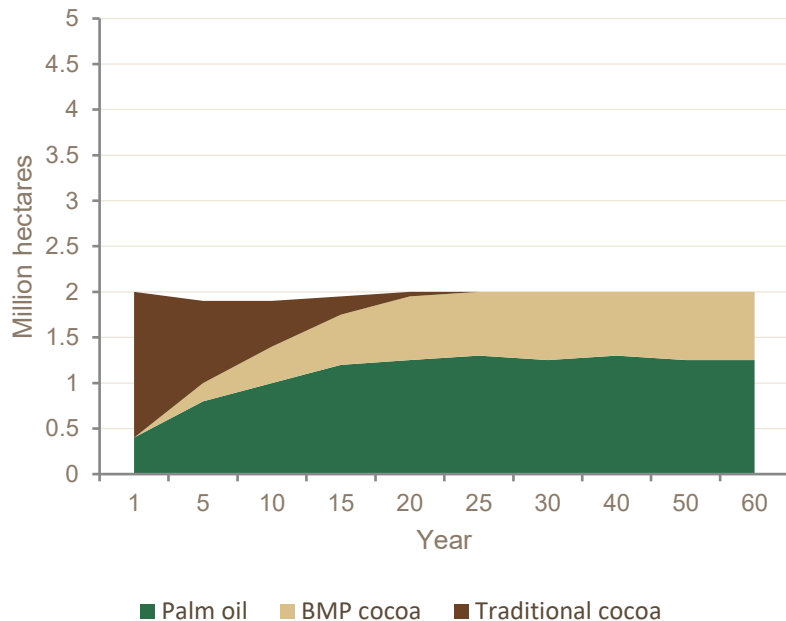
Ivory Coast

- Redirects a large share of retiring cocoa land into oil palm
- Palm area expands from 0.4M to ~2.5M hectares at its peak

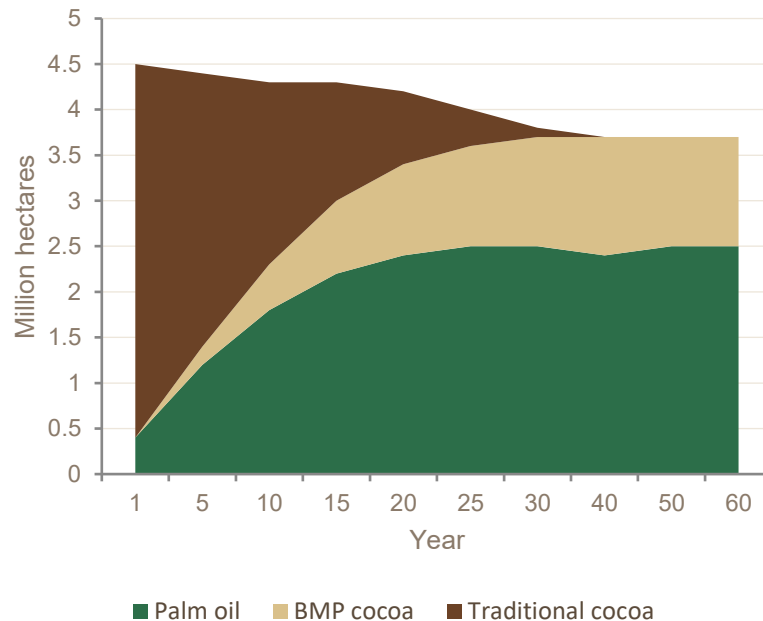
The cocoa ceiling binds throughout: land freed by retiring traditional stands can flow only to palm oil or fallow — never back into a larger cocoa footprint.

Land Use Over Time Under Optimal Adoption

Ghana

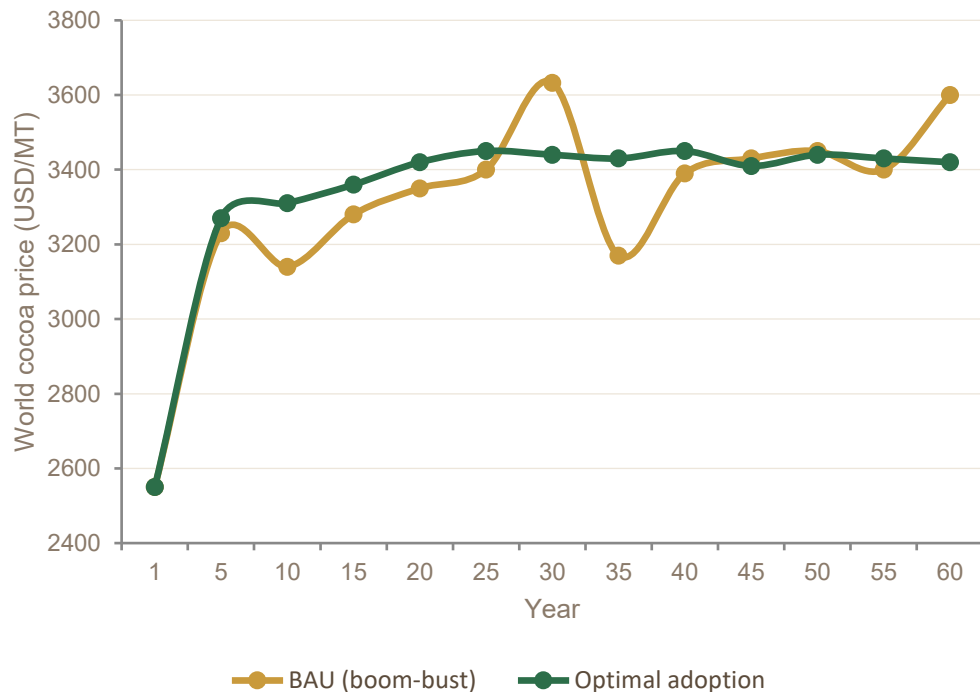


Ivory Coast



Illustrative acreage paths based on model results (Figure 1 of the paper). Traditional cocoa is replaced by BMP within 2–3 decades; freed land flows into palm oil.

Result 2: Prices Stabilize — They Don't Collapse



Cocoa

The planner staggers cohort transitions, smoothing supply. Average prices are slightly higher under adoption (\$3,432 vs. \$3,364/MT) — the boom-bust cycle of BAU is dampened.

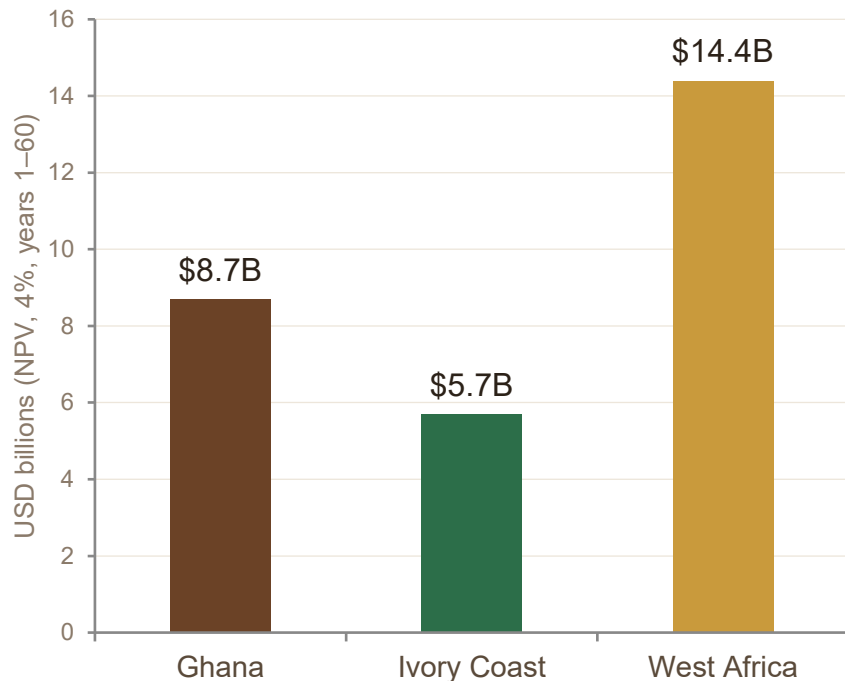
Palm oil

Expanded supply lowers palm prices by ~\$41/MT (~5%) — a terms-of-trade cost the model internalizes; the welfare gains are net of it.

The price-suppression fear does not survive the model.

Illustrative price paths based on model results (Figure 2 of the paper).

Result 3: Large, Durable Welfare Gains



\$14.4B

combined discounted profit gain over 60 years vs. business-as-usual

+27% / +7%

gain over each country's own BAU baseline (Ghana / Ivory Coast)

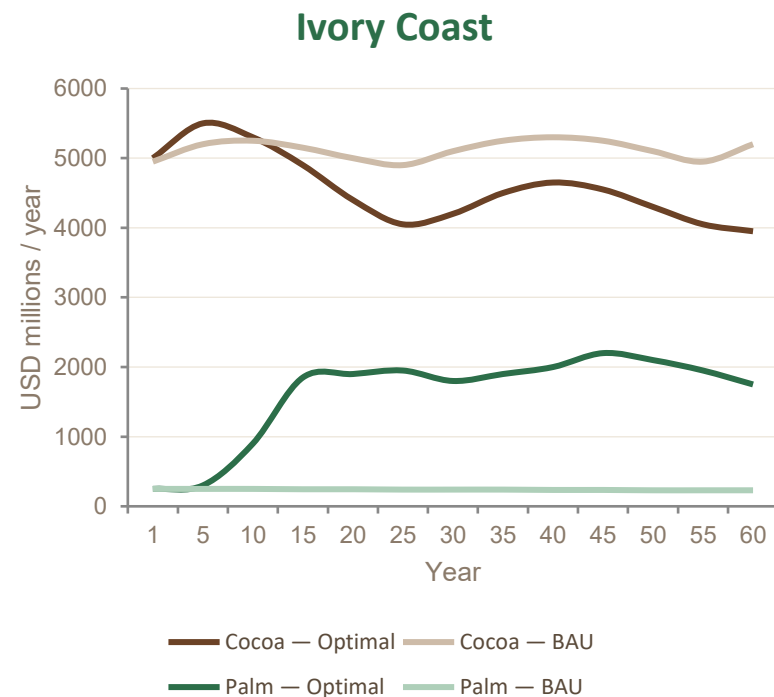
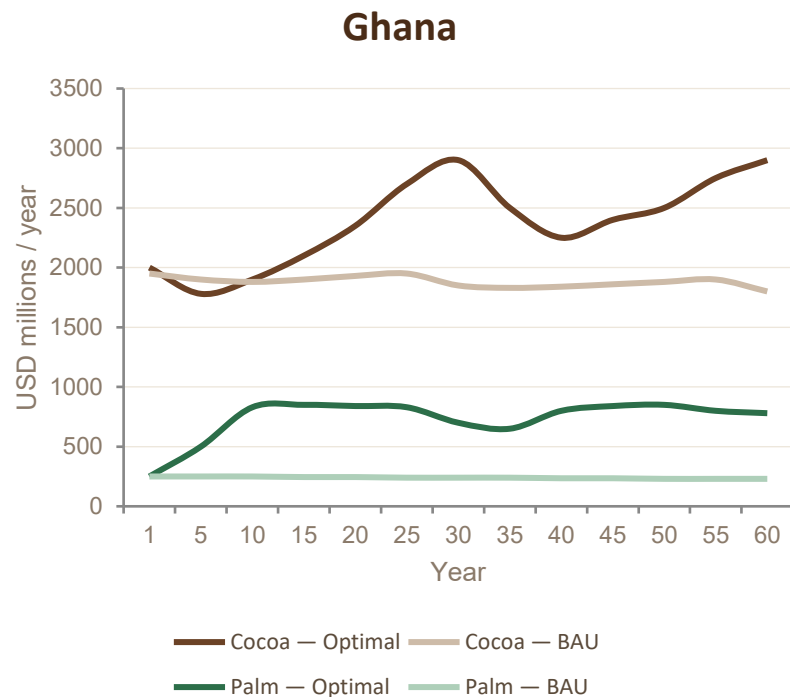
≈1.9×

West Africa's baseline annual cocoa + palm revenue (~\$7.5B/yr)

Early losses

upfront investment and immature stands turn sharply positive as BMP matures

Gross Revenue Over Time by Commodity



Illustrative revenue paths based on model results (Figure 5 of the paper). Ghana's cocoa revenue rises from BMP yields; Ivory Coast trades a slight cocoa decline for a large palm oil surge.

The Intuition: Why the Fear Is Unwarranted



The area cap blocks the extensive margin

Higher yields per hectare cannot become more hectares of cocoa — the feared supply surge is ruled out by design.



Staggered cohorts smooth supply

The planner spreads replanting across age classes, dampening the boom-bust cycles that cohort retirement creates under BAU.



Gains come from real productivity

Decomposition: the adoption effect (\$8.5B Ghana, \$4.6B IVC) dwarfs the price effect (\$0.3B, \$1.1B) — not market power or price manipulation.

Infrastructure: The Binding Constraint Is Speed, Not Money



~\$2.0B

total discounted investment in palm oil milling capacity (\$0.6B Ghana, \$1.4B Ivory Coast)



BCR > 3

benefit–cost ratios on milling investment — returns far above the cost of capital



$\leq 10\%/yr$

capacity growth limit: how fast mills and nurseries can physically be built is what binds

Policy implication: policies that shorten the time to build — removing institutional and logistical bottlenecks — generate higher returns than equivalent subsidies on the cost of building.

The Policy Challenge

Turning a \$14.4 billion opportunity into reality requires action on three fronts.



Convince governments

Persuade Ghana and Ivory Coast to champion the move to high-yield cocoa — the model shows the oversupply fear behind their hesitancy is unwarranted.



Obtain finance

Mobilize funding for the transition: investment is highly profitable ($BCR > 3$) and both countries gain without external transfers, but upfront capital is needed.



Build palm oil infrastructure

Construct large-scale milling capacity — fresh fruit bunches must be processed within hours of harvest, so mills must precede palm expansion.

Takeaways

- 1 Sustainable intensification works** — High-yield cocoa plus a land cap frees land for palm oil and raises rural incomes — a template for bioeconomy solutions.
- 2 Prices stabilize, they don't collapse** — Managed adoption dampens boom-bust cycles; average cocoa prices are, if anything, slightly higher.
- 3 The gains are large: ~\$14.4 billion** — Ghana +\$8.7B (+27%), Ivory Coast +\$5.7B (+7%) over 60 years — both countries share meaningfully.
- 4 Build fast, not just cheap** — The constraint is construction speed of mills and nurseries; accelerating timelines beats subsidizing costs.