Land Allocation and the Carbon Consequences of Biofuel Expansion

Online Appendix

Contents

A. Structural Model

We develop a static, multi-country, multi-sector general-equilibrium model of production, trade, consumption, energy use, and land allocation. The economy contains ten production sectors: five crops, livestock, managed forest, biofuel, OtherEnergy, and OtherGoods. All sectors use labor and intermediate inputs, while land additionally enters the agricultural and forestry sectors. Biofuel and OtherEnergy are imperfect substitutes in both intermediate demand and final consumption, and goods are differentiated by country of origin under an Armington trade structure (Armington, 1969). These features provide the common economic environment through which biofuel policy affects agricultural production, trade, and land use (Hertel et al., 2010).

Land is differentiated by agro-ecological zone (AEZ) source type and is allocated in two layers: first among idle land, cropland, pasture, and managed forest, and then, conditional on cropland, across the five crop sectors. We represent these allocation margins using five alternative structures drawn from the land-use literature: Fréchet heterogeneous land (Farrokhi and Pellegrina, 2023), CET (Keeney and Hertel, 2009), ACET (Zhao et al., 2020b), Classical Logit (Fujimori et al., 2014), and Entropy Logit (Carpentier and Letort, 2014). We hold all non-land components of the model fixed across specifications, so the only structural difference is the land-allocation mechanism. Differences in this mechanism alter the equilibrium relationship between land-use returns and land allocations and, through land's role in production, propagate to the rest of the general equilibrium.

A.1. Land-Using Production and Land Returns

Countries are indexed by $n, i \in \mathcal{N}$ and AEZ source types by $\tau \in \mathcal{T}$. Let $\mathcal{K}_1$ denote the five crop sectors, $\mathcal{K}_2$ livestock, and $\mathcal{K}_3$ managed forest. Let $\mathcal{E}$ contain the two energy sectors and $\mathcal{J}$ the residual OtherGoods sector.

Thus

$$\begin{aligned} &\mathcal{K}_1 \equiv \{\text{CrGrains}, \text{Oilseeds}, \text{Sugarcane}, \text{OthGrains}, \text{OthAgri}\}, \\ &\mathcal{K}_2 \equiv \{\text{Livestock}\}, \qquad \mathcal{K}_3 \equiv \{\text{ManagedForest}\}, \qquad \mathcal{K} \equiv \mathcal{K}_1 \cup \mathcal{K}_2 \cup \mathcal{K}_3, \\ &\mathcal{E} \equiv \{\text{bio}, \text{other}\}, \qquad \mathcal{J} \equiv \{\text{OtherGoods}\}, \qquad \mathcal{G} \equiv \mathcal{K} \cup \mathcal{E} \cup \mathcal{J}. \end{aligned} \tag{A.1}$$

Hence $k \in \mathcal{K}$ indexes a land-using sector and $j \in \mathcal{G}$ indexes a generic production sector.

We apply the same production technology in all five specifications. Under Fréchet, each plot has a use-specific productivity draw. Plot q of source type τ has productivity $e_{n,k,\tau}(q)$ in use k and produces

$$Q_{n,k,\tau}(q) = [e_{n,k,\tau}(q) L_{n,k,\tau}(q)]^{\gamma^L_{n,k}} N_{n,k,\tau}(q)^{\gamma^N_{n,k}} M_{n,k,\tau}(q)^{\gamma^M_{n,k}}, \qquad \gamma^L_{n,k} + \gamma^N_{n,k} + \gamma^M_{n,k} = 1. \tag{A.2}$$

Cost minimization implies

$$R_{n,k,\tau}(q) = e_{n,k,\tau}(q) h_{n,k}, \qquad h_{n,k} \equiv p_{n,k} \hbar_{n,k}, \tag{A.3}$$

where $p_{n,k}$ is the producer price and $\hbar_{n,k}$ collects the wage and intermediate-input price terms in the agricultural unit-cost function. The complete unit-cost expression is reported in Appendix F.

For CET, ACET, Classical Logit, and Entropy Logit, land productivity is represented at the source-use level rather than at the individual-plot level:

$$Q_{n,k,\tau} = [E_{n,k,\tau} L_{n,k,\tau}]^{\gamma^L_{n,k}} N_{n,k,\tau}^{\gamma^N_{n,k}} M_{n,k,\tau}^{\gamma^M_{n,k}}, \qquad R_{n,k,\tau} = E_{n,k,\tau} h_{n,k}. \tag{A.4}$$

When a land use expands under Fréchet, the composition of plots selected into that use changes, so average selected productivity changes with acreage. Related heterogeneous-land mechanisms are central to quantitative models of agricultural comparative advantage (Sands and Leimbach, 2003; Costinot et al., 2016; Sotelo, 2020; Farrokhi and Pellegrina, 2023).

A.2. Land Allocation

Country n is endowed with $\bar{L}_{n,\tau}$ units of source-τ land. Land allocation proceeds through the same two nests in all five specifications. Define the upper-layer choice set

$$\mathcal{G}^L \equiv \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}, \qquad \pi^L_{n,k,\tau} = \pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}, \quad k \in \mathcal{K}_1, \tag{A.5}$$

where 0 denotes idle land. For Fréchet, ACET, Classical Logit, and Entropy Logit, the allocation coefficients are physical acreage shares:

$$L_{n,g,\tau} = \bar{L}_{n,\tau}\pi^L_{n,g,\tau}, \qquad L_{n,k,\tau} = \bar{L}_{n,\tau}\pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}. \tag{A.6}$$

CET instead allocates transformed land services. This difference is important for interpreting counterfactual land quantities because only the former four specifications impose literal physical adding-up across uses.

Idle land enters the upper nest as an outside option. Let $E_{n,0,\tau}$ denote the source-specific activation or replacement requirement in labor units:

$$R_{n,0,\tau} = E_{n,0,\tau}W_n, \qquad R_{n,0,\tau}(q) = e_{n,0,\tau}(q)W_n \quad \text{under Fréchet.} \tag{A.7}$$

The return to idle land is therefore the value of the activation requirement that is avoided when land remains inactive.[1]

Fréchet. We assign each heterogeneous plot to the use yielding the highest preference-adjusted return. Let $\xi_{n,k,\tau} > 0$ be a land-use preference shifter, with $\xi_{n,0,\tau} = 1$. The plot-level choice is

$$\max\left\{\{\xi_{n,k,\tau}R_{n,k,\tau}(q)\}_{k\in\mathcal{K}}, R_{n,0,\tau}(q)\right\} = R_{n,0,\tau}(q) + \max\left\{\{\xi_{n,k,\tau}R_{n,k,\tau}(q) - R_{n,0,\tau}(q)\}_{k\in\mathcal{K}}, 0\right\}. \tag{A.8}$$

Productivity follows the two-layer nested Fréchet distribution

$$\begin{aligned}&\Pr(\mathbf{e}_{n,\tau}(q) \le \mathbf{e}_{n,\tau}) \\ &= \exp\left\{-[\Gamma(1-1/\nu_1)]^{-\nu_1}\left[\left(\frac{e_{n,0,\tau}}{E_{n,0,\tau}}\right)^{-\nu_1} + \sum_{m=1}^{3}\left(\left[\sum_{k\in\mathcal{K}_m}\left(\frac{e_{n,k,\tau}}{E_{n,k,\tau}}\right)^{-\nu_2}\right]^{-1/\nu_2}\right)^{-\nu_1}\right]\right\},\end{aligned} \tag{A.9}$$

where $\mathbb{E}[e_{n,k,\tau}(q)] = E_{n,k,\tau}$. Define the preference-adjusted mean return

$$\widetilde{R}_{n,k,\tau} \equiv \xi_{n,k,\tau}R_{n,k,\tau}, \qquad \xi_{n,0,\tau} = 1. \tag{A.10}$$

[1] Equivalently, the source-specific setup requirement may be valued before allocation: active land absorbs the requirement, whereas idle land saves the corresponding avoided setup cost.

The lower and upper allocation rules are

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \left(\frac{\widetilde{R}_{n,k,\tau}}{\widetilde{R}_{n,\mathcal{K}_1,\tau}}\right)^{\nu_2}, \qquad \widetilde{R}_{n,\mathcal{K}_1,\tau} = \left[\sum_{\ell\in\mathcal{K}_1} \widetilde{R}^{\nu_2}_{n,\ell,\tau}\right]^{1/\nu_2}, \tag{A.11}$$

$$\pi^L_{n,g,\tau} = \left(\frac{\widetilde{R}_{n,g,\tau}}{\widetilde{R}_{n,\tau}}\right)^{\nu_1}, \qquad \widetilde{R}_{n,\tau} = \left[\sum_{m\in\mathcal{G}^L} \widetilde{R}^{\nu_1}_{n,m,\tau}\right]^{1/\nu_1}. \tag{A.12}$$

The preference shifters also reconcile physical and land-revenue shares:

$$\pi^{RL}_{n,k,\tau} = \frac{\pi^L_{n,k,\tau}/\xi_{n,k,\tau}}{\sum_{j\in\{0\}\cup\mathcal{K}} \pi^L_{n,j,\tau}/\xi_{n,j,\tau}}. \tag{A.13}$$

CET. The standard CET specification treats land allocation as revenue maximization subject to nested transformation frontiers (Hertel and Tsigas, 1988). Conditional on cropland,

$$\max_{\{L_{n,k,\tau}\}_{k\in\mathcal{K}_1}} \sum_{k\in\mathcal{K}_1} R_{n,k,\tau}L_{n,k,\tau} \quad \text{s.t.} \quad L_{n,\mathcal{K}_1,\tau} = \left[\sum_{k\in\mathcal{K}_1} \beta_{n,k,\tau} L^{(1+\eta_2)/\eta_2}_{n,k,\tau}\right]^{\eta_2/(1+\eta_2)}. \tag{A.14}$$

At the upper layer,

$$\max_{\{L_{n,g,\tau}\}_{g\in\mathcal{G}^L}} \sum_{g\in\mathcal{G}^L} R_{n,g,\tau}L_{n,g,\tau} \quad \text{s.t.} \quad \bar{L}_{n,\tau} = \left[\sum_{g\in\mathcal{G}^L} \phi_{n,g,\tau} L^{(1+\eta_1)/\eta_1}_{n,g,\tau}\right]^{\eta_1/(1+\eta_1)}. \tag{A.15}$$

The first-order conditions imply

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \beta^{-\eta_2}_{n,k,\tau}\left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}}\right)^{\eta_2}, \qquad R_{n,\mathcal{K}_1,\tau} = \left[\sum_{\ell\in\mathcal{K}_1} \beta^{-\eta_2}_{n,\ell,\tau} R^{1+\eta_2}_{n,\ell,\tau}\right]^{1/(1+\eta_2)}, \tag{A.16}$$

$$\pi^L_{n,g,\tau} = \phi^{-\eta_1}_{n,g,\tau}\left(\frac{R_{n,g,\tau}}{R_{n,\tau}}\right)^{\eta_1}, \qquad R_{n,\tau} = \left[\sum_{m\in\mathcal{G}^L} \phi^{-\eta_1}_{n,m,\tau} R^{1+\eta_1}_{n,m,\tau}\right]^{1/(1+\eta_1)}. \tag{A.17}$$

The resulting branch quantities are transformed land services. Their transformation constraint replaces the physical area-balance constraint imposed by ACET and the Logit specifications.

ACET. ACET preserves a constant-elasticity mapping from relative returns to land shares while imposing additive physical-land constraints (Zhao et al., 2020b; Taheripour et al., 2020; Zhao et al., 2020a). Conditional on cropland,

$$\max_{\{L_{n,k,\tau}\}_{k\in\mathcal{K}_1}} \left[\sum_{k\in\mathcal{K}_1} \beta_{n,k,\tau}(R_{n,k,\tau}L_{n,k,\tau})^{\nu_2/(1+\nu_2)}\right]^{(1+\nu_2)/\nu_2} \quad \text{s.t.} \quad \sum_{k\in\mathcal{K}_1} L_{n,k,\tau} = L_{n,\mathcal{K}_1,\tau}. \tag{A.18}$$

At the upper layer,

$$\max_{\{L_{n,g,\tau}\}_{g\in\mathcal{G}^L}} \left[\sum_{g\in\mathcal{G}^L} \phi_{n,g,\tau}(R_{n,g,\tau}L_{n,g,\tau})^{\nu_1/(1+\nu_1)}\right]^{(1+\nu_1)/\nu_1} \quad \text{s.t.} \quad \sum_{g\in\mathcal{G}^L} L_{n,g,\tau} = \bar{L}_{n,\tau}. \tag{A.19}$$

The resulting lower and upper allocation rules are

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \beta^{1+\nu_2}_{n,k,\tau}\left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}}\right)^{\nu_2}, \qquad R_{n,\mathcal{K}_1,\tau} = \left[\sum_{\ell\in\mathcal{K}_1} \beta^{1+\nu_2}_{n,\ell,\tau}R^{\nu_2}_{n,\ell,\tau}\right]^{1/\nu_2}, \tag{A.20}$$

$$\pi^L_{n,g,\tau} = \frac{\phi^{1+\nu_1}_{n,g,\tau}R^{\nu_1}_{n,g,\tau}}{\sum\limits_{m\in\mathcal{G}^L}\phi^{1+\nu_1}_{n,m,\tau}R^{\nu_1}_{n,m,\tau}}, \qquad R_{n,\tau} = \left[\sum_{m\in\mathcal{G}^L}\phi^{1+\nu_1}_{n,m,\tau}R^{\nu_1}_{n,m,\tau}\right]^{1/\nu_1}. \tag{A.21}$$

Unlike CET, the additive constraints make the branch quantities a literal partition of the source-specific physical land endowment.

Classical Logit. The Classical Logit specification also allocates physical land, but obtains the shares from stochastic payoff maximization rather than a power transformation frontier. This formulation follows the standard random-utility interpretation of multinomial Logit (Train, 2009) and its application to acreage and land-use choice (Carpentier and Letort, 2014; Fujimori et al., 2014). Conditional on entering cropland, a plot q of source type τ chooses among the crop uses $k \in \mathcal{K}_1$:

$$k^C_{n,\tau}(q) \in \arg\max_{k\in\mathcal{K}_1}\left\{R_{n,k,\tau} + a^C_{n,k,\tau} + \frac{\varepsilon^C_{n,k,\tau}(q)}{\alpha_2}\right\}. \tag{A.22}$$

Here $R_{n,k,\tau}$ is the return to source-τ land in crop k; $a^C_{n,k,\tau}$ is a deterministic crop-specific payoff shifter; $\alpha_2 > 0$ is the inverse scale of lower-layer payoff dispersion; and $\varepsilon^C_{n,k,\tau}(q)$ is an i.i.d. Type-I extreme-value payoff shock. We normalize the location of the extreme-value shocks so that the inclusive return takes the log-sum form below.

Only differences in the payoff shifters affect conditional crop shares. We therefore normalize their common location and define

$$\psi^C_{n,k,\tau} \equiv \exp\left(\alpha_2 a^C_{n,k,\tau}\right), \qquad \psi^C_{n,k,\tau} > 0, \qquad \sum_{k\in\mathcal{K}_1}\psi^C_{n,k,\tau} = 1. \tag{A.23}$$

The lower-layer choice probabilities are then

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \frac{\psi^C_{n,k,\tau}\exp(\alpha_2 R_{n,k,\tau})}{\sum\limits_{\ell\in\mathcal{K}_1}\psi^C_{n,\ell,\tau}\exp(\alpha_2 R_{n,\ell,\tau})}, \qquad k \in \mathcal{K}_1. \tag{A.24}$$

The corresponding inclusive return to the cropland nest is

$$R_{n,\mathcal{K}_1,\tau} = \frac{1}{\alpha_2}\ln\left[\sum_{\ell\in\mathcal{K}_1}\psi^C_{n,\ell,\tau}\exp(\alpha_2 R_{n,\ell,\tau})\right]. \tag{A.25}$$

Thus $R_{n,\mathcal{K}_1,\tau}$ summarizes the value of the optimally chosen crop use within the lower nest and becomes the return to the cropland alternative in the upper layer.

At the upper layer, the choice set is $\mathcal{G}^L = \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}$, consisting of idle land, the cropland composite, pasture, and managed forest. A plot chooses

$$g^U_{n,\tau}(q) \in \arg\max_{g \in \mathcal{G}^L} \left\{ R_{n,g,\tau} + a^U_{n,g,\tau} + \frac{\varepsilon^U_{n,g,\tau}(q)}{\alpha_1} \right\}. \tag{A.26}$$

Here $R_{n,\mathcal{K}_1,\tau}$ from equation (A.25) is the return of the cropland alternative; $a^U_{n,g,\tau}$ is an upper-layer alternative-specific payoff shifter; $\alpha_1 > 0$ is the inverse scale of upper-layer payoff dispersion; and $\varepsilon^U_{n,g,\tau}(q)$ is an i.i.d. Type-I extreme-value payoff shock with the same location normalization.

We normalize the common location of the upper-layer payoff shifters and define

$$\psi^U_{n,g,\tau} \equiv \exp\left(\alpha_1 a^U_{n,g,\tau}\right), \qquad \psi^U_{n,g,\tau} > 0, \qquad \sum_{g \in \mathcal{G}^L} \psi^U_{n,g,\tau} = 1. \tag{A.27}$$

The upper-layer allocation shares are

$$\pi^L_{n,g,\tau} = \frac{\psi^U_{n,g,\tau} \exp(\alpha_1 R_{n,g,\tau})}{\sum_{m \in \mathcal{G}^L} \psi^U_{n,m,\tau} \exp(\alpha_1 R_{n,m,\tau})}, \qquad g \in \mathcal{G}^L, \tag{A.28}$$

and the corresponding inclusive return is

$$R_{n,\tau} = \frac{1}{\alpha_1} \ln\left[\sum_{m \in \mathcal{G}^L} \psi^U_{n,m,\tau} \exp(\alpha_1 R_{n,m,\tau}) \right]. \tag{A.29}$$

The idiosyncratic payoff shocks generate cross-plot dispersion in land-use choices without using aggregate resources.

Entropy Logit. Entropy Logit provides a deterministic optimization representation of a Logit allocation. Instead of interpreting dispersion as idiosyncratic payoff shocks, it associates departures from a reference allocation with convex management requirements. This representation builds on the use of Logit shares in multicrop and global land-allocation models (Carpentier and Letort, 2014; Fujimori et al., 2014). Let $\varpi^C_{n,\tau} > 0$ and $\varpi^U_{n,\tau} > 0$ denote labor required per unit of lower- and upper-layer management service, respectively. Given the wage W_n, the corresponding monetary costs per unit of management service are

$$W^{\varpi,C}_{n,\tau} \equiv W_n \varpi^C_{n,\tau}, \qquad W^{\varpi,U}_{n,\tau} \equiv W_n \varpi^U_{n,\tau}. \tag{A.30}$$

Let $\psi^C_{n,k,\tau}$ and $\psi^U_{n,g,\tau}$ denote the reference allocation shares for the lower and upper nests. They satisfy

$$\psi^C_{n,k,\tau} > 0, \qquad \sum_{k \in \mathcal{K}_1} \psi^C_{n,k,\tau} = 1, \qquad \psi^U_{n,g,\tau} > 0, \qquad \sum_{g \in \mathcal{G}^L} \psi^U_{n,g,\tau} = 1. \tag{A.31}$$

Let $\bar{m}^C_{n,\tau}$ and $\bar{m}^U_{n,\tau}$ denote the allocation-invariant baseline management requirements per hectare.

The total management requirements per hectare are

$$m^C_{n,\tau} = \bar{m}^C_{n,\tau} + \frac{1}{\alpha_2} \sum_{k \in \mathcal{K}_1} \pi^L_{n,k|\mathcal{K}_1,\tau} \ln\left(\frac{\pi^L_{n,k|\mathcal{K}_1,\tau}}{\psi^C_{n,k,\tau}} \right), \tag{A.32}$$

$$m^U_{n,\tau} = \bar{m}^U_{n,\tau} + \frac{1}{\alpha_1} \sum_{g \in \mathcal{G}^L} \pi^L_{n,g,\tau} \ln\left(\frac{\pi^L_{n,g,\tau}}{\psi^U_{n,g,\tau}} \right). \tag{A.33}$$

Here $\alpha_2 > 0$ and $\alpha_1 > 0$ govern the curvature of the lower- and upper-layer management requirements. Because both π^L and ψ are allocation shares, the second term in each equation is a relative-entropy distance from the corresponding reference allocation.

Conditional on entering cropland, the manager chooses conditional crop shares to maximize land returns net of management costs:

$$\max_{\{\pi^L_{n,k|\mathcal{K}_1,\tau}\}_{k \in \mathcal{K}_1}} \left\{ \sum_{k \in \mathcal{K}_1} \pi^L_{n,k|\mathcal{K}_1,\tau} R_{n,k,\tau} - W^{\varpi,C}_{n,\tau} m^C_{n,\tau} \right\} \quad \text{s.t.} \quad \sum_{k \in \mathcal{K}_1} \pi^L_{n,k|\mathcal{K}_1,\tau} = 1. \tag{A.34}$$

The first-order conditions imply

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \frac{\psi^C_{n,k,\tau} \exp\left(\alpha_2 R_{n,k,\tau} / W^{\varpi,C}_{n,\tau}\right)}{\sum_{\ell \in \mathcal{K}_1} \psi^C_{n,\ell,\tau} \exp\left(\alpha_2 R_{n,\ell,\tau} / W^{\varpi,C}_{n,\tau}\right)}, \qquad k \in \mathcal{K}_1. \tag{A.35}$$

The gross inclusive return generated by the crop nest is

$$R_{n,\mathcal{K}_1,\tau} = \frac{W^{\varpi,C}_{n,\tau}}{\alpha_2} \ln\left[\sum_{\ell \in \mathcal{K}_1} \psi^C_{n,\ell,\tau} \exp\left(\alpha_2 \frac{R_{n,\ell,\tau}}{W^{\varpi,C}_{n,\tau}} \right) \right]. \tag{A.36}$$

Accordingly, the maximized lower-layer return net of the baseline management requirement is

$$R_{n,\mathcal{K}_1,\tau} - W^{\varpi,C}_{n,\tau} \bar{m}^C_{n,\tau},$$

while $R_{n,\mathcal{K}_1,\tau}$ is the return carried by the cropland alternative into the upper land nest.

At the upper layer, the manager allocates source-τ land among $g \in \mathcal{G}^L = \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}$ by solving

$$\max_{\{\pi^L_{n,g,\tau}\}_{g \in \mathcal{G}^L}} \left\{ \sum_{g \in \mathcal{G}^L} \pi^L_{n,g,\tau} R_{n,g,\tau} - W^{\varpi,U}_{n,\tau} m^U_{n,\tau} \right\} \quad \text{s.t.} \quad \sum_{g \in \mathcal{G}^L} \pi^L_{n,g,\tau} = 1, \tag{A.37}$$

where the cropland return $R_{n,\mathcal{K}_1,\tau}$ is given by equation (A.36). The first-order conditions imply

$$\pi^L_{n,g,\tau} = \frac{\psi^U_{n,g,\tau} \exp\left(\alpha_1 R_{n,g,\tau} / W^{\varpi,U}_{n,\tau}\right)}{\sum_{m \in \mathcal{G}^L} \psi^U_{n,m,\tau} \exp\left(\alpha_1 R_{n,m,\tau} / W^{\varpi,U}_{n,\tau}\right)}, \qquad g \in \mathcal{G}^L. \tag{A.38}$$

The corresponding gross inclusive return is

$$R_{n,\tau} = \frac{W^{\varpi,U}_{n,\tau}}{\alpha_1} \ln\left[\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} \exp\left(\alpha_1 \frac{R_{n,m,\tau}}{W^{\varpi,U}_{n,\tau}}\right)\right]. \tag{A.39}$$

The maximized upper-layer return net of the baseline management requirement is $R_{n,\tau} - W^{\varpi,U}_{n,\tau}\bar{m}^U_{n,\tau}$.

Unlike the stochastic shocks in Classical Logit, management services use real resources. Upper-layer management applies to the entire source-τ land endowment, whereas lower-layer management applies only to land entering cropland. Aggregate management labor demand is

$$N^M_n = \sum_{\tau\in\mathcal{T}} \left[\varpi^U_{n,\tau}\bar{L}_{n,\tau}m^U_{n,\tau} + \varpi^C_{n,\tau}\bar{L}_{n,\tau}\pi^L_{n,\mathcal{K}_1,\tau}m^C_{n,\tau}\right]. \tag{A.40}$$

Land allocation and output. Selected productivity determines how the land shares above contribute to production. The resulting output is

$$Q_{n,k} = \sum_{\tau\in\mathcal{T}} \bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau} \begin{cases} (\pi^L_{n,\mathcal{K}_1,\tau})^{(\nu_1-1)/\nu_1}(\pi^L_{n,k|\mathcal{K}_1,\tau})^{(\nu_2-1)/\nu_2}, & \text{Fréchet, } k\in\mathcal{K}_1,\\ (\pi^L_{n,k,\tau})^{(\nu_1-1)/\nu_1}, & \text{Fréchet, } k\in\mathcal{K}_2\cup\mathcal{K}_3,\\ \pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}, & \text{otherwise, } k\in\mathcal{K}_1,\\ \pi^L_{n,k,\tau}, & \text{otherwise, } k\in\mathcal{K}_2\cup\mathcal{K}_3. \end{cases} \tag{A.41}$$

Under Fréchet, output is concave in the relevant allocation share because expansion draws progressively less productive plots into the selected use. Thus, identical acreage responses can produce different output responses across land specifications. For CET, the branch quantities entering this mapping are transformed land services rather than physical hectares.

Activating previously idle land requires setup labor. The source-specific requirement is

$$S_{n,\mathrm{agr},\tau} = E_{n,0,\tau}\bar{L}_{n,\tau} \begin{cases} 1-(\pi^L_{n,0,\tau})^{(\nu_1-1)/\nu_1}, & \text{Fréchet},\\ \sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^L_{n,g,\tau}, & \text{CET/ACET/Classical Logit/Entropy Logit.} \end{cases} \tag{A.42}$$

Net land revenue equals active-land revenue less setup costs and, under Entropy Logit, management costs. The complete income and idle-replacement accounting is reported in Appendix F.

A.3. Non-Land Production, Energy, and Trade

The three non-land sectors consist of the two energy sectors $j\in\mathcal{E}$ and the residual OtherGoods sector $j\in\mathcal{J}$. For each $j\in\mathcal{E}\cup\mathcal{J}$, production and unit cost are

$$Q_{n,j} = A_{n,j}N_{n,j}^{\gamma^N_{n,j}}M_{n,j}^{\gamma^M_{n,j}}, \qquad c_{n,j} = \Upsilon_{n,j}A^{-1}_{n,j}W_n^{\gamma^N_{n,j}}(P^M_{n,j})^{\gamma^M_{n,j}}, \qquad \gamma^N_{n,j}+\gamma^M_{n,j}=1. \tag{A.43}$$

Intermediate demand incorporates an explicit energy substitution margin, as in quantitative biofuel models that allow changes in relative energy prices to alter the demand for biofuel and conventional energy (Hertel et al., 2010; Golub and Hertel, 2012). The intermediate-input structure is common to every production sector $j\in\mathcal{G}$, including the land-using sectors. Biofuel and OtherEnergy are first combined into a CES energy composite, denoted by e. This energy composite then enters the sectoral intermediate-input bundle together with the non-energy intermediate goods.

The price of the production energy composite is

$$P^{p}_{nj,e} = \left[\phi^{e,p}_{nj} P^{1-\sigma^{e,p}}_{n,\text{bio}} + (1-\phi^{e,p}_{nj}) P^{1-\sigma^{e,p}}_{n,\text{other}}\right]^{1/(1-\sigma^{e,p})}, \tag{A.44}$$

and the corresponding expenditure shares are

$$\omega^{e,p}_{nj,\text{bio}} = \phi^{e,p}_{nj} \left(\frac{P_{n,\text{bio}}}{P^{p}_{nj,e}}\right)^{1-\sigma^{e,p}}, \qquad \omega^{e,p}_{nj,\text{other}} = (1-\phi^{e,p}_{nj}) \left(\frac{P_{n,\text{other}}}{P^{p}_{nj,e}}\right)^{1-\sigma^{e,p}}. \tag{A.45}$$

Define

$$\mathcal{G}' \equiv (\mathcal{G} \setminus \mathcal{E}) \cup \{e\}, \tag{A.46}$$

so that the two energy goods in $\mathcal{E}$ are replaced by the single energy composite e in the intermediate-input nest. The complete intermediate-input price is

$$P^{M}_{n,j} = \left(\frac{P^{p}_{nj,e}}{\gamma^{X}_{n,je}}\right)^{\gamma^{X}_{n,je}} \prod_{\ell \in \mathcal{G}' \setminus \{e\}} \left(\frac{P_{n,\ell}}{\gamma^{X}_{n,j\ell}}\right)^{\gamma^{X}_{n,j\ell}}. \tag{A.47}$$

Here $\gamma^{X}_{n,j\ell}$ denotes the expenditure share of intermediate category ℓ in sector j.

A biofuel producer subsidy satisfies

$$(1+\omega^{p}_{n,\text{bio}}) p_{n,\text{bio}} = c_{n,\text{bio}}, \qquad T^{p}_{n} = \frac{\omega^{p}_{n,\text{bio}}}{1+\omega^{p}_{n,\text{bio}}} Y_{n,\text{bio}}. \tag{A.48}$$

International sourcing follows the Armington assumption that goods of the same sector supplied by different origins are imperfect substitutes (Armington, 1969). With delivered price $P_{ni,j} = \kappa_{ni,j} p_{i,j}$, expenditure minimization gives

$$P_{n,j} = \left[\sum_{i} \zeta_{ni,j} P^{1-\sigma_j}_{ni,j}\right]^{1/(1-\sigma_j)}, \qquad \lambda_{ni,j} = \frac{\zeta_{ni,j} P^{1-\sigma_j}_{ni,j}}{\sum_{m} \zeta_{nm,j} P^{1-\sigma_j}_{nm,j}}. \tag{A.49}$$

A.4. Households and Equilibrium

Final consumption is Cobb–Douglas across non-energy categories and a CES energy composite. A final-consumption biofuel subsidy $\tau^{c}_{n,\text{bio}}$ changes only the household price of biofuel. The household energy price is

$$P^{c}_{n,e} = \left[\phi^{e,c} \left((1-\tau^{c}_{n,\text{bio}}) P_{n,\text{bio}}\right)^{1-\sigma^{e,c}} + (1-\phi^{e,c}) P^{1-\sigma^{e,c}}_{n,\text{other}}\right]^{1/(1-\sigma^{e,c})}, \tag{A.50}$$

with within-energy expenditure shares

$$\omega^{e,c}_{n,\text{bio}} = \phi^{e,c} \left[\frac{(1-\tau^{c}_{n,\text{bio}}) P_{n,\text{bio}}}{P^{c}_{n,e}}\right]^{1-\sigma^{e,c}}, \qquad \omega^{e,c}_{n,\text{other}} = (1-\phi^{e,c}) \left(\frac{P_{n,\text{other}}}{P^{c}_{n,e}}\right)^{1-\sigma^{e,c}}. \tag{A.51}$$

The aggregate consumption price index is

$$P_n^C = \left(\frac{P_{n,e}^c}{\alpha_{n,e}^C}\right)^{\alpha_{n,e}^C} \prod_{j\in\mathcal{G}'\setminus\{e\}} \left(\frac{P_{n,j}}{\alpha_{n,j}^C}\right)^{\alpha_{n,j}^C}. \tag{A.52}$$

The consumer-subsidy cost and household budget are

$$T_n^c = \tau_{n,\mathrm{bio}}^c P_{n,\mathrm{bio}} C_{n,\mathrm{bio}}, \qquad P_n^C C_n = W_n N_n + \mathrm{NLR}_n + D_n - T_n^p - T_n^c, \tag{A.53}$$

where C_n is aggregate consumption, N_n is the labor endowment, and D_n is the benchmark-consistent net transfer, with $\sum_n D_n = 0$. Its portfolio implementation is given in Appendix F.

Aggregate net land revenue is

$$\mathrm{NLR}_n = \begin{cases} \displaystyle\sum_{\tau\in\mathcal{T}} \sum_{k\in\{0\}\cup\mathcal{K}} \mathbb{E}[R_{n,k,\tau}(q)\,|\,q\in\Omega_{n,k,\tau}]\, L_{n,k,\tau} - W_n \sum_{\tau\in\mathcal{T}} \mathbb{E}[e_{n,0,\tau}(q)]\bar{L}_{n,\tau}, & \text{Fréchet,} \\ \displaystyle\sum_{\tau\in\mathcal{T}} \sum_{k\in\{0\}\cup\mathcal{K}} R_{n,k,\tau} L_{n,k,\tau} - W_n \sum_{\tau\in\mathcal{T}} E_{n,0,\tau}\bar{L}_{n,\tau}, & \text{ACET/CET/Classical Logit,} \\ \displaystyle\sum_{\tau\in\mathcal{T}} \sum_{k\in\{0\}\cup\mathcal{K}} R_{n,k,\tau} L_{n,k,\tau} - W_n \sum_{\tau\in\mathcal{T}} E_{n,0,\tau}\bar{L}_{n,\tau} - W_n N_n^M, & \text{Entropy Logit.} \end{cases} \tag{A.54}$$

Under Fréchet, $\Omega_{n,k,\tau}$ is the set of plots selected into use k, so land payments use returns conditional on selection and the replacement cost uses expected idle productivity. ACET, CET, and Classical Logit instead use source–use returns and subtract the corresponding replacement cost $W_n E_{n,0,\tau}\bar{L}_{n,\tau}$. Entropy Logit has the same accounting but additionally subtracts the real management cost $W_n N_n^M$.

Goods-market clearing links final and intermediate expenditure to producer sales; the complete sectoral absorption equations are collected in Appendix F. Labor-market clearing is

$$W_n N_n = \begin{cases} \displaystyle\sum_{j\in\mathcal{G}} \gamma_{n,j}^N Y_{n,j} + W_n \sum_{\tau\in\mathcal{T}} S_{n,\mathrm{agr},\tau}, & \text{Fréchet/ACET/CET/Classical Logit,} \\ \displaystyle\sum_{j\in\mathcal{G}} \gamma_{n,j}^N Y_{n,j} + W_n \sum_{\tau\in\mathcal{T}} S_{n,\mathrm{agr},\tau} + W_n N_n^M, & \text{Entropy Logit.} \end{cases} \tag{A.55}$$

Here $Y_{n,j}$ is producer sales in sector j, $S_{n,\mathrm{agr},\tau}$ is the source-specific land-activation labor requirement defined above, and N_n^M is aggregate management labor under Entropy Logit. Thus the three terms on the right-hand side correspond to labor used in production, land activation, and, when applicable, land management.

External balance is

$$\sum_i \sum_j X_{ni,j} = \sum_i \sum_j X_{in,j} + D_n, \tag{A.56}$$

where $X_{ni,j}$ denotes expenditure in destination n on sector-j goods supplied by origin i. Thus the two sums are country n's total expenditure and total sales, respectively.

Given productivities, endowments, trade and policy wedges, and technology and preference parameters, an equilibrium consists of prices, wages, land returns, land allocations, production, trade, and consumption such that firms and households optimize and goods, labor, land, fiscal, and international-payment conditions hold. Counterfactual equilibria are solved in exact proportional changes, $\widehat{x} = x'/x$, following Dekle et al. (2008). The complete level and exact-change systems are reported in Appendix F.

B. Comparative Properties of Land-Allocation Models

We compare how land returns determine shares and how allocated land contributes to output. Land reallocation changes production, factor demand, prices, and trade, which in turn affect equilibrium land returns. Because the two land nests share the same mathematical structure, we state the results for a generic nest and suppress unnecessary subscripts. Let $i, j \in \mathcal{I}$ index land uses, π_i^L denote land shares, $R_i > 0$ land returns, and $\bar{L}$ the land available to the nest. Detailed derivations and proofs are provided in Appendix C.

B.1. Physical Land and Partial-Equilibrium Allocation

Fréchet, ACET, and the two Logit specifications allocate physical land, whereas CET allocates transformed land services.

Proposition 1 (Physical land additivity)**.** *Under Fréchet, ACET, Classical Logit, and Entropy Logit,*

$$L_i = \pi_i^L \bar{L}, \qquad \sum_{i\in\mathcal{I}} \pi_i^L = 1, \qquad \sum_{i\in\mathcal{I}} L_i = \bar{L}. \tag{B.1}$$

Under CET,

$$\bar{L} = \left[\sum_{i\in\mathcal{I}} \beta_i L_i^{(1+\eta)/\eta}\right]^{\eta/(1+\eta)} \tag{B.2}$$

so that $\sum_{i\in\mathcal{I}} L_i \neq \bar{L}$ in general.

Fréchet and ACET share the same proportional-return mapping, CET follows the transformation relationship implied by its frontier, and the two Logit specifications respond to return levels. The following proposition characterizes these differences.

Proposition 2 (Conditional land-share responses)**.** *For the partial-equilibrium comparison, take counterfactual return changes as given and, for Entropy Logit, also take the change in the unit cost of management services as given. The exact land-share responses are*

$$\widehat{R} = \begin{cases} \left[\sum_{j\in\mathcal{I}} \pi_j^{L,0} \widehat{R}_j^{\nu}\right]^{1/\nu}, & \textit{Fréchet and ACET}, \\ \left[\sum_{j\in\mathcal{I}} \pi_j^{RL,0} \widehat{R}_j^{1+\eta}\right]^{1/(1+\eta)}, & \textit{CET}, \end{cases}$$

$$\widehat{\exp(R)} = \left[\sum_{j\in\mathcal{I}} \pi_j^{L,0}\left(\widehat{\exp(R_j)}\right)^{\alpha}\right]^{1/\alpha}, \qquad \textit{Classical Logit},$$

$$\widehat{\exp(R/W^{\varpi})} = \left[\sum_{j\in\mathcal{I}} \pi_j^{L,0}\left(\widehat{\exp(R_j/W^{\varpi})}\right)^{\alpha}\right]^{1/\alpha}, \qquad \textit{Entropy Logit},$$

$$\widehat{\pi}_i^L = \begin{cases} \left(\dfrac{\widehat{R}_i}{\widehat{R}}\right)^{\nu}, & \textit{Fréchet and ACET}, \\ \left(\dfrac{\widehat{R}_i}{\widehat{R}}\right)^{\eta}, & \textit{CET}, \\ \left[\dfrac{\widehat{\exp(R_i)}}{\widehat{\exp(R)}}\right]^{\alpha}, & \textit{Classical Logit}, \\ \left[\dfrac{\widehat{\exp(R_i/W^{\varpi})}}{\widehat{\exp(R/W^{\varpi})}}\right]^{\alpha}, & \textit{Entropy Logit}, \end{cases} \qquad i \in \mathcal{I}. \tag{B.3}$$

Here $\pi_j^{L,0} \equiv L_j^0/\sum_{\ell\in\mathcal{I}} L_\ell^0$ and $\pi_j^{RL,0} \equiv R_j^0 L_j^0/\sum_{\ell\in\mathcal{I}} R_\ell^0 L_\ell^0$ denote the initial physical-land and land-revenue shares, respectively, where L_j^0 is land allocated to use j and R_j^0 is its return per unit of land. Hats denote exact proportional changes, and α is the Logit scale parameter. For Classical Logit, $\widehat{\exp(R_i)} \equiv \exp[R_i(\widehat{R}_i - 1)]$. For Entropy Logit, $\widehat{\exp(R_i/W^{\varpi})} \equiv \exp\{(R_i/W^{\varpi})[\widehat{R}_i/\widehat{W}^{\varpi} - 1]\}$, where W^{ϖ} denotes the unit cost of management services.

Fréchet, ACET, and the two Logit specifications use physical-land shares in the aggregate term of equation (B.3), whereas CET uses land-revenue shares. Fréchet, ACET, and CET depend on ratios of proportional return changes, whereas the Logit specifications depend on ratios of exponential return indices.

The parameters ν and η are elasticities with respect to proportional returns, whereas α scales return levels. For Classical Logit, the local elasticity with respect to a proportional change in R_i is therefore αR_i, and for Entropy Logit it is $\alpha R_i / W^{\varpi}$. Thus, matching a Logit specification locally to a power specification requires αR_i^0 (or $\alpha R_i^0 / W^{\varpi,0}$) to match the corresponding power elasticity at the initial equilibrium. Once returns move away from that point, α remains fixed but the implied local elasticity changes with the return level.

B.2. Return Metrics and Share Elasticities

Proposition 3 (Return metrics)**.** *For any $i, j \in \mathcal{I}$, the exact counterfactual change in relative land shares is*

$$\ln\left(\frac{\widehat{\pi}_i^L}{\widehat{\pi}_j^L}\right) = \begin{cases} \nu \ln\left(\dfrac{\widehat{R}_i}{\widehat{R}_j}\right), & \textit{Fréchet and ACET}, \\ \eta \ln\left(\dfrac{\widehat{R}_i}{\widehat{R}_j}\right), & \textit{CET}, \\ \alpha\left[R_i(\widehat{R}_i - 1) - R_j(\widehat{R}_j - 1)\right], & \textit{Classical Logit}, \\ \alpha\left[\dfrac{R_i}{W^{\varpi}}\left(\dfrac{\widehat{R}_i}{\widehat{W}^{\varpi}} - 1\right) - \dfrac{R_j}{W^{\varpi}}\left(\dfrac{\widehat{R}_j}{\widehat{W}^{\varpi}} - 1\right)\right], & \textit{Entropy Logit}. \end{cases} \tag{B.4}$$

In Proposition 3, Fréchet, ACET, and CET map proportional changes in relative returns into relative land-share changes, with ν or η governing the strength of that response. The two Logit specifications instead map differences in return levels into relative land shares. Classical Logit depends on $R_i(\widehat{R}_i - 1) - R_j(\widehat{R}_j - 1)$, while Entropy Logit depends on the corresponding difference in returns relative to the unit cost of management services. Hence ν and η are proportional-return response parameters, whereas α scales a level-based return index and is not directly comparable to them.

To compare local responsiveness on a common proportional-return basis, define

$$\varepsilon_{ii}^R \equiv \frac{\partial \ln \pi_i^L}{\partial \ln R_i}, \qquad \varepsilon_{ij}^R \equiv \frac{\partial \ln \pi_i^L}{\partial \ln R_j}, \qquad i \neq j. \tag{B.5}$$

Corollary 1 (Own- and cross-return elasticities)**.** *At any allocation,*

$$\left(\varepsilon_{ii}^R, \varepsilon_{ij}^R\right) = \begin{cases} \left(\nu(1-\pi_i^L), -\nu\pi_j^L\right), & \textit{Fréchet and ACET}, \\ \left(\eta(1-\pi_i^{RL}), -\eta\pi_j^{RL}\right), & \textit{CET}, \\ \left(\alpha R_i(1-\pi_i^L), -\alpha R_j \pi_j^L\right), & \textit{Classical Logit}, \\ \left(\alpha \dfrac{R_i}{W^{\varpi}}(1-\pi_i^L), -\alpha\dfrac{R_j}{W^{\varpi}}\pi_j^L\right), & \textit{Entropy Logit}. \end{cases} \tag{B.6}$$

In Corollary 1, the Fréchet and ACET response coefficient is the fixed parameter ν, and in CET it is the fixed parameter η; the corresponding own- and cross-return elasticities additionally depend on the relevant land shares. In Classical Logit, the proportional-return response coefficient is instead αR_i, while in Entropy Logit it is $\alpha R_i / W^{\varpi}$. Thus α itself is not a proportional-return elasticity.

The local own- and cross-return elasticities in the Logit specifications vary with return levels, and in Entropy Logit also with the unit cost of management services.

We choose the Logit scales to approximate the benchmark own- and cross-return responses of the proportional-return specifications.[2] After a shock, the proportional-return coefficients ν and η remain fixed, whereas the corresponding Logit coefficients, αR_i and $\alpha R_i/W^{\varpi}$, vary with endogenous returns and, for Entropy Logit, the unit cost of management services. Thus, the own- and cross-return elasticities can diverge across specifications as the economy moves away from the benchmark equilibrium.

B.3. Selection and General Equilibrium

We next examine how allocation affects production through Fréchet selection across heterogeneous plots, holding land returns fixed.

Proposition 4 (Selection and output)**.** *For an allocation margin with Fréchet shape parameter ν, average productivity among plots selected into use i is*

$$\mathbb{E}\left[e_i(q) \mid q \in \Omega_i\right] = E_i(\pi_i^L)^{-1/\nu}. \tag{B.7}$$

The corresponding output is

$$Q_i = \bar{L}(\gamma_i^L)^{-1}\hbar_i E_i \begin{cases} (\pi_i^L)^{(\nu-1)/\nu}, & \textit{Fréchet}, \\ \pi_i^L, & \textit{ACET, CET, Classical Logit, and Entropy Logit}. \end{cases} \tag{B.8}$$

Here, Q_i denotes output from use i, $\bar{L}$ is land entering the allocation margin, γ_i^L is the land cost share, and $\hbar_i$ is the production-side term defined in Section A. E_i denotes mean land productivity and π_i^L the allocation coefficient. Under Fréchet, $e_i(q)$ is plot-specific productivity and Ω_i is the set of plots selected into use i.

As a land use expands under Fréchet, it draws progressively less productive plots into that use. The conditional mean productivity of selected land therefore declines as its land share rises. Accordingly, equation (B.8) implies a less-than-proportional output response to land expansion under Fréchet. The other specifications have no endogenous selection across heterogeneous plots, so this composition effect is absent.

For given return changes, Fréchet and ACET can generate similar land-share responses while producing unequal output responses: only Fréchet links land expansion to selected productivity. A given output increase can therefore require more acreage under Fréchet.

Classical Logit requires no additional resources for reallocation, whereas Entropy Logit uses management services and creates management labor demand.

Land reallocation changes output, factor demand, prices, and trade, which in turn change land returns and induce further reallocation. Under Fréchet, selection modifies this feedback through the mapping from land allocation to output. Hence the conditional results above isolate the direct

[2] Detailed calibration is provided in Appendix E. The relevant proportional-return response coefficient is ν or η in the power specifications, αR_i in Classical Logit, and $\alpha R_i/W^{\varpi}$ in Entropy Logit. Matching this coefficient aligns the associated own- and cross-return elasticities. Because one Logit scale applies to land uses with different initial returns, exact matching for all uses is generally impossible; the scale is therefore chosen to minimize these discrepancies at the initial equilibrium.

return-to-share response, while equilibrium returns and land allocation are jointly determined once these feedbacks are allowed to operate.

C. Derivations and Proofs

This appendix derives the five land-allocation specifications used in Appendices A and B. To avoid repeating the same algebra at the two land nests, we first derive each specification for a generic allocation problem and then apply the result to the lower crop nest and the upper land nest. We keep the distinction between physical hectares and transformed land services explicit throughout.

C.1. Common Two-Layer Notation

Countries are indexed by n and land source types (AEZs) by $\tau \in \mathcal{T}$, with source-specific land endowment $\bar{L}_{n,\tau}$. Let $\mathcal{K}_1$ denote the crop set and define the upper choice set

$$\mathcal{G}^L \equiv \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}, \tag{C.1}$$

where 0 denotes idle land, $\mathcal{K}_1$ cropland, $\mathcal{K}_2$ pasture, and $\mathcal{K}_3$ managed forest. Let $R_{n,g,\tau}$ denote the return to upper alternative $g \in \mathcal{G}^L$ and $R_{n,k,\tau}$ the return to crop $k \in \mathcal{K}_1$.

Write $\pi^L_{n,g,\tau}$ for the upper allocation coefficient and $\pi^L_{n,k|\mathcal{K}_1,\tau}$ for the conditional crop coefficient. The unconditional crop coefficient is

$$\pi^L_{n,k,\tau} = \pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}, \qquad k \in \mathcal{K}_1. \tag{C.2}$$

For Fréchet, ACET, Classical Logit, and Entropy Logit these coefficients are physical land shares, so

$$L_{n,k,\tau} = \bar{L}_{n,\tau}\pi^L_{n,k,\tau} = \bar{L}_{n,\tau}\pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}. \tag{C.3}$$

For CET, the same notation $\pi^L \equiv L/\bar{L}$ is used for branch coefficients, but L denotes transformed land services rather than an additive partition of physical hectares.

For active use k, the benchmark return per unit of land service is

$$R_{n,k,\tau} = E_{n,k,\tau}h_{n,k}, \qquad h_{n,k} = p_{n,k}\hbar_{n,k}, \tag{C.4}$$

while the idle return is $R_{n,0,\tau} = E_{n,0,\tau}W_n$.

C.2. Fréchet Heterogeneous Land

We derive the allocation probabilities, selected productivity, exact changes, and local return elasticities of the nested Fréchet model.

Productivity draws and allocation. For country n and source type τ, let $q \in [0,1]$ index a continuum of plots. A measurable set $A \subseteq [0,1]$ has physical area $\bar{L}_{n,\tau}\mu(A)$. Plot productivities follow the nested Fréchet distribution

$$\Pr(\mathbf{e}_{n,\tau}(q) \le \mathbf{e}_{n,\tau}) = \exp\left\{-\bar{\varphi}\left[\left(\frac{e_{n,0,\tau}}{E_{n,0,\tau}}\right)^{-\nu_1} + \sum_{m=1}^{3}\left(\sum_{k\in\mathcal{K}_m}\left(\frac{e_{n,k,\tau}}{E_{n,k,\tau}}\right)^{-\nu_2}\right)^{\nu_1/\nu_2}\right]\right\}, \tag{C.5}$$

with

$$\bar{\varphi} = \left[\Gamma\left(1 - \frac{1}{\nu_1}\right)\right]^{-\nu_1}, \qquad 1 < \nu_1 \leq \nu_2. \tag{C.6}$$

The normalization implies

$$\mathbb{E}[e_{n,k,\tau}(q)] = E_{n,k,\tau}. \tag{C.7}$$

Indeed, the marginal distribution is $F(e) = \exp[-\bar{\varphi}(e/E)^{-\nu_1}]$, whose mean is $\bar{\varphi}^{1/\nu_1} E\Gamma(1 - 1/\nu_1) = E$.

Let $\xi_{n,k,\tau} > 0$ be an assignment shifter, with $\xi_{n,0,\tau} = 1$, and define

$$Y_{n,k,\tau}(q) \equiv \xi_{n,k,\tau} R_{n,k,\tau}(q), \qquad \widetilde{R}_{n,k,\tau} \equiv \xi_{n,k,\tau} R_{n,k,\tau}. \tag{C.8}$$

Plot q is assigned to

$$k^*_{n,\tau}(q) \in \arg \max_{j \in \{0\} \cup \mathcal{K}} Y_{n,j,\tau}(q), \tag{C.9}$$

and $\Omega_{n,k,\tau}$ denotes the set of plots assigned to k. In terms of adjusted returns, the joint CDF is

$$F_{\mathbf{Y}}(\mathbf{y}) = \exp\left\{-\bar{\varphi}\left[\left(\frac{y_0}{\widetilde{R}_0}\right)^{-\nu_1} + \sum_{m=1}^{3}\left(\sum_{k \in \mathcal{K}_m}\left(\frac{y_k}{\widetilde{R}_k}\right)^{-\nu_2}\right)^{\nu_1/\nu_2}\right]\right\}. \tag{C.10}$$

Composite returns and allocation shares. For cropland, define $M_{\mathcal{K}_1}(q) = \max_{k \in \mathcal{K}_1} Y_k(q)$. Setting all crop thresholds equal to y in (C.10) gives

$$\Pr[M_{\mathcal{K}_1}(q) \leq y] = \exp\left[-\bar{\varphi}\widetilde{R}^{\nu_1}_{\mathcal{K}_1} y^{-\nu_1}\right], \qquad \widetilde{R}_{n,\mathcal{K}_1,\tau} = \left[\sum_{k \in \mathcal{K}_1} \widetilde{R}^{\nu_2}_{n,k,\tau}\right]^{1/\nu_2}. \tag{C.11}$$

The normalization in (C.6) implies $\mathbb{E}[M_{n,\mathcal{K}_1,\tau}] = \widetilde{R}_{n,\mathcal{K}_1,\tau}$. Applying the same argument to the maximum over the upper alternatives yields

$$\widetilde{R}_{n,\tau} = \left[\widetilde{R}^{\nu_1}_{n,0,\tau} + \sum_{m=1}^{3} \widetilde{R}^{\nu_1}_{n,\mathcal{K}_m,\tau}\right]^{1/\nu_1} = \mathbb{E}[M_{n,\tau}(q)]. \tag{C.12}$$

Thus

$$\{\widetilde{R}_{n,k,\tau}\}_{k \in \mathcal{K}_1} \longrightarrow \widetilde{R}_{n,\mathcal{K}_1,\tau} \longrightarrow \widetilde{R}_{n,\tau}. \tag{C.13}$$

Differentiating the joint CDF with respect to the threshold of alternative k and integrating over the common maximum gives

$$\Pr(q \in \Omega_{n,k,\tau}) = \left(\frac{\widetilde{R}_{n,\mathcal{K}_1,\tau}}{\widetilde{R}_{n,\tau}}\right)^{\nu_1}\left(\frac{\widetilde{R}_{n,k,\tau}}{\widetilde{R}_{n,\mathcal{K}_1,\tau}}\right)^{\nu_2}, \qquad k \in \mathcal{K}_1. \tag{C.14}$$

Hence

$$\pi^L_{n,\mathcal{K}_1,\tau} = \left(\frac{\widetilde{R}_{n,\mathcal{K}_1,\tau}}{\widetilde{R}_{n,\tau}}\right)^{\nu_1}, \tag{C.15}$$

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \left(\frac{\widetilde{R}_{n,k,\tau}}{\widetilde{R}_{n,\mathcal{K}_1,\tau}}\right)^{\nu_2}, \qquad k \in \mathcal{K}_1, \tag{C.16}$$

$$\pi^L_{n,g,\tau} = \left(\frac{\widetilde{R}_{n,g,\tau}}{\widetilde{R}_{n,\tau}}\right)^{\nu_1}, \qquad g \in \{0, \mathcal{K}_2, \mathcal{K}_3\}. \tag{C.17}$$

The upper and conditional lower shares each add to one. Thus, Fréchet allocates physical land, and for crops

$$L_{n,k,\tau} = \bar{L}_{n,\tau}\pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}. \tag{C.18}$$

Selection and output. Conditional on selection into use k, the adjusted return has the same Fréchet distribution as the overall maximum. Therefore

$$\Pr[Y_k(q) \le y \mid q \in \Omega_k] = \exp[-\bar{\varphi}\widetilde{R}^{\nu_1}y^{-\nu_1}], \tag{C.19}$$

and

$$\mathbb{E}[e_{n,k,\tau}(q) \mid \Omega_{n,k,\tau}] = E_{n,k,\tau}\frac{\widetilde{R}_{n,\tau}}{\widetilde{R}_{n,k,\tau}}. \tag{C.20}$$

For crops this becomes

$$\mathbb{E}[e_{n,k,\tau}(q) \mid \Omega_{n,k,\tau}] = E_{n,k,\tau}(\pi^L_{n,\mathcal{K}_1,\tau})^{-1/\nu_1}(\pi^L_{n,k|\mathcal{K}_1,\tau})^{-1/\nu_2}. \tag{C.21}$$

Thus expansion into a use lowers average productivity among selected plots. Using the production-side land payment identity gives, for crops,

$$Q_{n,k,\tau} = \bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}(\pi^L_{n,\mathcal{K}_1,\tau})^{(\nu_1-1)/\nu_1}(\pi^L_{n,k|\mathcal{K}_1,\tau})^{(\nu_2-1)/\nu_2}, \tag{C.22}$$

and for $k \in \mathcal{K}_2 \cup \mathcal{K}_3$,

$$Q_{n,k,\tau} = \bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}(\pi^L_{n,k,\tau})^{(\nu_1-1)/\nu_1}. \tag{C.23}$$

Aggregate output is $Q_{n,k} = \sum_{\tau\in\mathcal{T}} Q_{n,k,\tau}$.

Setup requirement and land payments. For idle land, $\mathbb{E}[e_{n,0,\tau} \mid \Omega_{n,0,\tau}] = E_{n,0,\tau}(\pi^L_{n,0,\tau})^{-1/\nu_1}$. The law of total expectation then implies

$$S_{n,\mathrm{agr},\tau} = E_{n,0,\tau}\bar{L}_{n,\tau}\left[1 - (\pi^L_{n,0,\tau})^{(\nu_1-1)/\nu_1}\right], \tag{C.24}$$

$$S_{n,0,\tau} = E_{n,0,\tau}\bar{L}_{n,\tau}(\pi^L_{n,0,\tau})^{(\nu_1-1)/\nu_1}, \tag{C.25}$$

so $S_{n,\mathrm{agr},\tau} + S_{n,0,\tau} = E_{n,0,\tau}\bar{L}_{n,\tau}$.

For an active use k,

$$RL_{n,k,\tau} = \bar{L}_{n,\tau}\widetilde{R}_{n,\tau}\frac{\pi^L_{n,k,\tau}}{\zeta_{n,k,\tau}}. \tag{C.26}$$

Thus, for alternatives in a common payment denominator $\mathcal{A}$,

$$\pi^{RL}_{n,k,\tau} = \frac{\pi^{L}_{n,k,\tau}/\xi_{n,k,\tau}}{\sum_{j\in\mathcal{A}} \pi^{L}_{n,j,\tau}/\xi_{n,j,\tau}}. \tag{C.27}$$

This relation identifies relative assignment shifters from physical and revenue shares.

Exact changes and local responses. For a generic Fréchet nest with curvature ν and fixed assignment shifters,

$$\widehat{\overline{R}} = \left[\sum_j \pi^{L,0}_j \widehat{R}^{\nu}_j\right]^{1/\nu}, \tag{C.28}$$

$$\widehat{\pi}^{L}_i = \left(\frac{\widehat{R}_i}{\widehat{\overline{R}}}\right)^{\nu}, \tag{C.29}$$

$$\ln\left(\frac{\widehat{\pi}^{L}_i}{\widehat{\pi}^{L}_j}\right) = \nu \ln\left(\frac{\widehat{R}_i}{\widehat{R}_j}\right). \tag{C.30}$$

The lower and upper nests use ν_2 and ν_1, respectively. The output changes follow directly from the level equations; for crops,

$$\widehat{Q}_{n,k,\tau} = \widehat{\overline{L}}_{n,\tau}\widehat{\hbar}_{n,k}\widehat{E}_{n,k,\tau}(\widehat{\pi}^{L}_{n,\mathcal{K}_1,\tau})^{(\nu_1-1)/\nu_1}(\widehat{\pi}^{L}_{n,k|\mathcal{K}_1,\tau})^{(\nu_2-1)/\nu_2}. \tag{C.31}$$

The setup changes are

$$\widehat{S}_{n,\mathrm{agr},\tau} = \widehat{E}_{n,0,\tau}\widehat{\overline{L}}_{n,\tau}\frac{1-(\pi^{L}_{n,0,\tau}\widehat{\pi}^{L}_{n,0,\tau})^{a_1}}{1-(\pi^{L}_{n,0,\tau})^{a_1}}, \qquad a_1 \equiv \frac{\nu_1-1}{\nu_1}, \tag{C.32}$$

$$\widehat{S}_{n,0,\tau} = \widehat{E}_{n,0,\tau}\widehat{\overline{L}}_{n,\tau}(\widehat{\pi}^{L}_{n,0,\tau})^{a_1}. \tag{C.33}$$

Differentiating the generic share equation gives

$$\frac{\partial \ln \pi^{L}_i}{\partial \ln R_j} = \nu[\mathbf{1}\{i=j\} - \pi^{L}_j], \tag{C.34}$$

so

$$J^{\mathrm{F}} = \nu\left[I - \mathbf{1}(\boldsymbol{\pi}^{L})'\right]. \tag{C.35}$$

For two alternatives in the same nest, $\partial \ln(\pi^{L}_i/\pi^{L}_j)/\partial \ln(R_i/R_j) = \nu$. Hence the common response coefficients imply

$$\nu_1 = \vartheta_1, \qquad \nu_2 = \vartheta_2. \tag{C.36}$$

C.3. Standard CET

Standard CET allocates transformed land services subject to a constant-elasticity transformation frontier. The generic derivation is used at both land nests.

Generic one-nest problem. Let $\bar{L}$ be the parent CET aggregate and L_i the transformed service supplied to branch i. The manager solves

$$V^* = \max_{\{L_i\}} \sum_i R_i L_i \quad \text{s.t.} \quad \bar{L} = \left[\sum_i \beta_i L_i^{(1+\eta)/\eta} \right]^{\eta/(1+\eta)}. \tag{C.37}$$

The first-order condition is

$$R_i = \lambda \beta_i L_i^{1/\eta}, \qquad L_i = \left(\frac{R_i}{\lambda \beta_i} \right)^{\eta}. \tag{C.38}$$

Substitution into the frontier and the identity $V^* = \lambda \bar{L}^{(1+\eta)/\eta}$ yield the optimized return per unit of the parent aggregate,

$$R \equiv \frac{V^*}{\bar{L}} = \left[\sum_i \beta_i^{-\eta} R_i^{1+\eta} \right]^{1/(1+\eta)}. \tag{C.39}$$

The branch coefficient and revenue share are

$$\pi_i^L \equiv \frac{L_i}{\bar{L}} = \beta_i^{-\eta} \left(\frac{R_i}{R} \right)^{\eta}, \tag{C.40}$$

$$\pi_i^{RL} \equiv \frac{R_i L_i}{R \bar{L}} = \beta_i^{-\eta} \left(\frac{R_i}{R} \right)^{1+\eta}, \qquad \sum_i \pi_i^{RL} = 1. \tag{C.41}$$

The transformation constraint implies $\sum_i \beta_i (\pi_i^L)^{(1+\eta)/\eta} = 1$, not $\sum_i \pi_i^L = 1$. Thus CET branch quantities are transformed land services. The envelope conditions are

$$\frac{\partial R}{\partial R_i} = \pi_i^L, \qquad \frac{\partial \ln R}{\partial \ln R_i} = \pi_i^{RL}. \tag{C.42}$$

Two-layer application. Applying the generic result to the lower crop nest gives

$$R_{n,\mathcal{K}_1,\tau} = \left[\sum_{k \in \mathcal{K}_1} \beta_{n,k,\tau}^{-\eta_2} R_{n,k,\tau}^{1+\eta_2} \right]^{1/(1+\eta_2)}, \tag{C.43}$$

$$\pi_{n,k|\mathcal{K}_1,\tau}^L = \beta_{n,k,\tau}^{-\eta_2} \left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}} \right)^{\eta_2}. \tag{C.44}$$

At the upper nest,

$$R_{n,\tau} = \left[\sum_{g \in \mathcal{G}^L} \phi_{n,g,\tau}^{-\eta_1} R_{n,g,\tau}^{1+\eta_1} \right]^{1/(1+\eta_1)}, \tag{C.45}$$

$$\pi_{n,g,\tau}^L = \phi_{n,g,\tau}^{-\eta_1} \left(\frac{R_{n,g,\tau}}{R_{n,\tau}} \right)^{\eta_1}. \tag{C.46}$$

Hence

$$\{R_{n,k,\tau}\}_{k \in \mathcal{K}_1} \longrightarrow R_{n,\mathcal{K}_1,\tau} \longrightarrow R_{n,\tau}. \tag{C.47}$$

For crops, $L_{n,k,\tau} = \bar{L}_{n,\tau}\pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}$, but these quantities are transformed services rather than physical hectares. Output is linear in the CET branch quantity:

$$Q_{n,k,\tau} = (\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}L_{n,k,\tau}, \qquad Q_{n,k} = \sum_\tau Q_{n,k,\tau}. \tag{C.48}$$

Setup and land-income accounting. Consistent with the model in Appendix A, the setup requirement uses the sum of active CET branch coefficients:

$$S_{n,\text{agr},\tau} = E_{n,0,\tau}\bar{L}_{n,\tau}\sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}}\pi^L_{n,g,\tau}, \tag{C.49}$$

$$S_{n,0,\tau} = E_{n,0,\tau}\bar{L}_{n,\tau}\pi^L_{n,0,\tau}. \tag{C.50}$$

CET leaves the sum of branch coefficients unconstrained. Thus, $S_{n,\text{agr},\tau} + S_{n,0,\tau}$ is not generally equal to $E_{n,0,\tau}\bar{L}_{n,\tau}$. Using $R_{n,\tau}\bar{L}_{n,\tau} = \sum_{g\in\mathcal{G}^L} R_{n,g,\tau}L_{n,g,\tau}$ and $R_{n,0,\tau} = E_{n,0,\tau}W_n$, net land income is

$$\text{NLR}^{\text{CET}}_{n,\tau} = R_{n,\tau}\bar{L}_{n,\tau} - W_nE_{n,0,\tau}\bar{L}_{n,\tau}\sum_{g\in\mathcal{G}^L}\pi^L_{n,g,\tau}. \tag{C.51}$$

This expression preserves the transformed-service interpretation of CET.

Exact changes and local responses. Holding transformation weights fixed, the generic exact-change system is

$$\widehat{R} = \left[\sum_i \pi^{RL,0}_i \widehat{R}^{1+\eta}_i\right]^{1/(1+\eta)}, \tag{C.52}$$

$$\widehat{\pi}^L_i = \left(\frac{\widehat{R}_i}{\widehat{R}}\right)^\eta, \qquad \widehat{L}_i = \widehat{\bar{L}}\widehat{\pi}^L_i. \tag{C.53}$$

The lower and upper nests use $(\eta_2, \pi^{RL}_{k|\mathcal{K}_1})$ and (η_1, π^{RL}_g), respectively. Output obeys

$$\widehat{Q}_{n,k,\tau} = \widehat{\hbar}_{n,k}\widehat{E}_{n,k,\tau}\widehat{L}_{n,k,\tau}. \tag{C.54}$$

The setup requirement changes according to

$$\widehat{S}_{n,\text{agr},\tau} = \widehat{E}_{n,0,\tau}\widehat{\bar{L}}_{n,\tau}\frac{\sum_{g\neq 0}\pi^L_{n,g,\tau}\widehat{\pi}^L_{n,g,\tau}}{\sum_{g\neq 0}\pi^L_{n,g,\tau}}. \tag{C.55}$$

Differentiating the generic branch coefficient gives

$$\frac{\partial\ln\pi^L_i}{\partial\ln R_j} = \eta[\mathbf{1}\{i=j\} - \pi^{RL}_j], \tag{C.56}$$

or $J^{\text{CET}} = \eta[I - \mathbf{1}(\boldsymbol{\pi}^{RL})']$. For two alternatives in the same nest, $\partial\ln(\pi^L_i/\pi^L_j)/\partial\ln(R_i/R_j) = \eta$. Hence the two common response coefficients imply $\eta_1 = \vartheta_1$ and $\eta_2 = \vartheta_2$.

C.4. Additive CET

ACET preserves a proportional-return response to relative returns while imposing literal physical-land adding up.

Generic one-nest problem. For physical land $\bar{L}$ entering a generic nest, the manager solves

$$V^* = \max_{\{L_i\}} \left[\sum_i \beta_i (R_i L_i)^{\nu/(1+\nu)} \right]^{(1+\nu)/\nu} \quad \text{s.t.} \quad \sum_i L_i = \bar{L}. \tag{C.57}$$

Writing $\rho = \nu/(1+\nu)$, the first-order conditions imply

$$V^* = \lambda \bar{L}, \qquad L_i = \bar{L} \beta_i^{1+\nu} R_i^{\nu} \lambda^{-\nu}. \tag{C.58}$$

Adding up land determines the optimized value per unit of physical land,

$$R \equiv \frac{V^*}{\bar{L}} = \left[\sum_i \beta_i^{1+\nu} R_i^{\nu} \right]^{1/\nu}, \tag{C.59}$$

and therefore

$$\pi_i^L \equiv \frac{L_i}{\bar{L}} = \beta_i^{1+\nu} \left(\frac{R_i}{R} \right)^{\nu} = \frac{\beta_i^{1+\nu} R_i^{\nu}}{\sum_j \beta_j^{1+\nu} R_j^{\nu}}. \tag{C.60}$$

Thus $\sum_i \pi_i^L = 1$ and $\sum_i L_i = \bar{L}$. Relative shares satisfy

$$\frac{\pi_i^L}{\pi_j^L} = \left(\frac{\beta_i}{\beta_j} \right)^{1+\nu} \left(\frac{R_i}{R_j} \right)^{\nu}, \tag{C.61}$$

and the envelope condition is

$$\frac{\partial \ln R}{\partial \ln R_j} = \pi_j^L. \tag{C.62}$$

Two-layer application. At the lower crop nest,

$$R_{n,\mathcal{K}_1,\tau} = \left[\sum_{k \in \mathcal{K}_1} \beta_{n,k,\tau}^{1+\nu_2} R_{n,k,\tau}^{\nu_2} \right]^{1/\nu_2}, \tag{C.63}$$

$$\pi_{n,k|\mathcal{K}_1,\tau}^L = \beta_{n,k,\tau}^{1+\nu_2} \left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}} \right)^{\nu_2}. \tag{C.64}$$

At the upper nest,

$$R_{n,\tau} = \left[\sum_{g \in \mathcal{G}^L} \phi_{n,g,\tau}^{1+\nu_1} R_{n,g,\tau}^{\nu_1} \right]^{1/\nu_1}, \tag{C.65}$$

$$\pi_{n,g,\tau}^L = \phi_{n,g,\tau}^{1+\nu_1} \left(\frac{R_{n,g,\tau}}{R_{n,\tau}} \right)^{\nu_1}. \tag{C.66}$$

Hence

$$\{R_{n,k,\tau}\}_{k\in\mathcal{K}_1} \longrightarrow R_{n,\mathcal{K}_1,\tau} \longrightarrow R_{n,\tau}. \tag{C.67}$$

Both nests allocate physical land. Output is therefore linear in acreage:

$$Q_{n,k,\tau} = (\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}L_{n,k,\tau}, \qquad Q_{n,k} = \sum_\tau Q_{n,k,\tau}. \tag{C.68}$$

Setup and land-income accounting. Because physical land adds arithmetically,

$$S_{n,\mathrm{agr},\tau} = E_{n,0,\tau}\bar{L}_{n,\tau}(1-\pi^L_{n,0,\tau}), \tag{C.69}$$

$$S_{n,0,\tau} = E_{n,0,\tau}\bar{L}_{n,\tau}\pi^L_{n,0,\tau}, \tag{C.70}$$

so their sum equals $E_{n,0,\tau}\bar{L}_{n,\tau}$. Actual branch payments are $RL_{n,k,\tau} = R_{n,k,\tau}L_{n,k,\tau}$, with generic revenue share

$$\pi^{RL}_i = \frac{\pi^L_i R_i}{\sum_j \pi^L_j R_j}. \tag{C.71}$$

The ACET optimized value $R\bar{L}$ is not generally equal to the arithmetic sum of primitive branch payments. Net land income is

$$\mathrm{NLR}^{\mathrm{ACET}}_{n,\tau} = \sum_{k\in\mathcal{K}} R_{n,k,\tau}L_{n,k,\tau} - W_n S_{n,\mathrm{agr},\tau}. \tag{C.72}$$

Exact changes and local responses. Holding structural weights fixed,

$$\widehat{R} = \left[\sum_i \pi^{L,0}_i \widehat{R}^\nu_i\right]^{1/\nu}, \tag{C.73}$$

$$\widehat{\pi}^L_i = \left(\frac{\widehat{R}_i}{\widehat{R}}\right)^\nu. \tag{C.74}$$

The same formula applies with ν_2 at the lower nest and ν_1 at the upper nest. Because L is physical, $\widehat{L}_{n,g,\tau} = \widehat{\bar{L}}_{n,\tau}\widehat{\pi}^L_{n,g,\tau}$, and

$$\widehat{Q}_{n,k,\tau} = \widehat{\hbar}_{n,k}\widehat{E}_{n,k,\tau}\widehat{L}_{n,k,\tau}. \tag{C.75}$$

The setup requirement obeys

$$\widehat{S}_{n,\mathrm{agr},\tau} = \widehat{E}_{n,0,\tau}\widehat{\bar{L}}_{n,\tau}\frac{1-\pi^L_{n,0,\tau}\widehat{\pi}^L_{n,0,\tau}}{1-\pi^L_{n,0,\tau}}. \tag{C.76}$$

Differentiating the share equation gives

$$\frac{\partial \ln \pi^L_i}{\partial \ln R_j} = \nu[\mathbf{1}\{i=j\} - \pi^L_j], \tag{C.77}$$

so $J^{\mathrm{ACET}} = \nu[I - \mathbf{1}(\boldsymbol{\pi}^L)']$. The relative share elasticity is ν, so the common calibration gives

$$\nu_r = \vartheta_r, \qquad \nu_1 = \vartheta_1, \qquad \nu_2 = \vartheta_2. \tag{C.78}$$

C.5. Classical Logit

Classical Logit allocates physical land using additive idiosyncratic payoff shocks measured in return units. These shocks smooth land choices but do not represent physical productivity and do not use aggregate resources.

Generic one-nest problem. For a generic choice set $\mathcal{I}$, plot q receives payoff

$$U_i(q) = V_i + \frac{\varepsilon_i(q)}{\alpha}, \qquad \alpha > 0, \tag{C.79}$$

where the ε_i are independent centered Type-I extreme-value shocks,

$$F(\varepsilon) = \exp\{-\exp[-(\varepsilon + \gamma_{\mathrm{E}})]\}. \tag{C.80}$$

Standard integration of the choice probability gives

$$P_i = \frac{e^{\alpha V_i}}{\sum_j e^{\alpha V_j}}. \tag{C.81}$$

The optimized payoff $Z(q) = \max_i\{V_i + \varepsilon_i(q)/\alpha\}$ has expected value

$$\mathbb{E}[Z(q)] = \frac{1}{\alpha} \ln\left[\sum_i e^{\alpha V_i}\right], \tag{C.82}$$

and the envelope condition is

$$\frac{\partial \mathbb{E}[Z(q)]}{\partial V_i} = P_i. \tag{C.83}$$

Thus the log-sum return is the expected value of the optimized payoff problem, not an additional return aggregator.

Two-layer application. At the lower crop nest, define $\psi^C_{n,k,\tau} = \exp(\alpha_2 a^C_{n,k,\tau})$, normalized to sum to one. Then

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \frac{\psi^C_{n,k,\tau} e^{\alpha_2 R_{n,k,\tau}}}{\sum_{\ell \in \mathcal{K}_1} \psi^C_{n,\ell,\tau} e^{\alpha_2 R_{n,\ell,\tau}}}, \tag{C.84}$$

$$R_{n,\mathcal{K}_1,\tau} = \frac{1}{\alpha_2} \ln\left[\sum_{\ell \in \mathcal{K}_1} \psi^C_{n,\ell,\tau} e^{\alpha_2 R_{n,\ell,\tau}}\right]. \tag{C.85}$$

The lower envelope condition is

$$\frac{\partial R_{n,\mathcal{K}_1,\tau}}{\partial R_{n,k,\tau}} = \pi^L_{n,k|\mathcal{K}_1,\tau}. \tag{C.86}$$

At the upper nest, define $\psi^U_{n,g,\tau} = \exp(\alpha_1 a^U_{n,g,\tau})$, again normalized to one. Using the lower inclusive return for the cropland alternative,

$$\pi^L_{n,g,\tau} = \frac{\psi^U_{n,g,\tau} e^{\alpha_1 R_{n,g,\tau}}}{\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} e^{\alpha_1 R_{n,m,\tau}}}, \tag{C.87}$$

$$R_{n,\tau} = \frac{1}{\alpha_1} \ln\left[\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} e^{\alpha_1 R_{n,m,\tau}}\right]. \tag{C.88}$$

Hence

$$\{R_{n,k,\tau}\}_{k\in\mathcal{K}_1} \longrightarrow R_{n,\mathcal{K}_1,\tau} \longrightarrow R_{n,\tau}. \tag{C.89}$$

If the two layers are represented as a single nested-GEV system, the usual regularity condition is $0 < \alpha_1/\alpha_2 \leq 1$.

The Logit probabilities are physical shares. Therefore

$$L_{n,k,\tau} = \begin{cases} \bar{L}_{n,\tau} \pi^L_{n,\mathcal{K}_1,\tau} \pi^L_{n,k|\mathcal{K}_1,\tau}, & k \in \mathcal{K}_1, \\ \bar{L}_{n,\tau} \pi^L_{n,k,\tau}, & k \in \{0\} \cup \mathcal{K}_2 \cup \mathcal{K}_3, \end{cases} \tag{C.90}$$

and $\sum_k L_{n,k,\tau} = \bar{L}_{n,\tau}$. Because the payoff shocks do not alter physical productivity,

$$Q_{n,k,\tau} = (\gamma^L_{n,k})^{-1} \hbar_{n,k} E_{n,k,\tau} L_{n,k,\tau}. \tag{C.91}$$

Setup and land-income accounting. The setup objects are

$$S_{n,\text{agr},\tau} = E_{n,0,\tau} \bar{L}_{n,\tau} (1 - \pi^L_{n,0,\tau}), \qquad S_{n,0,\tau} = E_{n,0,\tau} \bar{L}_{n,\tau} \pi^L_{n,0,\tau}. \tag{C.92}$$

The payoff shocks use no aggregate resources. Net land income is therefore

$$\text{NLR}^{\text{CL}}_n = \sum_{\tau\in\mathcal{T}} \sum_{k\in\mathcal{K}} R_{n,k,\tau} L_{n,k,\tau} - W_n \sum_{\tau\in\mathcal{T}} S_{n,\text{agr},\tau}. \tag{C.93}$$

The inclusive returns are value indices and are not additional primitive land payments.

Exact changes and local responses. For a generic Logit nest,

$$R = \frac{1}{\alpha} \ln\left[\sum_j \psi_j e^{\alpha R_j}\right]. \tag{C.94}$$

Holding ψ_j and α fixed,

$$R' - R = \frac{1}{\alpha} \ln\left[\sum_j \pi^L_j e^{\alpha R_j (\widehat{R}_j - 1)}\right], \tag{C.95}$$

$$\widehat{\pi}^L_i = \frac{e^{\alpha R_i (\widehat{R}_i - 1)}}{\sum_j \pi^L_j e^{\alpha R_j (\widehat{R}_j - 1)}}. \tag{C.96}$$

These formulas apply sequentially with α_2 at the crop nest and α_1 at the upper nest.

Differentiating the share equation yields

$$\frac{\partial \ln \pi_i^L}{\partial \ln R_j} = \alpha R_j[\mathbf{1}\{i = j\} - \pi_j^L], \tag{C.97}$$

so

$$J^{\mathrm{CL}} = \alpha[I - \mathbf{1}(\boldsymbol{\pi}^L)'] \operatorname{diag}(\mathbf{R}). \tag{C.98}$$

Thus exact column-j matching to a power response ϑ would require $\alpha R_j = \vartheta$. A single α cannot generally match every column when benchmark returns vary across uses.

C.6. Entropy Logit

Entropy Logit also allocates physical land, but smooth reallocation is generated by convex management requirements rather than random payoff shocks. Management services use labor and therefore enter resource accounting.

Generic one-nest problem. Let W^{ϖ} denote the unit cost of management services. For reference weights $\psi_i > 0$, $\sum_i \psi_i = 1$, define management services per unit of land as

$$m(\boldsymbol{\pi}^L) = \bar{m} + \frac{1}{\alpha}\sum_i \pi_i^L \ln\left(\frac{\pi_i^L}{\psi_i}\right). \tag{C.99}$$

The manager solves

$$V^* = \max_{\{\pi_i^L\}} \left\{ \sum_i \pi_i^L R_i - W^{\varpi}\bar{m} - \frac{W^{\varpi}}{\alpha}\sum_i \pi_i^L \ln(\pi_i^L/\psi_i) \right\} \quad \text{s.t.} \quad \sum_i \pi_i^L = 1. \tag{C.100}$$

The first-order conditions imply

$$\pi_i^L = \frac{\psi_i e^{\alpha R_i/W^{\varpi}}}{\sum_j \psi_j e^{\alpha R_j/W^{\varpi}}}. \tag{C.101}$$

Substitution back into the objective gives

$$V^* = \frac{W^{\varpi}}{\alpha} \ln\left[\sum_j \psi_j e^{\alpha R_j/W^{\varpi}}\right] - W^{\varpi}\bar{m}. \tag{C.102}$$

Define the gross inclusive return

$$R^I \equiv V^* + W^{\varpi}\bar{m} = \frac{W^{\varpi}}{\alpha} \ln\left[\sum_j \psi_j e^{\alpha R_j/W^{\varpi}}\right]. \tag{C.103}$$

Equivalently,

$$R^I = \sum_i \pi_i^L R_i - \frac{W^{\varpi}}{\alpha}\sum_i \pi_i^L \ln(\pi_i^L/\psi_i). \tag{C.104}$$

The envelope conditions are

$$\frac{\partial R^I}{\partial R_i} = \pi_i^L, \qquad -\frac{\partial V^*}{\partial W^{\varpi}} = m(\boldsymbol{\pi}^L). \tag{C.105}$$

Two-layer application. Let $W^{\varpi,C}_{n,\tau} = W_n \varpi^C_{n,\tau}$ and $W^{\varpi,U}_{n,\tau} = W_n \varpi^U_{n,\tau}$ denote the lower- and upper-management prices. The objects $m^C_{n,\tau}$ and $m^U_{n,\tau}$ are obtained from (C.99) using the corresponding lower- and upper-nest shares, reference weights, and scale parameters. At the crop nest,

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \frac{\psi^C_{n,k,\tau} \exp(\alpha_2 R_{n,k,\tau}/W^{\varpi,C}_{n,\tau})}{\sum_{\ell\in\mathcal{K}_1} \psi^C_{n,\ell,\tau} \exp(\alpha_2 R_{n,\ell,\tau}/W^{\varpi,C}_{n,\tau})}, \tag{C.106}$$

$$R_{n,\mathcal{K}_1,\tau} = \frac{W^{\varpi,C}_{n,\tau}}{\alpha_2} \ln\left[\sum_{\ell\in\mathcal{K}_1} \psi^C_{n,\ell,\tau} \exp(\alpha_2 R_{n,\ell,\tau}/W^{\varpi,C}_{n,\tau})\right]. \tag{C.107}$$

At the upper nest,

$$\pi^L_{n,g,\tau} = \frac{\psi^U_{n,g,\tau} \exp(\alpha_1 R_{n,g,\tau}/W^{\varpi,U}_{n,\tau})}{\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} \exp(\alpha_1 R_{n,m,\tau}/W^{\varpi,U}_{n,\tau})}, \tag{C.108}$$

$$R_{n,\tau} = \frac{W^{\varpi,U}_{n,\tau}}{\alpha_1} \ln\left[\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} \exp(\alpha_1 R_{n,m,\tau}/W^{\varpi,U}_{n,\tau})\right]. \tag{C.109}$$

Thus

$$\{R_{n,k,\tau}\}_{k\in\mathcal{K}_1} \longrightarrow R_{n,\mathcal{K}_1,\tau} \longrightarrow R_{n,\tau}. \tag{C.110}$$

The cropland return passed to the upper nest is the gross lower inclusive return; the allocation-invariant lower management requirement remains in resource accounting.

Both nests allocate physical land, and management does not alter physical productivity. Hence

$$Q_{n,k,\tau} = (\gamma^L_{n,k})^{-1} \hbar_{n,k} E_{n,k,\tau} L_{n,k,\tau}, \qquad Q_{n,k} = \sum_\tau Q_{n,k,\tau}. \tag{C.111}$$

Management and land-income accounting. The setup objects are the same as under the other physical-land specifications:

$$S_{n,\text{agr},\tau} = E_{n,0,\tau} \bar{L}_{n,\tau} (1 - \pi^L_{n,0,\tau}), \qquad S_{n,0,\tau} = E_{n,0,\tau} \bar{L}_{n,\tau} \pi^L_{n,0,\tau}. \tag{C.112}$$

Management labor is

$$N^M_n = \sum_{\tau\in\mathcal{T}} \left[\varpi^U_{n,\tau} \bar{L}_{n,\tau} m^U_{n,\tau} + \varpi^C_{n,\tau} \bar{L}_{n,\tau} \pi^L_{n,\mathcal{K}_1,\tau} m^C_{n,\tau}\right]. \tag{C.113}$$

Net land income is therefore

$$\text{NLR}^{\text{EL}}_n = \sum_{\tau\in\mathcal{T}} \sum_{k\in\mathcal{K}} R_{n,k,\tau} L_{n,k,\tau} - W_n \sum_{\tau\in\mathcal{T}} S_{n,\text{agr},\tau} - W_n N^M_n. \tag{C.114}$$

Exact changes and local responses. For a generic entropy nest define

$$\widehat{W^\varpi} \equiv \frac{W^{\varpi\prime}}{W^\varpi}, \qquad \Delta_j \equiv \frac{R_j}{W^\varpi} \left(\frac{\widehat{R}_j}{\widehat{W^\varpi}} - 1\right). \tag{C.115}$$

Holding ψ_j, α, and the management technology fixed,

$$\widehat{\pi}_i^L = \frac{e^{\alpha\Delta_i}}{\sum_j \pi_j^L e^{\alpha\Delta_j}}, \tag{C.116}$$

$$\frac{R^{I\prime}}{W^{\varpi\prime}} - \frac{R^I}{W^{\varpi}} = \frac{1}{\alpha}\ln\left[\sum_j \pi_j^L e^{\alpha\Delta_j}\right]. \tag{C.117}$$

These equations are applied first to the lower nest and then to the upper nest, using the counterfactual lower inclusive return as the cropland return in the upper problem.

Holding W^{ϖ} fixed, differentiation of the share equation gives

$$\frac{\partial \ln \pi_i^L}{\partial \ln R_j} = \frac{\alpha R_j}{W^{\varpi}}[\mathbf{1}\{i=j\} - \pi_j^L]. \tag{C.118}$$

Thus

$$J^{\text{EL}} = \frac{\alpha}{W^{\varpi}}[I - \mathbf{1}(\boldsymbol{\pi}^L)']\,\text{diag}(\mathbf{R}). \tag{C.119}$$

Because $W^{\varpi} = W\varpi$,

$$\frac{\partial \ln \pi_i^L}{\partial \ln W} = -\frac{\alpha}{W^{\varpi}}\left(R_i - \sum_j \pi_j^L R_j\right). \tag{C.120}$$

Exact column-j matching to a power response ϑ would require $(\alpha/\varpi)(R_j/W) = \vartheta$. A common α/ϖ therefore cannot generally match every column when returns per unit of management services vary across uses.

C.7. Comparative Results

This subsection records how the preceding derivations imply the propositions and corollary in Appendix B.

Physical land additivity. Equations (C.3), (C.18), (C.60), (C.90), and (C.101) imply arithmetic adding up for Fréchet, ACET, Classical Logit, and Entropy Logit. Under CET, (C.37) instead imposes the transformation frontier, so the branch quantities do not generally sum to $\bar{L}$.

Conditional land-share responses. For Fréchet and ACET, the exact-change equations use benchmark physical-land shares and take the common power form

$$\widehat{R} = \left[\sum_j \pi_j^{L,0}\widehat{R}_j^{\nu}\right]^{1/\nu}, \qquad \widehat{\pi}_i^L = \left(\frac{\widehat{R}_i}{\widehat{R}}\right)^{\nu}. \tag{C.121}$$

Thus, when the two models share the same benchmark physical allocation and ν, they generate the same land-share response conditional on the same return changes. CET has the same proportional-return share response but its return index uses benchmark land-revenue shares, while the two Logit models use return-level changes rather than proportional-return changes.

Return metrics and local elasticities. Taking ratios of the exact-change share equations gives

$$\ln\left(\frac{\widehat{\pi}_i^L}{\widehat{\pi}_j^L}\right) = \begin{cases} \nu \ln(\widehat{R}_i/\widehat{R}_j), & \text{Fréchet and ACET,} \\ \eta \ln(\widehat{R}_i/\widehat{R}_j), & \text{CET,} \\ \alpha[R_i(\widehat{R}_i - 1) - R_j(\widehat{R}_j - 1)], & \text{Classical Logit,} \\ \alpha(\Delta_i - \Delta_j), & \text{Entropy Logit.} \end{cases} \tag{C.122}$$

Differentiating at any allocation yields the local elasticities reported in the return-elasticity corollary in Appendix B. In particular, the Logit scale parameter multiplies return-level differences, so the implied elasticity with respect to proportional return changes depends on the underlying return levels.

Selection and output. Equation (C.21) shows that average productivity among selected Fréchet plots falls as a land share expands. Substitution into production yields (C.22)–(C.23). In ACET, CET, Classical Logit, and Entropy Logit, $E_{n,k,\tau}$ does not vary with the amount of land assigned to use k, so branch land enters production linearly. The same conditional land-share response can therefore imply a different output response under Fréchet and ACET.

General equilibrium. The comparisons above condition on return changes. In the full model, the five land-allocation specifications imply different production responses and, under Entropy Logit, different management labor demand. These outcomes are jointly determined with goods and factor markets, so each specification can imply its own equilibrium land returns under the same policy shock. The full general-equilibrium counterfactual combines the conditional allocation responses with these endogenous return changes.

D. Data Construction

We construct the benchmark objects from the GTAP-BIO and Penn World Table accounts. The model dimensions and the region, sector, commodity/activity, land-use, and AEZ concordances are reported in Appendix F.7.

D.1. Data Inputs

The principal benchmark source is GTAP-BIO (Dimaranan, 2006; Birur et al., 2008; Hertel et al., 2010). Raw objects are first read in their original dimensions and then mapped to the model classification above. The Penn World Table provides the benchmark labor quantity (Feenstra et al., 2015).

The expenditure and factor-payment accounts are reported in Table D.1.

Table D.1. GTAP-BIO Expenditure and Factor-Payment Inputs

Object	Dimension	Definition
`VIMS`	$22 \times 18 \times 18$	Bilateral imports of tradable commodities at importer's market prices.
`VDPA`	22×18	Private household purchases of domestically supplied commodities at agents' prices.
`VDGA`	22×18	Government purchases of domestically supplied commodities at agents' prices.
`VDFA`	$22 \times 21 \times 18$	Firms' purchases of domestically supplied commodities by production activity at agents' prices.
`VIPA`	22×18	Private household purchases of imported commodities at agents' prices.
`VIGA`	22×18	Government purchases of imported commodities at agents' prices.
`VIFA`	$22 \times 21 \times 18$	Firms' purchases of imported commodities by production activity at agents' prices.
`EVFA`	$22 \times 21 \times 18$	Purchases of primary-factor endowments by production activities at agents' prices. The first dimension is the endowment dimension.

The remaining calibration inputs are reported in Table D.2.

Table D.2. GTAP-BIO Auxiliary Calibration Inputs

Object	Dimension	Definition
`REVE`	2×18	Revenue split between Ethanol1 and DDGS produced by the `EthanolC` activity.
`REVB`	2×18	Revenue split between Biodieself and BDBP produced by the `Biodiesel` activity.
`ESBM`	22×1	Source-substitution elasticities at the GTAP-BIO commodity level.
`ELHB`	country vector	Bioenergy–other-energy substitution elasticity.
`ETL1`, `ETL2`	scalars	Upper- and lower-nest GTAP-BIO land-transformation elasticity inputs.
`COVR`	$18 \times 4 \times 18$	Physical land cover by AEZ, broad land-cover category, and region.
`AREA`	$18 \times 5 \times 18$	Harvested area by AEZ, crop category, and region.
PWT `emp`	country vector	Number of persons engaged, measured in millions.

The bilateral expenditure matrix uses `VIMS` for foreign purchases. Domestic expenditure is constructed from `VDPA`, `VDGA`, and `VDFA`. Final demand combines the domestic and imported private and government accounts. Intermediate demand combines `VDFA` and `VIFA`. The endowment account `EVFA` is used for primary-factor payments.

The activity-side mapping uses `REVE` and `REVB`. `EthanolC` is split between Ethanol1 and DDGS using `REVE`; `Biodiesel` is split between Biodieself and BDBP using `REVB`. Fuel outputs enter biofuel and the byproducts enter OtherGoods.

For land, `COVR` provides physical land cover by AEZ and broad land-cover category. `AREA` provides harvested area by AEZ and crop and is used to divide cropland among the five crop uses. The elasticity inputs are `ESBM`, `ELHB`, `ETL1`, and `ETL2`. PWT `emp` provides the labor quantity used below.

D.2. Common Benchmark Accounts

We construct the common benchmark accounts in sequence: bilateral expenditure and sales, final demand, intermediate demand, factor payments, physical land, and labor.

D.2.1. Bilateral Expenditure, Sales, and Trade Shares

Let c denote an original GTAP-BIO tradable commodity, n the destination country, and i the source country. Before aggregation to the model sectors, define

$$B^{cal}_{nic} = \begin{cases} VDPA_{cn} + VDGA_{cn} + \sum_a VDFA_{can}, & i = n, \\ VIMS_{cin}, & i \neq n. \end{cases} \tag{D.1}$$

Thus B^{cal}_{nic} is expenditure in destination n on original commodity c supplied by country i. Source-country sales of commodity c are

$$Y^B_{ci} = \sum_n B^{cal}_{nic}. \tag{D.2}$$

Let $\mathcal{C}_j$ denote the set of original commodities assigned to model sector j. Sector-level bilateral expenditure is

$$X^{raw}_{ni,j} = \sum_{c \in \mathcal{C}_j} B^{cal}_{nic}. \tag{D.3}$$

When positive-value treatment is required, it is applied after aggregation to the model dimensions. Define

$$\underline{x} = \min\left\{10^{-4} \min\left\{X^{raw}_{ni,j} : X^{raw}_{ni,j} > 0\right\}, 1\right\}, \tag{D.4}$$

and set

$$X_{ni,j} = \max\left\{X^{raw}_{ni,j}, \underline{x}\right\}. \tag{D.5}$$

Total sectoral expenditure and producer sales are

$$X_{n,j} = \sum_i X_{ni,j}, \qquad Y_{n,j} = \sum_m X_{mn,j}, \tag{D.6}$$

where m is a dummy destination-country index in the second expression.

The benchmark trade imbalance and Armington sourcing shares are

$$D_n = \sum_j X_{n,j} - \sum_j Y_{n,j}, \qquad \lambda_{ni,j} = \frac{X_{ni,j}}{X_{n,j}}. \tag{D.7}$$

D.2.2. Final Demand and the Consumption Energy Nest

Final expenditure on model sector j combines private and government purchases of domestic and imported commodities:

$$FD_{n,j} = \sum_{c \in \mathcal{C}_j} \left(VDPA_{cn} + VIPA_{cn} + VDGA_{cn} + VIGA_{cn}\right). \tag{D.8}$$

Biofuel and OtherEnergy form the final-consumption energy composite. Define

$$FD_n^E = FD_{n,\text{bio}} + FD_{n,\text{other}}, \qquad FD_n^{top} = \sum_{j \in \mathcal{G} \setminus \mathcal{E}} FD_{n,j} + FD_n^E. \tag{D.9}$$

The corresponding upper-level expenditure shares are

$$\alpha_{n,j}^C = \frac{FD_{n,j}}{FD_n^{top}}, \qquad j \in \mathcal{G} \setminus \mathcal{E}, \qquad \alpha_{n,e}^C = \frac{FD_n^E}{FD_n^{top}}. \tag{D.10}$$

Within the energy composite,

$$\omega_{n,\text{bio}}^{e,c} = \frac{FD_{n,\text{bio}}}{FD_n^E}, \qquad \omega_{n,\text{other}}^{e,c} = 1 - \omega_{n,\text{bio}}^{e,c}. \tag{D.11}$$

D.2.3. Intermediate Inputs and the Production Energy Nest

Let h denote the model input sector and j the model output sector. GTAP-BIO domestic and imported intermediate use are combined as

$$Z_{can}^{raw} = VDFA_{can} + VIFA_{can}. \tag{D.12}$$

Let ω_{ajn} denote the activity-to-sector mapping weight for activity a in country n. The model-dimensional intermediate-use matrix is

$$IO_{n,h,j} = \sum_a \omega_{ajn} \sum_{c \in \mathcal{C}_h} Z_{can}^{raw}. \tag{D.13}$$

Biofuel and OtherEnergy form the production energy composite:

$$IO_{n,j}^E = IO_{n,\text{bio},j} + IO_{n,\text{other},j}, \qquad IO_{n,j}^M = \sum_{h \in \mathcal{G} \setminus \mathcal{E}} IO_{n,h,j} + IO_{n,j}^E. \tag{D.14}$$

The within-energy shares are

$$\omega_{nj,\text{bio}}^{e,p} = \frac{IO_{n,\text{bio},j}}{IO_{n,j}^E}, \qquad \omega_{nj,\text{other}}^{e,p} = 1 - \omega_{nj,\text{bio}}^{e,p}. \tag{D.15}$$

The upper-level intermediate-input shares are

$$\gamma_{n,hj}^X = \frac{IO_{n,h,j}}{IO_{n,j}^M}, \qquad h \in \mathcal{G} \setminus \mathcal{E}, \qquad \gamma_{n,ej}^X = \frac{IO_{n,j}^E}{IO_{n,j}^M}. \tag{D.16}$$

D.2.4. Factor Payments and Production Cost Shares

GTAP-BIO `EVFA` records payments from production activities to primary-factor endowments. After applying the activity concordance, its non-land entries are aggregated to obtain $PAY_{n,j}^N$, the benchmark non-land primary-factor payment of sector j.

Let $RL_{n,k,\tau}^{data}$ denote the benchmark payment to active land use k from AEZ source τ. Total land payments by a land-using sector are

$$PAY^{L}_{n,j} = \sum_{\tau} RL^{data}_{n,j,\tau}, \qquad j \in \mathcal{K}, \tag{D.17}$$

with $PAY^{L}_{n,j} = 0$ for non-land sectors.

Using benchmark sales $Y_{n,j}$, the production cost shares are

$$\gamma^{N}_{n,j} = \frac{PAY^{N}_{n,j}}{Y_{n,j}}, \qquad \gamma^{L}_{n,j} = \frac{PAY^{L}_{n,j}}{Y_{n,j}}, \qquad \gamma^{M}_{n,j} = 1 - \gamma^{N}_{n,j} - \gamma^{L}_{n,j}. \tag{D.18}$$

The share of intermediate category h in total production cost is

$$\Gamma^{M}_{n,hj} = \gamma^{M}_{n,j}\gamma^{X}_{n,hj}. \tag{D.19}$$

D.2.5. Physical Land

The GTAP-BIO `COVR` object records physical land cover by AEZ, broad land-cover category, and region. Its raw land-cover order is

$$\{\text{forestry}, \text{unmngland}, \text{crops}, \text{livestock}\}.$$

These categories are re-indexed to match the upper land nest:

$$\begin{aligned} L^{covr}_{n,0,\tau} &= COVR_{\tau,\text{unmngland},n}, & L^{covr}_{n,\mathcal{K}_1,\tau} &= COVR_{\tau,\text{crops},n}, \\ L^{covr}_{n,\mathcal{K}_2,\tau} &= COVR_{\tau,\text{livestock},n}, & L^{covr}_{n,\mathcal{K}_3,\tau} &= COVR_{\tau,\text{forestry},n}. \end{aligned} \tag{D.20}$$

The GTAP-BIO `AREA` object reports harvested area by AEZ, crop, and region. Its crop order is CrGrains, Oilseeds, Sugarcane, OthGrains, and OthAgri. For crop $q \in \mathcal{K}_1$, define

$$H^{q}_{n,\tau} = AREA_{\tau,q,n}, \qquad H^{crop}_{n,\tau} = \sum_{q \in \mathcal{K}_1} H^{q}_{n,\tau}. \tag{D.21}$$

For cells with positive reported harvested area,

$$s^{q}_{n,\tau} = \frac{H^{q}_{n,\tau}}{H^{crop}_{n,\tau}}, \qquad q \in \mathcal{K}_1. \tag{D.22}$$

For cells with no reported harvested area, the implementation assigns equal shares across the five crop uses.

The benchmark physical land quantities are

$$\begin{aligned} L_{n,0,\tau} &= L^{covr}_{n,0,\tau}, \\ L_{n,q,\tau} &= s^{q}_{n,\tau} L^{covr}_{n,\mathcal{K}_1,\tau}, \qquad q \in \mathcal{K}_1, \\ L_{n,\text{pasture},\tau} &= L^{covr}_{n,\mathcal{K}_2,\tau}, \\ L_{n,\text{forest},\tau} &= L^{covr}_{n,\mathcal{K}_3,\tau}. \end{aligned} \tag{D.23}$$

Cropland and total source-specific land are

$$L_{n,\mathcal{K}_1,\tau} = \sum_{q \in \mathcal{K}_1} L_{n,q,\tau}, \qquad \bar{L}_{n,\tau} = L_{n,0,\tau} + \sum_{k \in \mathcal{K}} L_{n,k,\tau}. \tag{D.24}$$

These quantities determine the benchmark upper-nest shares

$$\pi^L_{n,g,\tau} = \frac{L_{n,g,\tau}}{\bar{L}_{n,\tau}}, \qquad g \in \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}, \tag{D.25}$$

and the conditional crop shares

$$\pi^L_{n,q|\mathcal{K}_1,\tau} = \frac{L_{n,q,\tau}}{L_{n,\mathcal{K}_1,\tau}}, \qquad q \in \mathcal{K}_1. \tag{D.26}$$

D.2.6. Labor Endowment

The benchmark labor quantity is constructed from the Penn World Table `emp` series (Feenstra et al., 2015), which reports persons engaged in millions. Let $\mathcal{P}_n$ denote the set of PWT economies assigned to model region n. The regional labor endowment is

$$N_n = \sum_{c \in \mathcal{P}_n} emp_c. \tag{D.27}$$

For a region corresponding to one economy, this is the corresponding PWT observation; for an aggregate region, employment is summed across its constituent economies.

D.3. Elasticities

We construct each model-sector Armington elasticity as an average of the commodity-level `ESBM` entries weighted by benchmark sales. Let Y^B_c denote benchmark world sales of original commodity c. Then

$$\sigma_j = \sum_{c \in \mathcal{C}_j} \omega^{ESBM}_{c|j} ESBM_c, \qquad \omega^{ESBM}_{c|j} = \frac{Y^B_c}{\sum_{c' \in \mathcal{C}_j} Y^B_{c'}}. \tag{D.28}$$

The country-specific energy elasticity is

$$\sigma^e_n = ELHB_n. \tag{D.29}$$

GTAP-BIO reports the upper- and lower-nest land-transformation elasticities with negative signs under its transformation convention. The ACET and CET specifications use their positive magnitudes:

$$(\nu^A_1, \nu^A_2) = (\eta^C_1, \eta^C_2) = (|ETL1|, |ETL2|) = (0.20, 0.50). \tag{D.30}$$

The Fréchet baseline is

$$(\nu^F_1, \nu^F_2) = (1.10, 1.38), \tag{D.31}$$

where the lower-nest value follows Farrokhi and Pellegrina (2023).

D.4. Common Land Benchmark Objects

Physical broad-use land is taken from COVR. For each country n and AEZ source τ, it provides

$$L_{n,0,\tau}, \qquad L_{n,\mathcal{K}_1,\tau}, \qquad L_{n,\mathcal{K}_2,\tau}, \qquad L_{n,\mathcal{K}_3,\tau}.$$

The cropland aggregate is split with AREA. If $A_{n,k,\tau}$ denotes harvested area for crop $k \in \mathcal{K}_1$,

$$s^{crop}_{n,k,\tau} = \frac{A_{n,k,\tau}}{\sum_{\ell \in \mathcal{K}_1} A_{n,\ell,\tau}}, \qquad L_{n,k,\tau} = s^{crop}_{n,k,\tau} L_{n,\mathcal{K}_1,\tau}. \tag{D.32}$$

Total source land and the physical benchmark shares are

$$\bar{L}_{n,\tau} = L_{n,0,\tau} + \sum_{k \in \mathcal{K}} L_{n,k,\tau}, \tag{D.33}$$

$$\pi^{L,0}_{n,g,\tau} = \frac{L_{n,g,\tau}}{\bar{L}_{n,\tau}}, \qquad \pi^{L,0}_{n,k|\mathcal{K}_1,\tau} = \frac{L_{n,k,\tau}}{L_{n,\mathcal{K}_1,\tau}}. \tag{D.34}$$

The AEZ entries of EVFA provide the active land payments $RL^{data}_{n,k,\tau}$. Combining payments and physical land yields

$$R^{data}_{n,k,\tau} = \frac{RL^{data}_{n,k,\tau}}{L_{n,k,\tau}}, \qquad k \in \mathcal{K}. \tag{D.35}$$

There is no observed idle-land payment. The common empirical land benchmark is therefore the pair

$$\left\{ L_{n,k,\tau}, \, RL^{data}_{n,k,\tau} \right\},$$

together with the physical and active-payment shares constructed from these objects.

E. Calibration Details

We calibrate each specification from the lower crop nest to the active upper nest and then to the idle margin. Section E.1 sets the common response coefficients; Section E.2 recovers the remaining parameters from the benchmark land data.

E.1. Common Local-Response Calibration

Let $r = 1$ denote the upper land nest and $r = 2$ the lower crop nest. We use

$$\vartheta_1 = 1.10, \qquad \vartheta_2 = 1.38 \tag{E.1}$$

as the common benchmark response coefficients.

For Fréchet, the relative-share equation within a nest can be written as

$$\frac{\pi^L_i}{\pi^L_j} = \left(\frac{\widetilde{R}_i}{\widetilde{R}_j} \right)^{\nu^F_r}, \tag{E.2}$$

where $\widetilde{R}$ denotes the return object entering the Fréchet allocation equation. Holding the land-allocation shifters fixed,

$$\frac{\partial \ln(\pi_i^L/\pi_j^L)}{\partial \ln(R_i/R_j)} = \nu_r^F. \tag{E.3}$$

For ACET, the allocation equation implies

$$\frac{\pi_i^L}{\pi_j^L} = \left(\frac{\beta_i}{\beta_j}\right)^{1+\nu_r^A} \left(\frac{R_i}{R_j}\right)^{\nu_r^A}, \tag{E.4}$$

and therefore the corresponding relative-share elasticity is ν_r^A. For CET, taking the ratio of two first-order conditions gives

$$\frac{L_i}{L_j} = \left(\frac{\beta_i}{\beta_j}\right)^{-\eta_r^C} \left(\frac{R_i}{R_j}\right)^{\eta_r^C}, \tag{E.5}$$

so the relative-allocation elasticity is η_r^C. We therefore set

$$\nu_r^F = \nu_r^A = \eta_r^C = \vartheta_r, \qquad r \in \{1,2\}. \tag{E.6}$$

The two Logit specifications are written in return levels, so their response to a proportional return change also depends on the benchmark return level. The derivation starts from their benchmark share equations.

Classical Logit. For a generic nest with alternatives $m \in \mathcal{M}_r$, Classical Logit has

$$\pi_m^L = \frac{\psi_m \exp(\alpha_{r,n,\tau}^{CL} R_m)}{\sum_{h\in\mathcal{M}_r} \psi_h \exp(\alpha_{r,n,\tau}^{CL} R_h)}. \tag{E.7}$$

Differentiating equation (E.7) with respect to $\ln R_m$ gives

$$\frac{\partial \ln \pi_i^L}{\partial \ln R_m} = \alpha_{r,n,\tau}^{CL} R_m \left[\mathbf{1}\{i = m\} - \pi_m^L\right]. \tag{E.8}$$

Hence the own- and cross-return elasticities are

$$\varepsilon_{mm}^{R,CL} = \alpha_{r,n,\tau}^{CL} R_m (1-\pi_m^L), \qquad \varepsilon_{im}^{R,CL} = -\alpha_{r,n,\tau}^{CL} R_m \pi_m^L, \quad i \neq m. \tag{E.9}$$

The corresponding local responses from equation (E.6) are

$$\varepsilon_{mm}^{R,*} = \vartheta_r (1-\pi_m^L), \qquad \varepsilon_{im}^{R,*} = -\vartheta_r \pi_m^L. \tag{E.10}$$

One value of $\alpha_{r,n,\tau}^{CL}$ applies to all alternatives within the same (n,τ,r). We therefore choose it to minimize the benchmark-share-weighted squared distance between the own-return elasticities in equations (E.9) and (E.10):

$$\alpha_{r,n,\tau}^{CL} = \arg\min_{\alpha>0} \sum_{m\in\mathcal{M}_r} \pi_m^L \left[\alpha R_m (1-\pi_m^L) - \vartheta_r (1-\pi_m^L)\right]^2. \tag{E.11}$$

The first-order condition yields

$$\alpha^{CL}_{r,n,\tau} = \vartheta_r \frac{\sum\limits_{m\in\mathcal{M}_r} \pi^L_m (1-\pi^L_m)^2 R_m}{\sum\limits_{m\in\mathcal{M}_r} \pi^L_m (1-\pi^L_m)^2 R^2_m}. \tag{E.12}$$

At the lower nest,

$$\mathcal{M}_2 = \mathcal{K}_1, \tag{E.13}$$

so equation (E.12) uses the five crop alternatives. At the upper nest,

$$\mathcal{M}_1 = \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}, \tag{E.14}$$

and the matching uses the actual upper-nest shares of cropland, livestock, and managed forest. Idle land is not included because its benchmark return is not observed.

Entropy Logit. For Entropy Logit, define

$$\chi^r_{n,\tau} \equiv \frac{\alpha^{EL}_r}{W_n \varpi^r_{n,\tau}}. \tag{E.15}$$

The benchmark share equation is

$$\pi^L_m = \frac{\psi_m \exp(\chi^r_{n,\tau} R_m)}{\sum\limits_{h\in\mathcal{M}_r} \psi_h \exp(\chi^r_{n,\tau} R_h)}. \tag{E.16}$$

Differentiating equation (E.16) gives

$$\frac{\partial \ln \pi^L_i}{\partial \ln R_m} = \chi^r_{n,\tau} R_m \left[\mathbf{1}\{i=m\} - \pi^L_m\right]. \tag{E.17}$$

To approximate the same local responses in equation (E.10), we choose

$$\chi^r_{n,\tau} = \arg\min_{\chi>0} \sum_{m\in\mathcal{M}_r} \pi^L_m \left[\chi R_m (1-\pi^L_m) - \vartheta_r (1-\pi^L_m)\right]^2, \tag{E.18}$$

which gives

$$\chi^r_{n,\tau} = \vartheta_r \frac{\sum\limits_{m\in\mathcal{M}_r} \pi^L_m (1-\pi^L_m)^2 R_m}{\sum\limits_{m\in\mathcal{M}_r} \pi^L_m (1-\pi^L_m)^2 R^2_m}. \tag{E.19}$$

The lower-nest value is computed first from the five crop alternatives. The resulting crop return then enters the upper-nest matching together with livestock and managed forest. Once the benchmark wage is recovered,

$$\frac{\alpha^{EL}_r}{\varpi^r_{n,\tau}} = W_n \chi^r_{n,\tau}. \tag{E.20}$$

E.2. Land-Structure-Specific Calibration

Let

$$\mathcal{K} = \mathcal{K}_1 \cup \mathcal{K}_2 \cup \mathcal{K}_3, \tag{E.21}$$

where

$$\begin{aligned} \mathcal{K}_1 &= \{\text{CrGrains}, \text{Oilseeds}, \text{Sugarcane}, \text{OthGrains}, \text{OthAgri}\}, \\ \mathcal{K}_2 &= \{\text{Livestock}\}, \qquad \mathcal{K}_3 = \{\text{ManagedForest}\}. \end{aligned} \tag{E.22}$$

The index $k = 0$ denotes idle land. For each country n and AEZ source type τ, the observed benchmark objects are

$$\left\{L^{data}_{n,k,\tau}\right\}_{k\in\{0\}\cup\mathcal{K}}, \qquad \left\{RL^{data}_{n,k,\tau}\right\}_{k\in\mathcal{K}}. \tag{E.23}$$

Land quantity is observed for all eight uses, while land payment is observed for the seven active uses. In particular,

$$L^{data}_{n,0,\tau} \text{ is observed}, \qquad RL^{data}_{n,0,\tau} \text{ is not observed}. \tag{E.24}$$

For CET, ACET, Classical Logit, and Entropy Logit, the benchmark return to an active use is

$$R_{n,k,\tau} = \frac{RL^{data}_{n,k,\tau}}{L^{data}_{n,k,\tau}}, \qquad k \in \mathcal{K}. \tag{E.25}$$

Fréchet uses the same land quantities and active land payments through its selection and payment equations. The other four specifications use the active-use return in equation (E.25) directly.

Idle land has an observed quantity but no observed payment. Its return is therefore recovered from a common country-level setup-labor moment. Let ρ^{setup} denote setup labor payments as a share of production-labor payments plus setup-labor payments. We set

$$\rho^{\text{setup}} = 0.05 \tag{E.26}$$

and impose

$$W_n \sum_{\tau\in\mathcal{T}} S_{n,\text{agr},\tau} = \frac{\rho^{\text{setup}}}{1-\rho^{\text{setup}}} \sum_{j\in\mathcal{G}} \gamma^N_{n,j} Y_{n,j}. \tag{E.27}$$

Equivalently,

$$\frac{W_n \sum_{\tau\in\mathcal{T}} S_{n,\text{agr},\tau}}{\sum_{j\in\mathcal{G}} \gamma^N_{n,j} Y_{n,j} + W_n \sum_{\tau\in\mathcal{T}} S_{n,\text{agr},\tau}} = 0.05. \tag{E.28}$$

Under Entropy Logit, management labor is added after the setup margin has been calibrated and therefore enters the final labor-market clearing condition rather than equation (E.28).

E.2.1. Fréchet

Under Fréchet, crop land and payment shares first recover the lower-nest shifters. Aggregating the five crop payment equations then produces the cropland payment equation, which joins the livestock and forest equations at the upper nest. These three active payment equations recover their relative shifters. The setup-labor moment finally pins down the scale of the active alternatives relative to idle land. With these shifters in hand, the benchmark returns and labor requirements follow from the Fréchet share and payment equations.

Benchmark shares and payments. Total land and physical cropland are

$$\bar{L}_{n,\tau} = L^{data}_{n,0,\tau} + \sum_{k \in \mathcal{K}} L^{data}_{n,k,\tau}, \qquad L_{n,\mathcal{K}_1,\tau} = \sum_{k \in \mathcal{K}_1} L^{data}_{n,k,\tau}. \tag{E.29}$$

The upper-nest shares are

$$\pi^{L}_{n,g,\tau} = \frac{L_{n,g,\tau}}{\bar{L}_{n,\tau}}, \qquad g \in \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}, \tag{E.30}$$

where

$$L_{n,\mathcal{K}_2,\tau} = L^{data}_{n,\text{Livestock},\tau}, \qquad L_{n,\mathcal{K}_3,\tau} = L^{data}_{n,\text{ManagedForest},\tau}. \tag{E.31}$$

Within cropland,

$$\pi^{L}_{n,k|\mathcal{K}_1,\tau} = \frac{L^{data}_{n,k,\tau}}{L_{n,\mathcal{K}_1,\tau}}, \qquad k \in \mathcal{K}_1. \tag{E.32}$$

The corresponding conditional crop payment shares are

$$\pi^{RL}_{n,k|\mathcal{K}_1,\tau} = \frac{RL^{data}_{n,k,\tau}}{\sum_{\ell \in \mathcal{K}_1} RL^{data}_{n,\ell,\tau}}, \qquad k \in \mathcal{K}_1. \tag{E.33}$$

At the upper nest, define

$$RL^{data}_{n,\mathcal{K}_1,\tau} = \sum_{k \in \mathcal{K}_1} RL^{data}_{n,k,\tau}, \tag{E.34}$$

$$RL^{data,A}_{n,\tau} = RL^{data}_{n,\mathcal{K}_1,\tau} + RL^{data}_{n,\mathcal{K}_2,\tau} + RL^{data}_{n,\mathcal{K}_3,\tau}, \tag{E.35}$$

and

$$\pi^{RL,A}_{n,g,\tau} = \frac{RL^{data}_{n,g,\tau}}{RL^{data,A}_{n,\tau}}, \qquad g \in \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}. \tag{E.36}$$

Lower crop nest. The Fréchet selection result used in the model implies that the conditional return to land selected into use k is

$$\mathbb{E}[R_{n,k,\tau}(q) \mid q \in \Omega_{n,k,\tau}] = \frac{\widetilde{R}_{n,\tau}}{\xi_{n,k,\tau}}, \tag{E.37}$$

where $\widetilde{R}_{n,\tau}$ is common across selected uses within the same (n, τ). Since selected land in use k is $L_{n,k,\tau} = \bar{L}_{n,\tau}\pi^{L}_{n,k,\tau}$, multiplying equation (E.37) by selected land gives the payment identity

$$RL_{n,k,\tau} = \bar{L}_{n,\tau}\pi^{L}_{n,k,\tau}\frac{\widetilde{R}_{n,\tau}}{\xi_{n,k,\tau}}. \tag{E.38}$$

For a crop use $k \in \mathcal{K}_1$, the full shifter is

$$\xi_{n,k,\tau} = \xi^{U}_{n,\mathcal{K}_1,\tau}\xi^{C}_{n,k,\tau}, \tag{E.39}$$

and its full land share is

$$\pi^L_{n,k,\tau} = \pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}. \tag{E.40}$$

Substituting equations (E.39) and (E.40) into equation (E.38) gives

$$RL_{n,k,\tau} = \frac{\bar{L}_{n,\tau}\widetilde{R}_{n,\tau}\pi^L_{n,\mathcal{K}_1,\tau}}{\xi^U_{n,\mathcal{K}_1,\tau}}\frac{\pi^L_{n,k|\mathcal{K}_1,\tau}}{\xi^C_{n,k,\tau}}. \tag{E.41}$$

The first factor on the right-hand side is common to all five crops. Summing equation (E.41) over $k \in \mathcal{K}_1$ therefore gives total crop payment

$$RL_{n,\mathcal{K}_1,\tau} = \frac{\bar{L}_{n,\tau}\widetilde{R}_{n,\tau}\pi^L_{n,\mathcal{K}_1,\tau}}{\xi^U_{n,\mathcal{K}_1,\tau}}D^C_{n,\tau}, \tag{E.42}$$

where

$$D^C_{n,\tau} \equiv \sum_{k\in\mathcal{K}_1}\frac{\pi^L_{n,k|\mathcal{K}_1,\tau}}{\xi^C_{n,k,\tau}}. \tag{E.43}$$

Thus $D^C_{n,\tau}$ is the term obtained when the five crop payment equations are aggregated into the cropland payment equation.

Dividing equation (E.41) by equation (E.42) gives the conditional crop payment-share equation

$$\pi^{RL}_{n,k|\mathcal{K}_1,\tau} = \frac{\pi^L_{n,k|\mathcal{K}_1,\tau}/\xi^C_{n,k,\tau}}{D^C_{n,\tau}}. \tag{E.44}$$

Equivalently,

$$\pi^{RL}_{n,k|\mathcal{K}_1,\tau} = \frac{\pi^L_{n,k|\mathcal{K}_1,\tau}/\xi^C_{n,k,\tau}}{\sum_{\ell\in\mathcal{K}_1}\pi^L_{n,\ell|\mathcal{K}_1,\tau}/\xi^C_{n,\ell,\tau}}. \tag{E.45}$$

Normalizing

$$\sum_{k\in\mathcal{K}_1}\xi^C_{n,k,\tau} = 1 \tag{E.46}$$

then gives

$$\xi^C_{n,k,\tau} = \frac{\pi^L_{n,k|\mathcal{K}_1,\tau}/\pi^{RL}_{n,k|\mathcal{K}_1,\tau}}{\sum_{\ell\in\mathcal{K}_1}\pi^L_{n,\ell|\mathcal{K}_1,\tau}/\pi^{RL}_{n,\ell|\mathcal{K}_1,\tau}}, \qquad k \in \mathcal{K}_1 \tag{E.47}$$

Once $\xi^C_{n,k,\tau}$ is known, equation (E.43) computes $D^C_{n,\tau}$.

Active upper nest. Write the upper-nest shifters of the three active alternatives as

$$\xi^U_{n,g,\tau} = \xi^A_n\bar{\xi}^U_{n,g,\tau}, \qquad g \in \{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}, \tag{E.48}$$

where

$$\sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}}\bar{\xi}^U_{n,g,\tau} = 1. \tag{E.49}$$

Substituting $\xi^U_{n,\mathcal{K}_1,\tau} = \xi^A_n \bar{\xi}^U_{n,\mathcal{K}_1,\tau}$ into equation (E.42) gives

$$RL_{n,\mathcal{K}_1,\tau} = \frac{\bar{L}_{n,\tau}\widetilde{R}_{n,\tau}}{\xi^A_n} \frac{\pi^L_{n,\mathcal{K}_1,\tau} D^C_{n,\tau}}{\bar{\xi}^U_{n,\mathcal{K}_1,\tau}}. \tag{E.50}$$

For livestock and managed forest, equation (E.38) gives directly

$$RL_{n,g,\tau} = \frac{\bar{L}_{n,\tau}\widetilde{R}_{n,\tau}}{\xi^A_n} \frac{\pi^L_{n,g,\tau}}{\bar{\xi}^U_{n,g,\tau}}, \qquad g \in \{\mathcal{K}_2, \mathcal{K}_3\}. \tag{E.51}$$

All three active payments therefore share the factor $\bar{L}_{n,\tau}\widetilde{R}_{n,\tau}/\xi^A_n$. Define

$$D^A_{n,\tau} \equiv \frac{\pi^L_{n,\mathcal{K}_1,\tau} D^C_{n,\tau}}{\bar{\xi}^U_{n,\mathcal{K}_1,\tau}} + \frac{\pi^L_{n,\mathcal{K}_2,\tau}}{\bar{\xi}^U_{n,\mathcal{K}_2,\tau}} + \frac{\pi^L_{n,\mathcal{K}_3,\tau}}{\bar{\xi}^U_{n,\mathcal{K}_3,\tau}}. \tag{E.52}$$

Summing equations (E.50) and (E.51) gives

$$RL^A_{n,\tau} = \frac{\bar{L}_{n,\tau}\widetilde{R}_{n,\tau}}{\xi^A_n} D^A_{n,\tau}. \tag{E.53}$$

Dividing each active payment equation by equation (E.53) gives the conditional active payment shares. For cropland,

$$\pi^{RL,A}_{n,\mathcal{K}_1,\tau} = \frac{\pi^L_{n,\mathcal{K}_1,\tau} D^C_{n,\tau} / \bar{\xi}^U_{n,\mathcal{K}_1,\tau}}{D^A_{n,\tau}}, \tag{E.54}$$

and for livestock and managed forest,

$$\pi^{RL,A}_{n,g,\tau} = \frac{\pi^L_{n,g,\tau} / \bar{\xi}^U_{n,g,\tau}}{D^A_{n,\tau}}, \qquad g \in \{\mathcal{K}_2, \mathcal{K}_3\}. \tag{E.55}$$

Equation (E.54) is therefore obtained by aggregating the five lower crop payment equations and then dividing by total active land payments.

Equations (E.54)– (E.55) imply

$$d^U_{n,\mathcal{K}_1,\tau} \equiv \frac{\pi^L_{n,\mathcal{K}_1,\tau} D^C_{n,\tau}}{\pi^{RL,A}_{n,\mathcal{K}_1,\tau}}, \tag{E.56}$$

$$d^U_{n,g,\tau} \equiv \frac{\pi^L_{n,g,\tau}}{\pi^{RL,A}_{n,g,\tau}}, \qquad g \in \{\mathcal{K}_2, \mathcal{K}_3\}. \tag{E.57}$$

Because the same $D^A_{n,\tau}$ appears in all three active payment-share equations, normalizing the three shifters eliminates it and yields

$$\bar{\zeta}^U_{n,k,\tau} = \frac{d^U_{n,k,\tau}}{\sum_{\ell\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} d^U_{n,\ell,\tau}}, \qquad d^U_{n,k,\tau} = \begin{cases} \dfrac{\pi^L_{n,\mathcal{K}_1,\tau}}{\pi^{RL}_{n,\mathcal{K}_1,\tau} / \sum_{\ell\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^{RL}_{n,\ell,\tau}} \sum_{q\in\mathcal{K}_1} \dfrac{\pi^L_{n,q|\mathcal{K}_1,\tau}}{\pi^{RL}_{n,q|\mathcal{K}_1,\tau}}, & k = \mathcal{K}_1, \\ \dfrac{\pi^L_{n,k,\tau}}{\pi^{RL}_{n,k,\tau} / \sum_{\ell\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^{RL}_{n,\ell,\tau}}, & k \in \{\mathcal{K}_2,\mathcal{K}_3\}. \end{cases} \tag{E.58}$$

Idle margin. Let ζ^0_n denote the upper-nest idle shifter and ζ^A_n the scale of the three active upper-nest shifters. We normalize

$$\zeta^0_n + \zeta^A_n = 1, \qquad \lambda^F_n \equiv \frac{\zeta^A_n}{\zeta^0_n}. \tag{E.59}$$

From equation (E.53), observed total active payment implies

$$\widetilde{R}_{n,\tau} = \frac{RL^{data,A}_{n,\tau}\zeta^A_n}{\bar{L}_{n,\tau}D^A_{n,\tau}}. \tag{E.60}$$

The upper Fréchet land-share equation is

$$\pi^L_{n,g,\tau} = \left(\frac{\widetilde{R}_{n,g,\tau}}{\widetilde{R}_{n,\tau}}\right)^{\nu^F_1}, \qquad g \in \{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}, \tag{E.61}$$

with

$$\widetilde{R}_{n,g,\tau} = \zeta^U_{n,g,\tau} R_{n,g,\tau}. \tag{E.62}$$

For idle land, equations (E.61) and (E.62) give

$$R_{n,0,\tau} = \frac{\widetilde{R}_{n,\tau}}{\zeta^0_n}\left(\pi^L_{n,0,\tau}\right)^{1/\nu^F_1}. \tag{E.63}$$

Substituting equation (E.60) gives

$$R_{n,0,\tau} = \lambda^F_n \frac{RL^{data,A}_{n,\tau}}{\bar{L}_{n,\tau}D^A_{n,\tau}}\left(\pi^L_{n,0,\tau}\right)^{1/\nu^F_1}. \tag{E.64}$$

The Fréchet setup-labor equation is

$$W_n S_{n,\text{agr},\tau} = R_{n,0,\tau}\bar{L}_{n,\tau}\left[1 - \left(\pi^L_{n,0,\tau}\right)^{(\nu^F_1-1)/\nu^F_1}\right]. \tag{E.65}$$

Using equation (E.64),

$$W_n S_{n,\text{agr},\tau} = \lambda^F_n \frac{RL^{data,A}_{n,\tau}}{D^A_{n,\tau}}\left(\pi^L_{n,0,\tau}\right)^{1/\nu^F_1}\left[1 - \left(\pi^L_{n,0,\tau}\right)^{(\nu^F_1-1)/\nu^F_1}\right]. \tag{E.66}$$

Summing equation (E.66) over τ and matching equation (E.27) determines

$$\lambda_n^F = \frac{\frac{\rho^{\text{setup}}}{1-\rho^{\text{setup}}} \sum_{j \in \mathcal{G}} \gamma_{n,j}^N Y_{n,j}}{\sum_{\tau \in \mathcal{T}} \frac{RL_{n,\tau}^{data,A}}{D_{n,\tau}^A} \left(\pi_{n,0,\tau}^L\right)^{1/\nu_1^F} \left[1 - \left(\pi_{n,0,\tau}^L\right)^{(\nu_1^F-1)/\nu_1^F}\right]} \tag{E.67}$$

Equation (E.59) then gives

$$\xi_n^0 = \frac{1}{1+\lambda_n^F}, \qquad \xi_n^A = \frac{\lambda_n^F}{1+\lambda_n^F}. \tag{E.68}$$

Individual land-use returns. The model assigns a preference shifter to each individual land use. For crop uses,

$$\xi_{n,k,\tau} = \xi_n^A \bar{\xi}_{n,\mathcal{K}_1,\tau}^U \xi_{n,k,\tau}^C, \qquad k \in \mathcal{K}_1, \tag{E.69}$$

while

$$\xi_{n,0,\tau} = \xi_n^0, \qquad \xi_{n,\text{Livestock},\tau} = \xi_n^A \bar{\xi}_{n,\mathcal{K}_2,\tau}^U, \qquad \xi_{n,\text{ManagedForest},\tau} = \xi_n^A \bar{\xi}_{n,\mathcal{K}_3,\tau}^U. \tag{E.70}$$

Equation (E.61) gives

$$\widetilde{R}_{n,g,\tau} = \widetilde{R}_{n,\tau} \left(\pi_{n,g,\tau}^L\right)^{1/\nu_1^F}, \qquad g \in \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}. \tag{E.71}$$

At the lower nest,

$$\pi_{n,k|\mathcal{K}_1,\tau}^L = \left(\frac{\widetilde{R}_{n,k,\tau}}{\widetilde{R}_{n,\mathcal{K}_1,\tau}}\right)^{\nu_2^F}, \tag{E.72}$$

so

$$\widetilde{R}_{n,k,\tau} = \widetilde{R}_{n,\mathcal{K}_1,\tau} \left(\pi_{n,k|\mathcal{K}_1,\tau}^L\right)^{1/\nu_2^F}, \qquad k \in \mathcal{K}_1. \tag{E.73}$$

Finally, from equation (E.62),

$$R_{n,k,\tau} = \frac{\widetilde{R}_{n,k,\tau}}{\xi_{n,k,\tau}}, \qquad k \in \{0\} \cup \mathcal{K}. \tag{E.74}$$

Labor and wage. Using equation (E.65),

$$W_n = \frac{\sum_{j \in \mathcal{G}} \gamma_{n,j}^N Y_{n,j} + \sum_{\tau \in \mathcal{T}} R_{n,0,\tau} \bar{L}_{n,\tau} \left[1 - \left(\pi_{n,0,\tau}^L\right)^{(\nu_1^F-1)/\nu_1^F}\right]}{N_n}. \tag{E.75}$$

The corresponding labor quantities are

$$S_{n,\text{agr},\tau} = \frac{R_{n,0,\tau}}{W_n} \bar{L}_{n,\tau} \left[1 - \left(\pi_{n,0,\tau}^L\right)^{(\nu_1^F-1)/\nu_1^F}\right], \tag{E.76}$$

$$S_{n,0,\tau} = \frac{R_{n,0,\tau}}{W_n} \bar{L}_{n,\tau} \left(\pi_{n,0,\tau}^L\right)^{(\nu_1^F-1)/\nu_1^F}. \tag{E.77}$$

E.2.2. CET

At the CET crop nest, ratios of observed land quantities and returns recover the relative transformation weights and hence the crop aggregate. The same argument applied to cropland, livestock, and forest recovers the relative weights and return of the active upper nest. The setup-labor moment then pins down the idle return relative to this active return. The final upper-nest first-order condition determines the split between idle and active land.

Lower crop nest. For $k \in \mathcal{K}_1$, equation (E.25) gives $R_{n,k,\tau}$. The lower CET allocation equation is

$$\frac{L^{data}_{n,k,\tau}}{L_{n,\mathcal{K}_1,\tau}} = \beta_{n,k,\tau}^{-\eta_2^C} \left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}}\right)^{\eta_2^C}. \tag{E.78}$$

Take the ratio of equation (E.78) for crop k and a reference crop k_0. The common crop aggregate and crop return cancel, which gives

$$\frac{L^{data}_{n,k,\tau}}{L^{data}_{n,k_0,\tau}} = \left(\frac{\beta_{n,k,\tau}}{\beta_{n,k_0,\tau}}\right)^{-\eta_2^C} \left(\frac{R_{n,k,\tau}}{R_{n,k_0,\tau}}\right)^{\eta_2^C}. \tag{E.79}$$

Hence

$$\frac{\beta_{n,k,\tau}}{\beta_{n,k_0,\tau}} = \frac{R_{n,k,\tau}}{R_{n,k_0,\tau}} \left(\frac{L^{data}_{n,k_0,\tau}}{L^{data}_{n,k,\tau}}\right)^{1/\eta_2^C}. \tag{E.80}$$

The lower first-order conditions determine only relative weights. Imposing $\sum_{k\in\mathcal{K}_1} \beta_{n,k,\tau} = 1$ converts those relative weights into

$$\beta_{n,k,\tau} = \frac{R_{n,k,\tau}\left(L^{data}_{n,k,\tau}\right)^{-1/\eta_2^C}}{\sum_{\ell\in\mathcal{K}_1} R_{n,\ell,\tau}\left(L^{data}_{n,\ell,\tau}\right)^{-1/\eta_2^C}}, \qquad k \in \mathcal{K}_1 \tag{E.81}$$

Substituting these weights into the CET quantity aggregator gives

$$L_{n,\mathcal{K}_1,\tau} = \left[\sum_{k\in\mathcal{K}_1} \beta_{n,k,\tau}\left(L^{data}_{n,k,\tau}\right)^{(1+\eta_2^C)/\eta_2^C}\right]^{\eta_2^C/(1+\eta_2^C)}. \tag{E.82}$$

The dual return associated with this aggregate is

$$R_{n,\mathcal{K}_1,\tau} = \left[\sum_{k\in\mathcal{K}_1} \beta_{n,k,\tau}^{-\eta_2^C} R_{n,k,\tau}^{1+\eta_2^C}\right]^{1/(1+\eta_2^C)}. \tag{E.83}$$

The CET first-order conditions imply Euler's identity

$$R_{n,\mathcal{K}_1,\tau}L_{n,\mathcal{K}_1,\tau} = \sum_{k\in\mathcal{K}_1} R_{n,k,\tau}L^{data}_{n,k,\tau} = \sum_{k\in\mathcal{K}_1} RL^{data}_{n,k,\tau}. \tag{E.84}$$

Thus the same crop return can also be written as total crop payment divided by $L_{n,\mathcal{K}_1,\tau}$.

Active upper nest. Let

$$L_{n,\mathcal{K}_2,\tau} = L^{data}_{n,\text{Livestock},\tau}, \qquad L_{n,\mathcal{K}_3,\tau} = L^{data}_{n,\text{ManagedForest},\tau}. \tag{E.85}$$

The upper CET allocation equation for an active alternative g is

$$\frac{L_{n,g,\tau}}{L^A_{n,\tau}} = \bar{\phi}^{-\eta_1^C}_{n,g,\tau}\left(\frac{R_{n,g,\tau}}{R^A_{n,\tau}}\right)^{\eta_1^C}, \qquad g \in \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}, \tag{E.86}$$

where $L^A_{n,\tau}$ and $R^A_{n,\tau}$ denote the CET aggregate formed from the three active upper-nest alternatives. Taking the ratio of equation (E.86) for g and cropland gives

$$\frac{\bar{\phi}_{n,g,\tau}}{\bar{\phi}_{n,\mathcal{K}_1,\tau}} = \frac{R_{n,g,\tau}}{R_{n,\mathcal{K}_1,\tau}}\left(\frac{L_{n,\mathcal{K}_1,\tau}}{L_{n,g,\tau}}\right)^{1/\eta_1^C}, \qquad g \in \{\mathcal{K}_2, \mathcal{K}_3\} \tag{E.87}$$

Together with

$$\sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\phi}_{n,g,\tau} = 1, \tag{E.88}$$

this determines the three active weights. Their CET quantity and return are

$$L^A_{n,\tau} = \left[\sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\phi}_{n,g,\tau} L^{(1+\eta_1^C)/\eta_1^C}_{n,g,\tau}\right]^{\eta_1^C/(1+\eta_1^C)}, \tag{E.89}$$

$$R^A_{n,\tau} = \left[\sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\phi}^{-\eta_1^C}_{n,g,\tau} R^{1+\eta_1^C}_{n,g,\tau}\right]^{1/(1+\eta_1^C)}. \tag{E.90}$$

Idle margin. The active nest delivers $R^A_{n,\tau}$, but the idle return remains unobserved. We link its AEZ-specific level to the active return by

$$R_{n,0,\tau} = a^C_n R^A_{n,\tau}. \tag{E.91}$$

For CET, the setup-payment equation uses the arithmetic sum of the three active upper-branch quantities:

$$W_n S_{n,\text{agr},\tau} = R_{n,0,\tau}\left(L_{n,\mathcal{K}_1,\tau} + L_{n,\mathcal{K}_2,\tau} + L_{n,\mathcal{K}_3,\tau}\right). \tag{E.92}$$

Substituting equation (E.91) into equation (E.92), summing over τ, and matching equation (E.27) gives

$$a^C_n = \frac{\dfrac{\rho^{\text{setup}}}{1-\rho^{\text{setup}}}\displaystyle\sum_{j\in\mathcal{G}} \gamma^N_{n,j} Y_{n,j}}{\displaystyle\sum_{\tau\in\mathcal{T}} R^A_{n,\tau}\left(L_{n,\mathcal{K}_1,\tau} + L_{n,\mathcal{K}_2,\tau} + L_{n,\mathcal{K}_3,\tau}\right)} \tag{E.93}$$

Complete upper nest. Treating idle land and the active CET aggregate as the two alternatives at this step, the upper CET first-order condition implies

$$\frac{L^{data}_{n,0,\tau}}{L^{A}_{n,\tau}} = \left(\frac{\phi_{n,0,\tau}}{\phi^{A}_{n,\tau}}\right)^{-\eta^C_1} \left(\frac{R_{n,0,\tau}}{R^{A}_{n,\tau}}\right)^{\eta^C_1}. \tag{E.94}$$

Solving equation (E.94) gives

$$\frac{\phi_{n,0,\tau}}{\phi^{A}_{n,\tau}} = \frac{R_{n,0,\tau}}{R^{A}_{n,\tau}} \left(\frac{L^{A}_{n,\tau}}{L^{data}_{n,0,\tau}}\right)^{1/\eta^C_1}. \tag{E.95}$$

Together with $\phi_{n,0,\tau} + \phi^{A}_{n,\tau} = 1$, this determines the two weights, and

$$\phi_{n,g,\tau} = \phi^{A}_{n,\tau}\bar{\phi}_{n,g,\tau}, \qquad g \in \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}. \tag{E.96}$$

The completed upper CET aggregate is

$$\bar{L}_{n,\tau} = \left[\phi_{n,0,\tau}\left(L^{data}_{n,0,\tau}\right)^{(1+\eta^C_1)/\eta^C_1} + \sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \phi_{n,g,\tau} L^{(1+\eta^C_1)/\eta^C_1}_{n,g,\tau}\right]^{\eta^C_1/(1+\eta^C_1)}. \tag{E.97}$$

The CET allocation ratios used in the model are

$$\pi^{L}_{n,g,\tau} = \frac{L_{n,g,\tau}}{\bar{L}_{n,\tau}}, \qquad g \in \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}. \tag{E.98}$$

Labor and wage. From equation (E.92),

$$W_n = \frac{\sum_{j\in\mathcal{G}} \gamma^{N}_{n,j} Y_{n,j} + \sum_{\tau\in\mathcal{T}} R_{n,0,\tau}\left(L_{n,\mathcal{K}_1,\tau} + L_{n,\mathcal{K}_2,\tau} + L_{n,\mathcal{K}_3,\tau}\right)}{N_n}. \tag{E.99}$$

Hence

$$S_{n,\mathrm{agr},\tau} = \frac{R_{n,0,\tau}}{W_n}\left(L_{n,\mathcal{K}_1,\tau} + L_{n,\mathcal{K}_2,\tau} + L_{n,\mathcal{K}_3,\tau}\right), \tag{E.100}$$

$$S_{n,0,\tau} = \frac{R_{n,0,\tau}}{W_n} L^{data}_{n,0,\tau}. \tag{E.101}$$

E.2.3. ACET

Under ACET, crop shares and active returns recover the lower-nest allocation weights and the cropland return. Cropland, livestock, and forest then recover the relative weights and return of the active upper nest. The setup-labor moment pins down the idle return relative to this active return. The idle-versus-active share equation then completes the upper nest. Because ACET uses physical land, land quantities remain additive throughout the calculation.

Lower crop nest. For each crop, equation (E.25) gives $R_{n,k,\tau}$. The lower ACET share equation is

$$\frac{L^{data}_{n,k,\tau}}{L_{n,\mathcal{K}_1,\tau}} = \beta^{1+\nu^A_2}_{n,k,\tau}\left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}}\right)^{\nu^A_2}, \qquad k \in \mathcal{K}_1, \tag{E.102}$$

where

$$L_{n,\mathcal{K}_1,\tau} = \sum_{k \in \mathcal{K}_1} L^{data}_{n,k,\tau}. \tag{E.103}$$

Taking the ratio of equation (E.102) for crop k and a reference crop k_0 eliminates the common crop return and gives

$$\frac{\beta_{n,k,\tau}}{\beta_{n,k_0,\tau}} = \left[\frac{L^{data}_{n,k,\tau}}{L^{data}_{n,k_0,\tau}} \left(\frac{R_{n,k_0,\tau}}{R_{n,k,\tau}} \right)^{\nu^A_2} \right]^{1/(1+\nu^A_2)}. \tag{E.104}$$

The lower share equation determines only relative weights. With $\sum_{k \in \mathcal{K}_1} \beta_{n,k,\tau} = 1$, the calibrated weights are

$$\beta_{n,k,\tau} = \frac{\left[L^{data}_{n,k,\tau} R^{-\nu^A_2}_{n,k,\tau} \right]^{1/(1+\nu^A_2)}}{\sum_{\ell \in \mathcal{K}_1} \left[L^{data}_{n,\ell,\tau} R^{-\nu^A_2}_{n,\ell,\tau} \right]^{1/(1+\nu^A_2)}}, \qquad k \in \mathcal{K}_1 \tag{E.105}$$

The ACET crop return is then

$$R_{n,\mathcal{K}_1,\tau} = \left[\sum_{k \in \mathcal{K}_1} \beta^{1+\nu^A_2}_{n,k,\tau} R^{\nu^A_2}_{n,k,\tau} \right]^{1/\nu^A_2}. \tag{E.106}$$

Active upper nest. Let

$$L_{n,\mathcal{K}_2,\tau} = L^{data}_{n,\text{Livestock},\tau}, \qquad L_{n,\mathcal{K}_3,\tau} = L^{data}_{n,\text{ManagedForest},\tau}. \tag{E.107}$$

Conditional on active land, the upper ACET share equation is

$$\frac{L_{n,g,\tau}}{L^A_{n,\tau}} = \bar{\phi}^{1+\nu^A_1}_{n,g,\tau} \left(\frac{R_{n,g,\tau}}{R^A_{n,\tau}} \right)^{\nu^A_1}, \qquad g \in \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}, \tag{E.108}$$

where

$$L^A_{n,\tau} = L_{n,\mathcal{K}_1,\tau} + L_{n,\mathcal{K}_2,\tau} + L_{n,\mathcal{K}_3,\tau}. \tag{E.109}$$

Taking the ratio of equation (E.108) for g and cropland gives

$$\frac{\bar{\phi}_{n,g,\tau}}{\bar{\phi}_{n,\mathcal{K}_1,\tau}} = \left[\frac{L_{n,g,\tau}}{L_{n,\mathcal{K}_1,\tau}} \left(\frac{R_{n,\mathcal{K}_1,\tau}}{R_{n,g,\tau}} \right)^{\nu^A_1} \right]^{1/(1+\nu^A_1)}, \quad g \in \{\mathcal{K}_2, \mathcal{K}_3\} \tag{E.110}$$

Together with $\sum_g \bar{\phi}_{n,g,\tau} = 1$, this identifies the three active weights. The associated active return is

$$R^A_{n,\tau} = \left[\sum_{g \in \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}} \bar{\phi}^{1+\nu^A_1}_{n,g,\tau} R^{\nu^A_1}_{n,g,\tau} \right]^{1/\nu^A_1}. \tag{E.111}$$

Idle margin. The active nest delivers $R^A_{n,\tau}$. We link the unobserved idle return to this benchmark by

$$R_{n,0,\tau} = a^A_n R^A_{n,\tau}. \tag{E.112}$$

Under ACET, setup payment is

$$W_n S_{n,\text{agr},\tau} = R_{n,0,\tau} L^A_{n,\tau}. \tag{E.113}$$

Substituting equation (E.112) into equation (E.113), summing over τ, and matching equation (E.27) gives

$$a^A_n = \frac{\frac{\rho^{\text{setup}}}{1-\rho^{\text{setup}}} \sum_{j \in \mathcal{G}} \gamma^N_{n,j} Y_{n,j}}{\sum_{\tau \in \mathcal{T}} R^A_{n,\tau} L^A_{n,\tau}} \tag{E.114}$$

Complete upper nest. For the two alternatives idle and active, the ACET share equation implies

$$\frac{L^A_{n,\tau}}{L^{data}_{n,0,\tau}} = \left(\frac{\phi^A_{n,\tau}}{\phi_{n,0,\tau}}\right)^{1+\nu^A_1} \left(\frac{R^A_{n,\tau}}{R_{n,0,\tau}}\right)^{\nu^A_1}. \tag{E.115}$$

Solving gives

$$\frac{\phi^A_{n,\tau}}{\phi_{n,0,\tau}} = \left[\frac{L^A_{n,\tau}}{L^{data}_{n,0,\tau}} \left(\frac{R_{n,0,\tau}}{R^A_{n,\tau}}\right)^{\nu^A_1}\right]^{1/(1+\nu^A_1)}. \tag{E.116}$$

Together with $\phi_{n,0,\tau} + \phi^A_{n,\tau} = 1$, this determines the idle and active weights. The three full active weights are

$$\phi_{n,g,\tau} = \phi^A_{n,\tau} \bar{\phi}_{n,g,\tau}, \qquad g \in \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}. \tag{E.117}$$

Total physical land and the upper shares are therefore

$$\bar{L}_{n,\tau} = L^{data}_{n,0,\tau} + L^A_{n,\tau}, \qquad \pi^L_{n,g,\tau} = \frac{L_{n,g,\tau}}{\bar{L}_{n,\tau}}. \tag{E.118}$$

Labor and wage. Equation (E.113) gives

$$W_n = \frac{\sum_{j \in \mathcal{G}} \gamma^N_{n,j} Y_{n,j} + \sum_{\tau \in \mathcal{T}} R_{n,0,\tau} L^A_{n,\tau}}{N_n}. \tag{E.119}$$

Hence

$$S_{n,\text{agr},\tau} = \frac{R_{n,0,\tau}}{W_n} L^A_{n,\tau}, \qquad S_{n,0,\tau} = \frac{R_{n,0,\tau}}{W_n} L^{data}_{n,0,\tau}. \tag{E.120}$$

E.2.4. Classical Logit

At each Classical Logit nest, benchmark land shares and returns recover the normalized weights, which determine the corresponding inclusive return. The lower-nest return enters the active upper nest. The setup-labor moment then recovers the idle return, after which the complete upper-nest weights, wage, and labor requirements follow.

Benchmark shares and returns. Define

$$\bar{L}_{n,\tau} = L^{data}_{n,0,\tau} + \sum_{k \in \mathcal{K}} L^{data}_{n,k,\tau}, \qquad L_{n,\mathcal{K}_1,\tau} = \sum_{k \in \mathcal{K}_1} L^{data}_{n,k,\tau}. \tag{E.121}$$

The benchmark lower- and upper-nest shares are

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \frac{L^{data}_{n,k,\tau}}{L_{n,\mathcal{K}_1,\tau}}, \qquad \pi^L_{n,k,\tau} = \frac{L_{n,k,\tau}}{\bar{L}_{n,\tau}}. \tag{E.122}$$

Active-use returns are given by equation (E.25).

Lower crop nest. Equation (E.12) with $r = 2$ gives $\alpha^{CL}_{2,n,\tau}$. The lower Logit share equation is

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \frac{\psi^C_{n,k,\tau} \exp\left(\alpha^{CL}_{2,n,\tau} R_{n,k,\tau}\right)}{\sum_{\ell \in \mathcal{K}_1} \psi^C_{n,\ell,\tau} \exp\left(\alpha^{CL}_{2,n,\tau} R_{n,\ell,\tau}\right)}, \qquad k \in \mathcal{K}_1. \tag{E.123}$$

Using $\sum_{k \in \mathcal{K}_1} \psi^C_{n,k,\tau} = 1$, inversion of equation (E.123) gives

$$\psi^C_{n,k,\tau} = \frac{\pi^L_{n,k|\mathcal{K}_1,\tau} \exp\left(-\alpha^{CL}_{2,n,\tau} R_{n,k,\tau}\right)}{\sum_{\ell \in \mathcal{K}_1} \pi^L_{n,\ell|\mathcal{K}_1,\tau} \exp\left(-\alpha^{CL}_{2,n,\tau} R_{n,\ell,\tau}\right)}. \tag{E.124}$$

The associated crop inclusive return is

$$R_{n,\mathcal{K}_1,\tau} = \frac{1}{\alpha^{CL}_{2,n,\tau}} \ln\left[\sum_{k \in \mathcal{K}_1} \psi^C_{n,k,\tau} \exp\left(\alpha^{CL}_{2,n,\tau} R_{n,k,\tau}\right)\right]. \tag{E.125}$$

Active upper nest. Equation (E.12) with $r = 1$ gives $\alpha^{CL}_{1,n,\tau}$ from cropland, livestock, and managed forest. Let $\bar{\psi}^U_{n,k,\tau}$ denote the upper-nest weights normalized over these three active alternatives. Conditional on active land, the Logit share equation is

$$\frac{\pi^L_{n,k,\tau}}{\sum_{\ell \in \{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^L_{n,\ell,\tau}} = \frac{\bar{\psi}^U_{n,k,\tau} \exp\left(\alpha^{CL}_{1,n,\tau} R_{n,k,\tau}\right)}{\sum_{\ell \in \{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\psi}^U_{n,\ell,\tau} \exp\left(\alpha^{CL}_{1,n,\tau} R_{n,\ell,\tau}\right)}. \tag{E.126}$$

Taking the ratio of equation (E.126) for k and cropland gives

$$\frac{\bar{\psi}^U_{n,k,\tau}}{\bar{\psi}^U_{n,\mathcal{K}_1,\tau}} = \frac{\pi^L_{n,k,\tau}}{\pi^L_{n,\mathcal{K}_1,\tau}} \exp\left[-\alpha^{CL}_{1,n,\tau}\left(R_{n,k,\tau} - R_{n,\mathcal{K}_1,\tau}\right)\right], \qquad k \in \{\mathcal{K}_2, \mathcal{K}_3\}. \tag{E.127}$$

Together with

$$\sum_{k \in \{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\psi}^U_{n,k,\tau} = 1, \tag{E.128}$$

this determines the three active upper-nest weights. The active physical land and active inclusive return are

$$L^A_{n,\tau} = L_{n,\mathcal{K}_1,\tau} + L_{n,\mathcal{K}_2,\tau} + L_{n,\mathcal{K}_3,\tau} = \sum_{k \in \mathcal{K}} L^{data}_{n,k,\tau}, \tag{E.129}$$

$$R^A_{n,\tau} = \frac{1}{\alpha^{CL}_{1,n,\tau}} \ln\left[\sum_{k\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\psi}^U_{n,k,\tau} \exp\left(\alpha^{CL}_{1,n,\tau} R_{n,k,\tau}\right)\right]. \tag{E.130}$$

Idle margin and complete upper nest. The setup-labor moment determines the idle return relative to the active inclusive return:

$$R_{n,0,\tau} = a^{CL}_n R^A_{n,\tau}, \qquad a^{CL}_n = \frac{\dfrac{\rho^{\text{setup}}}{1-\rho^{\text{setup}}} \sum_{j\in\mathcal{G}} \gamma^N_{n,j} Y_{n,j}}{\sum_{\tau\in\mathcal{T}} R^A_{n,\tau} L^A_{n,\tau}}. \tag{E.131}$$

With $R_{n,0,\tau}$ known, the four upper-nest weights are recovered from the benchmark shares:

$$\psi^U_{n,k,\tau} = \frac{\pi^L_{n,k,\tau} \exp\left(-\alpha^{CL}_{1,n,\tau} R_{n,k,\tau}\right)}{\sum_{\ell\in\{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^L_{n,\ell,\tau} \exp\left(-\alpha^{CL}_{1,n,\tau} R_{n,\ell,\tau}\right)}, \qquad k \in \{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}. \tag{E.132}$$

The corresponding full upper inclusive return is

$$R_{n,\tau} = \frac{1}{\alpha^{CL}_{1,n,\tau}} \ln\left[\sum_{k\in\{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \psi^U_{n,k,\tau} \exp\left(\alpha^{CL}_{1,n,\tau} R_{n,k,\tau}\right)\right]. \tag{E.133}$$

Labor and wage. Setup labor satisfies

$$S_{n,\text{agr},\tau} = \frac{R_{n,0,\tau}}{W_n} L^A_{n,\tau}, \qquad S_{n,0,\tau} = \frac{R_{n,0,\tau}}{W_n} L^{data}_{n,0,\tau}. \tag{E.134}$$

Labor-market clearing gives

$$W_n = \frac{\sum_{j\in\mathcal{G}} \gamma^N_{n,j} Y_{n,j} + \sum_{\tau\in\mathcal{T}} R_{n,0,\tau} L^A_{n,\tau}}{N_n}. \tag{E.135}$$

E.2.5. Entropy Logit

For Entropy Logit, the common local-response calibration identifies the ratio

$$\frac{\alpha^{EL}_r}{W_n \varpi^r_{n,\tau}}, \qquad r \in \{1,2\}.$$

We therefore use this identified ratio directly below. The lower crop nest first recovers the normalized preference weights and the crop inclusive return. These objects enter the active upper nest, which recovers the active upper weights and return. The setup-labor moment then determines the idle return and the complete upper nest. Management payments are recovered last from the benchmark allocation wedges before the wage is determined.

Benchmark shares and returns. Use the same physical land totals and benchmark shares as under Classical Logit and the active-use returns in equation (E.25).

Lower crop nest. For the lower crop nest, the identified return-sensitivity ratio is $\alpha_2^{EL}/(W_n \varpi_{n,\tau}^C)$. The benchmark share equation is

$$\pi_{n,k|\mathcal{K}_1,\tau}^L = \frac{\psi_{n,k,\tau}^C \exp\left(\frac{\alpha_2^{EL}}{W_n \varpi_{n,\tau}^C} R_{n,k,\tau}\right)}{\sum_{\ell \in \mathcal{K}_1} \psi_{n,\ell,\tau}^C \exp\left(\frac{\alpha_2^{EL}}{W_n \varpi_{n,\tau}^C} R_{n,\ell,\tau}\right)}, \qquad k \in \mathcal{K}_1. \tag{E.136}$$

Multiplying equation (E.136) by $\exp[-\alpha_2^{EL} R_{n,k,\tau}/(W_n \varpi_{n,\tau}^C)]$ and imposing $\sum_{k \in \mathcal{K}_1} \psi_{n,k,\tau}^C = 1$ gives

$$\psi_{n,k,\tau}^C = \frac{\pi_{n,k|\mathcal{K}_1,\tau}^L \exp\left(-\frac{\alpha_2^{EL}}{W_n \varpi_{n,\tau}^C} R_{n,k,\tau}\right)}{\sum_{\ell \in \mathcal{K}_1} \pi_{n,\ell|\mathcal{K}_1,\tau}^L \exp\left(-\frac{\alpha_2^{EL}}{W_n \varpi_{n,\tau}^C} R_{n,\ell,\tau}\right)}. \tag{E.137}$$

The associated crop inclusive return is

$$R_{n,\mathcal{K}_1,\tau} = \frac{W_n \varpi_{n,\tau}^C}{\alpha_2^{EL}} \ln\left[\sum_{k \in \mathcal{K}_1} \psi_{n,k,\tau}^C \exp\left(\frac{\alpha_2^{EL}}{W_n \varpi_{n,\tau}^C} R_{n,k,\tau}\right)\right]. \tag{E.138}$$

Thus the lower-nest calibration maps the observed crop quantities and payments into $L_{n,\mathcal{K}_1,\tau}$, $\psi_{n,k,\tau}^C$, and $R_{n,\mathcal{K}_1,\tau}$.

Active upper nest. At the upper nest, the identified return-sensitivity ratio is $\alpha_1^{EL}/(W_n \varpi_{n,\tau}^U)$. Let $\bar{\psi}_{n,k,\tau}^U$ denote the preference weights normalized over the three active alternatives. Conditional on active land,

$$\frac{\pi_{n,k,\tau}^L}{\sum_{\ell \in \{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi_{n,\ell,\tau}^L} = \frac{\bar{\psi}_{n,k,\tau}^U \exp\left(\frac{\alpha_1^{EL}}{W_n \varpi_{n,\tau}^U} R_{n,k,\tau}\right)}{\sum_{\ell \in \{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\psi}_{n,\ell,\tau}^U \exp\left(\frac{\alpha_1^{EL}}{W_n \varpi_{n,\tau}^U} R_{n,\ell,\tau}\right)}. \tag{E.139}$$

Taking the ratio of equation (E.139) for k and cropland yields

$$\frac{\bar{\psi}_{n,k,\tau}^U}{\bar{\psi}_{n,\mathcal{K}_1,\tau}^U} = \frac{\pi_{n,k,\tau}^L}{\pi_{n,\mathcal{K}_1,\tau}^L} \exp\left[-\frac{\alpha_1^{EL}}{W_n \varpi_{n,\tau}^U} \left(R_{n,k,\tau} - R_{n,\mathcal{K}_1,\tau}\right)\right], \qquad k \in \{\mathcal{K}_2, \mathcal{K}_3\}. \tag{E.140}$$

Together with

$$\sum_{k \in \{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\psi}_{n,k,\tau}^U = 1, \tag{E.141}$$

this determines the three active upper-nest weights:

$$\bar{\psi}_{n,\mathcal{K}_1,\tau}^U = \left[1 + \sum_{k \in \{\mathcal{K}_2,\mathcal{K}_3\}} \frac{\pi_{n,k,\tau}^L}{\pi_{n,\mathcal{K}_1,\tau}^L} \exp\left(-\frac{\alpha_1^{EL}}{W_n \varpi_{n,\tau}^U} \left[R_{n,k,\tau} - R_{n,\mathcal{K}_1,\tau}\right]\right)\right]^{-1}, \tag{E.142}$$

$$\bar{\psi}_{n,k,\tau}^U = \bar{\psi}_{n,\mathcal{K}_1,\tau}^U \frac{\pi_{n,k,\tau}^L}{\pi_{n,\mathcal{K}_1,\tau}^L} \exp\left(-\frac{\alpha_1^{EL}}{W_n \varpi_{n,\tau}^U} \left[R_{n,k,\tau} - R_{n,\mathcal{K}_1,\tau}\right]\right), \quad k \in \{\mathcal{K}_2, \mathcal{K}_3\}. \tag{E.143}$$

Active physical land is

$$L^A_{n,\tau} = L_{n,\mathcal{K}_1,\tau} + L_{n,\mathcal{K}_2,\tau} + L_{n,\mathcal{K}_3,\tau}. \tag{E.144}$$

The corresponding active inclusive return is

$$R^A_{n,\tau} = \frac{W_n \varpi^U_{n,\tau}}{\alpha^{EL}_1} \ln\left[\sum_{k\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \bar{\psi}^U_{n,k,\tau} \exp\left(\frac{\alpha^{EL}_1}{W_n \varpi^U_{n,\tau}} R_{n,k,\tau}\right)\right]. \tag{E.145}$$

Idle margin and complete upper nest. The setup-labor moment in equation (E.27) determines the country-specific scale of the idle return. Since setup payment for source type τ is $R_{n,0,\tau} L^A_{n,\tau}$, the idle return is

$$R_{n,0,\tau} = R^A_{n,\tau} \frac{\dfrac{\rho^{\text{setup}}}{1-\rho^{\text{setup}}} \sum_{j\in\mathcal{G}} \gamma^N_{n,j} Y_{n,j}}{\sum_{\tau'\in\mathcal{T}} R^A_{n,\tau'} L^A_{n,\tau'}}. \tag{E.146}$$

With $R_{n,0,\tau}$ known, the four upper-nest preference weights follow by inverting the benchmark share equation:

$$\psi^U_{n,k,\tau} = \frac{\pi^L_{n,k,\tau} \exp\left(-\frac{\alpha^{EL}_1}{W_n \varpi^U_{n,\tau}} R_{n,k,\tau}\right)}{\sum_{\ell\in\{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^L_{n,\ell,\tau} \exp\left(-\frac{\alpha^{EL}_1}{W_n \varpi^U_{n,\tau}} R_{n,\ell,\tau}\right)}, \quad k \in \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}. \tag{E.147}$$

The full upper inclusive return is then

$$R_{n,\tau} = \frac{W_n \varpi^U_{n,\tau}}{\alpha^{EL}_1} \ln\left[\sum_{k\in\{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \psi^U_{n,k,\tau} \exp\left(\frac{\alpha^{EL}_1}{W_n \varpi^U_{n,\tau}} R_{n,k,\tau}\right)\right]. \tag{E.148}$$

Management payments. The upper- and lower-nest management requirements are

$$m^U_{n,\tau} = \frac{1}{\alpha^{EL}_1} \sum_{k\in\{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^L_{n,k,\tau} \ln\left(\frac{\pi^L_{n,k,\tau}}{\psi^U_{n,k,\tau}}\right), \tag{E.149}$$

$$m^C_{n,\tau} = \frac{1}{\alpha^{EL}_2} \sum_{k\in\mathcal{K}_1} \pi^L_{n,k|\mathcal{K}_1,\tau} \ln\left(\frac{\pi^L_{n,k|\mathcal{K}_1,\tau}}{\psi^C_{n,k,\tau}}\right). \tag{E.150}$$

Using

$$N^{M,U}_{n,\tau} = \varpi^U_{n,\tau} \bar{L}_{n,\tau} m^U_{n,\tau}, \qquad N^{M,C}_{n,\tau} = \varpi^C_{n,\tau} \bar{L}_{n,\tau} \pi^L_{n,\mathcal{K}_1,\tau} m^C_{n,\tau},$$

the wage-valued management payments are

$$W_n N^{M,U}_{n,\tau} = \frac{W_n \varpi^U_{n,\tau}}{\alpha^{EL}_1} \bar{L}_{n,\tau} \sum_{k\in\{0,\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^L_{n,k,\tau} \ln\left(\frac{\pi^L_{n,k,\tau}}{\psi^U_{n,k,\tau}}\right). \tag{E.151}$$

$$W_n N^{M,C}_{n,\tau} = \frac{W_n \varpi^C_{n,\tau}}{\alpha^{EL}_2} \bar{L}_{n,\tau} \pi^L_{n,\mathcal{K}_1,\tau} \sum_{k\in\mathcal{K}_1} \pi^L_{n,k|\mathcal{K}_1,\tau} \ln\left(\frac{\pi^L_{n,k|\mathcal{K}_1,\tau}}{\psi^C_{n,k,\tau}}\right). \tag{E.152}$$

The reciprocals $W_n \varpi^U_{n,\tau}/\alpha^{EL}_1$ and $W_n \varpi^C_{n,\tau}/\alpha^{EL}_2$ are already known from the local-response calibration because $\alpha^{EL}_r/(W_n \varpi^r_{n,\tau})$ is identified there. Hence the two management-payment terms are known before the benchmark wage is recovered.

Labor, wage, and management coefficients. Labor-market clearing gives

$$W_n = \frac{\sum_{j\in\mathcal{G}} \gamma^N_{n,j} Y_{n,j} + \sum_{\tau\in\mathcal{T}} R_{n,0,\tau} L^A_{n,\tau} + \sum_{\tau\in\mathcal{T}} \left(W_n N^{M,U}_{n,\tau} + W_n N^{M,C}_{n,\tau} \right)}{N_n}. \tag{E.153}$$

We normalize

$$\alpha^{EL}_1 = \alpha^{EL}_2 = 1. \tag{E.154}$$

Because the ratios $\alpha^{EL}_r/(W_n \varpi^r_{n,\tau})$ have already been identified, the management coefficients are then recovered as

$$\varpi^r_{n,\tau} = \frac{\alpha^{EL}_r}{W_n} \left[\vartheta_r \frac{\sum_{m\in\mathcal{M}_r} \pi^L_m (1-\pi^L_m)^2 R_m}{\sum_{m\in\mathcal{M}_r} \pi^L_m (1-\pi^L_m)^2 R^2_m} \right]^{-1}, \qquad r \in \{1,2\}. \tag{E.155}$$

Finally,

$$S_{n,\mathrm{agr},\tau} = \frac{R_{n,0,\tau}}{W_n} L^A_{n,\tau}, \qquad S_{n,0,\tau} = \frac{R_{n,0,\tau}}{W_n} L^{data}_{n,0,\tau}. \tag{E.156}$$

F. Equilibrium Conditions and Counterfactual Solution

Sections F.1 and F.2 report the equilibrium conditions in levels. The first list gives the land-allocation equations and the associated agricultural production equations for each of the five specifications. The second list reports the remaining conditions for production, trade, household demand, factor payments, and market clearing.

Following Dekle et al. (2008), define $\hat{x} \equiv x'/x$. Sections F.3 and F.4 report the corresponding exact-change equations used to compute the counterfactual equilibrium. In the counterfactual, the U.S. final-consumption biofuel subsidy $\tau^c_{\mathrm{USA,bio}}$ is adjusted endogenously to match the specified level of U.S. biofuel production.

F.1. Land Allocation and Associated Agricultural Production: Level Equations

H0 $\forall n, \tau,\ k \in \{0\} \cup \mathcal{K}$

$$\widetilde{R}_{n,k,\tau} = \xi_{n,k,\tau} R_{n,k,\tau}, \qquad \xi_{n,0,\tau} = 1.$$

H1 $\forall n, \tau,\ k \in \mathcal{K}_1$

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \left(\frac{\widetilde{R}_{n,k,\tau}}{\widetilde{R}_{n,\mathcal{K}_1,\tau}} \right)^{\nu_2}, \quad \widetilde{R}_{n,\mathcal{K}_1,\tau} = \left(\sum_{\ell\in\mathcal{K}_1} \widetilde{R}^{\nu_2}_{n,\ell,\tau} \right)^{1/\nu_2}.$$

H2 $\forall n, \tau,\ g \in \mathcal{G}^L$

$$\pi^L_{n,g,\tau} = \frac{\widetilde{R}^{\nu_1}_{n,g,\tau}}{\sum_{m\in\mathcal{G}^L} \widetilde{R}^{\nu_1}_{n,m,\tau}}, \quad \widetilde{R}_{n,\tau} = \left(\sum_{m\in\mathcal{G}^L} \widetilde{R}^{\nu_1}_{n,m,\tau} \right)^{1/\nu_1}, \quad \mathcal{G}^L = \{0, \mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}.$$

H3 $\forall n,\tau$

$$\mathbb{E}[R_{n,k,\tau}(q)\mid q\in\Omega_{n,k,\tau}]=\begin{cases}R_{n,k,\tau}(\pi^L_{n,\mathcal{K}_1,\tau})^{-1/\nu_1}(\pi^L_{n,k|\mathcal{K}_1,\tau})^{-1/\nu_2}, & k\in\mathcal{K}_1,\\ R_{n,k,\tau}(\pi^L_{n,k,\tau})^{-1/\nu_1}, & k\in\mathcal{K}_2\cup\mathcal{K}_3.\end{cases}$$

H4 $\forall n,k$

$$Q_{n,k}=\begin{cases}\sum_{\tau\in\mathcal{T}}\bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}(\pi^L_{n,\mathcal{K}_1,\tau})^{\frac{\nu_1-1}{\nu_1}}(\pi^L_{n,k|\mathcal{K}_1,\tau})^{\frac{\nu_2-1}{\nu_2}}, & k\in\mathcal{K}_1,\\ \sum_{\tau\in\mathcal{T}}\bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}(\pi^L_{n,k,\tau})^{\frac{\nu_1-1}{\nu_1}}, & k\in\mathcal{K}_2\cup\mathcal{K}_3.\end{cases}$$

A1 $\forall n,\tau,\ k\in\mathcal{K}_1$

$$\pi^L_{n,k|\mathcal{K}_1,\tau}=\beta^{1+\nu_2}_{n,k,\tau}\left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}}\right)^{\nu_2},\quad R_{n,\mathcal{K}_1,\tau}=\left(\sum_{\ell\in\mathcal{K}_1}\beta^{1+\nu_2}_{n,\ell,\tau}R^{\nu_2}_{n,\ell,\tau}\right)^{1/\nu_2}.$$

A2 $\forall n,\tau,\ g\in\mathcal{G}^L$

$$\pi^L_{n,g,\tau}=\frac{\phi^{1+\nu_1}_{n,g,\tau}R^{\nu_1}_{n,g,\tau}}{\sum_{m\in\mathcal{G}^L}\phi^{1+\nu_1}_{n,m,\tau}R^{\nu_1}_{n,m,\tau}},\quad R_{n,\tau}=\left(\sum_{m\in\mathcal{G}^L}\phi^{1+\nu_1}_{n,m,\tau}R^{\nu_1}_{n,m,\tau}\right)^{1/\nu_1}.$$

A3 $\forall n,k$

$$Q_{n,k}=\begin{cases}\sum_{\tau\in\mathcal{T}}\bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}\pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}, & k\in\mathcal{K}_1,\\ \sum_{\tau\in\mathcal{T}}\bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}\pi^L_{n,k,\tau}, & k\in\mathcal{K}_2\cup\mathcal{K}_3.\end{cases}$$

C1 $\forall n,\tau,\ k\in\mathcal{K}_1$

$$\pi^L_{n,k|\mathcal{K}_1,\tau}=\beta^{-\eta_2}_{n,k,\tau}\left(\frac{R_{n,k,\tau}}{R_{n,\mathcal{K}_1,\tau}}\right)^{\eta_2},\quad R_{n,\mathcal{K}_1,\tau}=\left(\sum_{\ell\in\mathcal{K}_1}\beta^{-\eta_2}_{n,\ell,\tau}R^{1+\eta_2}_{n,\ell,\tau}\right)^{1/(1+\eta_2)}.$$

C2 $\forall n,\tau,\ g\in\mathcal{G}^L$

$$\pi^L_{n,g,\tau}=\phi^{-\eta_1}_{n,g,\tau}\left(\frac{R_{n,g,\tau}}{R_{n,\tau}}\right)^{\eta_1},\quad R_{n,\tau}=\left(\sum_{m\in\mathcal{G}^L}\phi^{-\eta_1}_{n,m,\tau}R^{1+\eta_1}_{n,m,\tau}\right)^{1/(1+\eta_1)}.$$

C3 $\forall n,k$

$$Q_{n,k}=\begin{cases}\sum_{\tau\in\mathcal{T}}\bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}\pi^L_{n,\mathcal{K}_1,\tau}\pi^L_{n,k|\mathcal{K}_1,\tau}, & k\in\mathcal{K}_1,\\ \sum_{\tau\in\mathcal{T}}\bar{L}_{n,\tau}(\gamma^L_{n,k})^{-1}\hbar_{n,k}E_{n,k,\tau}\pi^L_{n,k,\tau}, & k\in\mathcal{K}_2\cup\mathcal{K}_3.\end{cases}$$

L1 $\forall n,\tau,\ k\in\mathcal{K}_1$

$$\pi^L_{n,k|\mathcal{K}_1,\tau}=\frac{\psi^C_{n,k,\tau}\exp(\alpha_2R_{n,k,\tau}/(W_n\varpi^C_{n,\tau}))}{\sum_{\ell\in\mathcal{K}_1}\psi^C_{n,\ell,\tau}\exp(\alpha_2R_{n,\ell,\tau}/(W_n\varpi^C_{n,\tau}))},\quad R_{n,\mathcal{K}_1,\tau}=\frac{W_n\varpi^C_{n,\tau}}{\alpha_2}\ln\left[\sum_{\ell\in\mathcal{K}_1}\psi^C_{n,\ell,\tau}\exp\left(\alpha_2\frac{R_{n,\ell,\tau}}{W_n\varpi^C_{n,\tau}}\right)\right].$$

L2 $\forall n, \tau,\ g \in \mathcal{G}^L$

$$\pi^L_{n,g,\tau} = \frac{\psi^U_{n,g,\tau} \exp(\alpha_1 R_{n,g,\tau}/(W_n \varpi^U_{n,\tau}))}{\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} \exp(\alpha_1 R_{n,m,\tau}/(W_n \varpi^U_{n,\tau}))}, \quad R_{n,\tau} = \frac{W_n \varpi^U_{n,\tau}}{\alpha_1} \ln\left[\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} \exp\left(\alpha_1 \frac{R_{n,m,\tau}}{W_n \varpi^U_{n,\tau}}\right)\right].$$

L3 $\forall n, k$

$$Q_{n,k} = \begin{cases} \sum_{\tau\in\mathcal{T}} \bar{L}_{n,\tau} (\gamma^L_{n,k})^{-1} \hbar_{n,k} E_{n,k,\tau} \pi^L_{n,\mathcal{K}_1,\tau} \pi^L_{n,k|\mathcal{K}_1,\tau}, & k \in \mathcal{K}_1, \\ \sum_{\tau\in\mathcal{T}} \bar{L}_{n,\tau} (\gamma^L_{n,k})^{-1} \hbar_{n,k} E_{n,k,\tau} \pi^L_{n,k,\tau}, & k \in \mathcal{K}_2 \cup \mathcal{K}_3. \end{cases}$$

L4 $\forall n, \tau$

$$m^U_{n,\tau} = \bar{m}^U_{n,\tau} + \frac{1}{\alpha_1} \sum_{g\in\mathcal{G}^L} \pi^L_{n,g,\tau} \ln\left(\frac{\pi^L_{n,g,\tau}}{\psi^U_{n,g,\tau}}\right),$$

$$m^C_{n,\tau} = \bar{m}^C_{n,\tau} + \frac{1}{\alpha_2} \sum_{k\in\mathcal{K}_1} \pi^L_{n,k|\mathcal{K}_1,\tau} \ln\left(\frac{\pi^L_{n,k|\mathcal{K}_1,\tau}}{\psi^C_{n,k,\tau}}\right).$$

L5 $\forall n, \tau$

$$N^{M,U}_{n,\tau} = \varpi^U_{n,\tau} \bar{L}_{n,\tau} m^U_{n,\tau}, \quad N^{M,C}_{n,\tau} = \varpi^C_{n,\tau} \bar{L}_{n,\tau} \pi^L_{n,\mathcal{K}_1,\tau} m^C_{n,\tau}, \quad N^M_n = \sum_{\tau\in\mathcal{T}} (N^{M,U}_{n,\tau} + N^{M,C}_{n,\tau}).$$

CL0 $\forall n, \tau$

$$\psi^C_{n,k,\tau} = \exp(\alpha_2 a^C_{n,k,\tau}), \qquad \psi^U_{n,g,\tau} = \exp(\alpha_1 a^U_{n,g,\tau}).$$

CL1 $\forall n, \tau,\ k \in \mathcal{K}_1$

$$\pi^L_{n,k|\mathcal{K}_1,\tau} = \frac{\psi^C_{n,k,\tau} \exp(\alpha_2 R_{n,k,\tau})}{\sum_{\ell\in\mathcal{K}_1} \psi^C_{n,\ell,\tau} \exp(\alpha_2 R_{n,\ell,\tau})}, \quad R_{n,\mathcal{K}_1,\tau} = \frac{1}{\alpha_2} \ln\left[\sum_{\ell\in\mathcal{K}_1} \psi^C_{n,\ell,\tau} \exp(\alpha_2 R_{n,\ell,\tau})\right].$$

CL2 $\forall n, \tau,\ g \in \mathcal{G}^L$

$$\pi^L_{n,g,\tau} = \frac{\psi^U_{n,g,\tau} \exp(\alpha_1 R_{n,g,\tau})}{\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} \exp(\alpha_1 R_{n,m,\tau})}, \quad R_{n,\tau} = \frac{1}{\alpha_1} \ln\left[\sum_{m\in\mathcal{G}^L} \psi^U_{n,m,\tau} \exp(\alpha_1 R_{n,m,\tau})\right].$$

CL3 $\forall n, k$

$$Q_{n,k} = \begin{cases} \sum_{\tau\in\mathcal{T}} \bar{L}_{n,\tau} (\gamma^L_{n,k})^{-1} \hbar_{n,k} E_{n,k,\tau} \pi^L_{n,\mathcal{K}_1,\tau} \pi^L_{n,k|\mathcal{K}_1,\tau}, & k \in \mathcal{K}_1, \\ \sum_{\tau\in\mathcal{T}} \bar{L}_{n,\tau} (\gamma^L_{n,k})^{-1} \hbar_{n,k} E_{n,k,\tau} \pi^L_{n,k,\tau}, & k \in \mathcal{K}_2 \cup \mathcal{K}_3. \end{cases}$$

F.2. Remaining Equilibrium Conditions: Level Equations

F1 $\forall n, k, \tau$

$$p_{n,k} = c_{n,k,\tau}(q) = \Upsilon_{n,k} R_{n,k,\tau}(q)^{\gamma^L_{n,k}} W_n^{\gamma^N_{n,k}} (P^M_{n,k})^{\gamma^M_{n,k}} e_{n,k,\tau}(q)^{-\gamma^L_{n,k}}, \quad \text{Fréchet.}$$

F2 $\forall n, k, \tau$

$$R_{n,k,\tau} = E_{n,k,\tau} h_{n,k}, \quad h_{n,k} = p_{n,k} \hbar_{n,k}, \quad \hbar_{n,k} = \left(\frac{W_n}{p_{n,k}}\right)^{-\gamma^N_{n,k}/\gamma^L_{n,k}} \left(\frac{P^M_{n,k}}{p_{n,k}}\right)^{-\gamma^M_{n,k}/\gamma^L_{n,k}} \Upsilon_{n,k}^{-1/\gamma^L_{n,k}}.$$

F3 $\forall n, \tau$

$$L_{n,g,\tau} = \pi^L_{n,g,\tau} \bar{L}_{n,\tau}, \quad L_{n,k,\tau} = \pi^L_{n,\mathcal{K}_1,\tau} \pi^L_{n,k|\mathcal{K}_1,\tau} \bar{L}_{n,\tau}, \quad k \in \mathcal{K}_1.$$

F4 $\forall n, k$

$$Q_{n,k} = A_{n,k} N_{n,k}^{\gamma^N_{n,k}} M_{n,k}^{\gamma^M_{n,k}}, \qquad \gamma^N_{n,k} + \gamma^M_{n,k} = 1, \quad k \in \mathcal{E} \cup \mathcal{J}.$$

F5 $\forall n, k \in \mathcal{E} \cup \mathcal{J}$

$$c_{n,k} = \Upsilon_{n,k} A_{n,k}^{-1} W_n^{\gamma^N_{n,k}} (P^M_{n,k})^{\gamma^M_{n,k}}, \quad \Upsilon_{n,k} = (\gamma^N_{n,k})^{-\gamma^N_{n,k}} (\gamma^M_{n,k})^{-\gamma^M_{n,k}}.$$

F6 $\forall n, k$

$$p_{n,k} = c_{n,k}, \qquad k \in \mathcal{E} \cup \mathcal{J}.$$

F7 $\forall n, k$

$$P^p_{nk,e} = \left[\phi^{e,p}_{nk} P_{n,\text{bio}}^{1-\sigma^{e,p}} + (1-\phi^{e,p}_{nk}) P_{n,\text{other}}^{1-\sigma^{e,p}}\right]^{1/(1-\sigma^{e,p})}, \quad P^M_{n,k} = \left(\frac{P^p_{nk,e}}{\gamma^X_{n,ke}}\right)^{\gamma^X_{n,ke}} \prod_{\ell \in \mathcal{G}' \setminus \{e\}} \left(\frac{P_{n,\ell}}{\gamma^X_{n,k\ell}}\right)^{\gamma^X_{n,k\ell}}.$$

F8 $\forall n, k$

$$\omega^{e,p}_{nk,\text{bio}} = \phi^{e,p}_{nk} \left(\frac{P_{n,\text{bio}}}{P^p_{nk,e}}\right)^{1-\sigma^{e,p}}, \qquad \omega^{e,p}_{nk,\text{other}} = (1-\phi^{e,p}_{nk}) \left(\frac{P_{n,\text{other}}}{P^p_{nk,e}}\right)^{1-\sigma^{e,p}}.$$

T1 $\forall n, i, j$

$$P_{ni,j} = \kappa_{ni,j} p_{i,j}.$$

T2 $\forall n, j$

$$P_{n,j} = \left[\sum_i \zeta_{ni,j} P_{ni,j}^{1-\sigma_j}\right]^{1/(1-\sigma_j)}.$$

T3 $\forall n, i, j$

$$\lambda_{ni,j} = \frac{\zeta_{ni,j} P_{ni,j}^{1-\sigma_j}}{\sum_m \zeta_{nm,j} P_{nm,j}^{1-\sigma_j}}.$$

C1 $\forall n$

$$P^c_{n,e} = \left[\phi^{e,c} \left((1-\tau^c_{n,\text{bio}}) P_{n,\text{bio}}\right)^{1-\sigma^{e,c}} + (1-\phi^{e,c}) P_{n,\text{other}}^{1-\sigma^{e,c}}\right]^{1/(1-\sigma^{e,c})}.$$

C2 $\forall n$

$$\omega^{e,c}_{n,\text{bio}} = \phi^{e,c}\left(\frac{(1-\tau^c_{n,\text{bio}})P_{n,\text{bio}}}{P^c_{n,e}}\right)^{1-\sigma^{e,c}}, \quad \omega^{e,c}_{n,\text{other}} = (1-\phi^{e,c})\left(\frac{P_{n,\text{other}}}{P^c_{n,e}}\right)^{1-\sigma^{e,c}}.$$

C3 $\forall n$

$$C_n = C_{n,e}^{\alpha^C_{n,e}} \prod_{j\in\mathcal{G}'\setminus\{e\}} C_{n,j}^{\alpha^C_{n,j}}, \quad P^C_n = \left(\frac{P^c_{n,e}}{\alpha^C_{n,e}}\right)^{\alpha^C_{n,e}} \prod_{j\in\mathcal{G}'\setminus\{e\}} \left(\frac{P_{n,j}}{\alpha^C_{n,j}}\right)^{\alpha^C_{n,j}}.$$

C4 $\forall n$

$$P^c_{n,e}C_{n,e} = \alpha^C_{n,e}P^C_nC_n, \quad P_{n,j}C_{n,j} = \alpha^C_{n,j}P^C_nC_n,\ j\in\mathcal{G}'\setminus\{e\}, \quad (1-\tau^c_{n,\text{bio}})P_{n,\text{bio}}C_{n,\text{bio}} = \omega^{e,c}_{n,\text{bio}}\alpha^C_{n,e}P^C_nC_n.$$

C5 $\forall n$

$$P_{n,\text{other}}C_{n,\text{other}} = \omega^{e,c}_{n,\text{other}}\alpha^C_{n,e}P^C_nC_n, \quad T^c_n = \tau^c_{n,\text{bio}}P_{n,\text{bio}}C_{n,\text{bio}} = \frac{\tau^c_{n,\text{bio}}}{1-\tau^c_{n,\text{bio}}}\omega^{e,c}_{n,\text{bio}}\alpha^C_{n,e}P^C_nC_n.$$

C6 $\forall n$

$$P^C_nC_n = W_nN_n + \text{NLR}_n - T^c_n + D_n.$$

C7 $\forall n$

$$VA_n = W_nN_n + \text{NLR}_n, \quad t^s = \frac{\sum_m \phi_m VA_m}{\sum_m N_m}, \quad D_n = N_nt^s - \phi_n VA_n, \quad \sum_n D_n = 0.$$

E1 $\forall n, i, j$

$$X_{ni,j} = P_{ni,j}Q_{ni,j} = \lambda_{ni,j}X_{n,j}, \qquad X_{n,j} = \sum_i X_{ni,j} = P_{n,j}Q_{n,j}.$$

E2 $\forall n$

$$\begin{aligned} X_{n,\text{bio}} &= \frac{\omega^{e,c}_{n,\text{bio}}\alpha^C_{n,e}P^C_nC_n}{1-\tau^c_{n,\text{bio}}} + \sum_{k\in\mathcal{G}} \gamma^M_{n,k}\gamma^X_{n,ke}\omega^{e,p}_{nk,\text{bio}}Y_{n,k}, \\ X_{n,\text{other}} &= \omega^{e,c}_{n,\text{other}}\alpha^C_{n,e}P^C_nC_n + \sum_{k\in\mathcal{G}} \gamma^M_{n,k}\gamma^X_{n,ke}\omega^{e,p}_{nk,\text{other}}Y_{n,k}, \\ X_{n,j} &= \alpha^C_{n,j}P^C_nC_n + \sum_{k\in\mathcal{G}} \gamma^M_{n,k}\gamma^X_{n,kj}Y_{n,k}, \quad j\in\mathcal{G}'\setminus\{e\}. \end{aligned}$$

E3 $\forall n, j$

$$Y_{n,j} = \sum_i \lambda_{in,j}X_{i,j}.$$

E4 $\forall n$

$$\sum_i\sum_j X_{ni,j} = \sum_i\sum_j X_{in,j} + D_n.$$

E5 $\forall n$

$$D_n = -\phi_n(W_nN_n + \text{NLR}_n) + \frac{N_n}{\sum_m N_m}\sum_m \phi_m(W_mN_m + \text{NLR}_m), \qquad \sum_n D_n = 0.$$

E6 $\forall n$

$$N_n^M = \sum_{\tau \in \mathcal{T}} (N_{n,\tau}^{M,U} + N_{n,\tau}^{M,C}), \qquad \text{Entropy-Logit only.}$$

E7 $\forall n$

$$W_n N_n = \begin{cases} \sum_{k \in \mathcal{G}} \gamma_{n,k}^N Y_{n,k} + W_n \sum_{\tau \in \mathcal{T}} S_{n,\mathrm{agr},\tau}, & \text{Fréchet/ACET/CET/Classical-Logit,} \\ \sum_{k \in \mathcal{G}} \gamma_{n,k}^N Y_{n,k} + W_n \sum_{\tau \in \mathcal{T}} S_{n,\mathrm{agr},\tau} + W_n N_n^M, & \text{Entropy-Logit.} \end{cases}$$

E8 $\forall n$

$$S_{n,\mathrm{agr}} = \sum_{\tau \in \mathcal{T}} S_{n,\mathrm{agr},\tau} = \begin{cases} \sum_{\tau \in \mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau} \left[1 - (\pi_{n,0,\tau}^L)^{(\nu_1 - 1)/\nu_1} \right], & \text{Fréchet,} \\ \sum_{\tau \in \mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau} \sum_{g \in \{\mathcal{K}_1, \mathcal{K}_2, \mathcal{K}_3\}} \pi_{n,g,\tau}^L, & \text{CET/ACET/Entropy-Logit/Classical-Logit.} \end{cases}$$

E9 $\forall n$

$$\mathrm{NLR}_n = \begin{cases} \sum_{\tau \in \mathcal{T}} \sum_{k \in \{0\} \cup \mathcal{K}} \mathbb{E}[R_{n,k,\tau}(q) \mid q \in \Omega_{n,k,\tau}] L_{n,k,\tau} - W_n \sum_{\tau \in \mathcal{T}} \mathbb{E}[e_{n,0,\tau}(q)] \bar{L}_{n,\tau}, & \text{Fréchet,} \\ \sum_{\tau \in \mathcal{T}} \sum_{k \in \{0\} \cup \mathcal{K}} R_{n,k,\tau} L_{n,k,\tau} - W_n \sum_{\tau \in \mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau}, & \text{ACET/CET/Classical-Logit,} \\ \sum_{\tau \in \mathcal{T}} \sum_{k \in \{0\} \cup \mathcal{K}} R_{n,k,\tau} L_{n,k,\tau} - W_n \sum_{\tau \in \mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau} - W_n N_n^M, & \text{Entropy-Logit.} \end{cases}$$

F.3. Land Allocation and Agricultural Production: Exact-Change Equations

H0 $\forall n, \tau, k$

$$\widehat{\widehat{R}}_{n,k,\tau} = \widehat{\xi}_{n,k,\tau} \widehat{R}_{n,k,\tau}, \qquad \widehat{\xi}_{n,0,\tau} = 1.$$

H1 $\forall n, \tau, k \in \mathcal{K}_1$

$$\widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau} = \left(\frac{\widehat{\widehat{R}}_{n,k,\tau}}{\widehat{\widehat{R}}_{n,\mathcal{K}_1,\tau}} \right)^{\nu_2}, \quad \widehat{\widehat{R}}_{n,\mathcal{K}_1,\tau} = \left[\sum_{\ell \in \mathcal{K}_1} \pi^L_{n,\ell|\mathcal{K}_1,\tau} (\widehat{\widehat{R}}_{n,\ell,\tau})^{\nu_2} \right]^{1/\nu_2}.$$

H2 $\forall n, \tau, g \in \mathcal{G}^L$

$$\widehat{\pi}^L_{n,g,\tau} = \frac{(\widehat{\widehat{R}}_{n,g,\tau})^{\nu_1}}{\sum_{m \in \mathcal{G}^L} \pi^L_{n,m,\tau} (\widehat{\widehat{R}}_{n,m,\tau})^{\nu_1}}, \quad \widehat{\widehat{R}}_{n,\tau} = \left[\sum_{m \in \mathcal{G}^L} \pi^L_{n,m,\tau} (\widehat{\widehat{R}}_{n,m,\tau})^{\nu_1} \right]^{1/\nu_1}.$$

H4 $\forall n, k$

$$\widehat{Q}_{n,k} = \begin{cases} \sum_{\tau \in \mathcal{T}} \frac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} (\widehat{\pi}^L_{n,\mathcal{K}_1,\tau})^{(\nu_1-1)/\nu_1} (\widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau})^{(\nu_2-1)/\nu_2}, & k \in \mathcal{K}_1, \\ \sum_{\tau \in \mathcal{T}} \frac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} (\widehat{\pi}^L_{n,k,\tau})^{(\nu_1-1)/\nu_1}, & k \in \mathcal{K}_2 \cup \mathcal{K}_3. \end{cases}$$

A1 $\forall n, \tau, k \in \mathcal{K}_1$

$$\widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau} = \left(\frac{\widehat{R}_{n,k,\tau}}{\widehat{R}_{n,\mathcal{K}_1,\tau}} \right)^{\nu_2}, \quad \widehat{R}_{n,\mathcal{K}_1,\tau} = \left[\sum_{\ell \in \mathcal{K}_1} \pi^L_{n,\ell|\mathcal{K}_1,\tau} \widehat{R}^{\nu_2}_{n,\ell,\tau} \right]^{1/\nu_2}.$$

A2 $\forall n, \tau, g \in \mathcal{G}^L$

$$\widehat{\pi}^L_{n,g,\tau} = \frac{\widehat{R}^{\nu_1}_{n,g,\tau}}{\sum_{m \in \mathcal{G}^L} \pi^L_{n,m,\tau} \widehat{R}^{\nu_1}_{n,m,\tau}}.$$

A3 $\forall n, k$

$$\widehat{Q}_{n,k} = \begin{cases} \sum_{\tau \in \mathcal{T}} \frac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,\mathcal{K}_1,\tau} \widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau}, & k \in \mathcal{K}_1, \\ \sum_{\tau \in \mathcal{T}} \frac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,k,\tau}, & k \in \mathcal{K}_2 \cup \mathcal{K}_3. \end{cases}$$

C1 $\forall n, \tau, k \in \mathcal{K}_1$

$$\widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau} = \left(\frac{\widehat{R}_{n,k,\tau}}{\widehat{R}_{n,\mathcal{K}_1,\tau}} \right)^{\eta_2}, \quad \widehat{R}_{n,\mathcal{K}_1,\tau} = \left[\sum_{\ell \in \mathcal{K}_1} \pi^{RL}_{n,\ell|\mathcal{K}_1,\tau} \widehat{R}^{1+\eta_2}_{n,\ell,\tau} \right]^{1/(1+\eta_2)}.$$

C2 $\forall n, \tau, g \in \mathcal{G}^L$

$$\widehat{\pi}^L_{n,g,\tau} = \left(\frac{\widehat{R}_{n,g,\tau}}{\widehat{R}_{n,\tau}} \right)^{\eta_1}, \quad \widehat{R}_{n,\tau} = \left[\sum_{m \in \mathcal{G}^L} \pi^{RL}_{n,m,\tau} \widehat{R}^{1+\eta_1}_{n,m,\tau} \right]^{1/(1+\eta_1)}.$$

C3 $\forall n, k$

$$\widehat{Q}_{n,k} = \begin{cases} \sum_{\tau \in \mathcal{T}} \dfrac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,\mathcal{K}_1,\tau} \widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau}, & k \in \mathcal{K}_1, \\ \sum_{\tau \in \mathcal{T}} \dfrac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,k,\tau}, & k \in \mathcal{K}_2 \cup \mathcal{K}_3. \end{cases}$$

L1 $\forall n, \tau, k \in \mathcal{K}_1$

$$\widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau} = \frac{\exp\left[\alpha_2 \frac{R_{n,k,\tau}}{W_n \varpi^C_{n,\tau}} \left(\frac{\widehat{R}_{n,k,\tau}}{\widehat{W}_n} - 1\right)\right]}{\sum_{\ell \in \mathcal{K}_1} \pi^L_{n,\ell|\mathcal{K}_1,\tau} \exp\left[\alpha_2 \frac{R_{n,\ell,\tau}}{W_n \varpi^C_{n,\tau}} \left(\frac{\widehat{R}_{n,\ell,\tau}}{\widehat{W}_n} - 1\right)\right]}, \quad \varpi^C_{n,\tau} \text{ fixed.}$$

L2 $\forall n, \tau, g \in \mathcal{G}^L$

$$\widehat{\pi}^L_{n,g,\tau} = \frac{\exp\left[\alpha_1 \frac{R_{n,g,\tau}}{W_n \varpi^U_{n,\tau}} \left(\frac{\widehat{R}_{n,g,\tau}}{\widehat{W}_n} - 1\right)\right]}{\sum_{m \in \mathcal{G}^L} \pi^L_{n,m,\tau} \exp\left[\alpha_1 \frac{R_{n,m,\tau}}{W_n \varpi^U_{n,\tau}} \left(\frac{\widehat{R}_{n,m,\tau}}{\widehat{W}_n} - 1\right)\right]}, \quad \varpi^U_{n,\tau} \text{ fixed.}$$

L3 $\forall n, k$

$$\widehat{Q}_{n,k} = \begin{cases} \sum_{\tau \in \mathcal{T}} \dfrac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,\mathcal{K}_1,\tau} \widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau}, & k \in \mathcal{K}_1, \\ \sum_{\tau \in \mathcal{T}} \dfrac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,k,\tau}, & k \in \mathcal{K}_2 \cup \mathcal{K}_3. \end{cases}$$

L4 $\forall n, \tau$

$$m^{U\prime}_{n,\tau} = \bar{m}^U_{n,\tau} + \frac{1}{\alpha_1} \sum_{g \in \mathcal{G}^L} \pi^{L\prime}_{n,g,\tau} \ln\left(\frac{\pi^{L\prime}_{n,g,\tau}}{\psi^U_{n,g,\tau}}\right),$$
$$m^{C\prime}_{n,\tau} = \bar{m}^C_{n,\tau} + \frac{1}{\alpha_2} \sum_{k \in \mathcal{K}_1} \pi^{L\prime}_{n,k|\mathcal{K}_1,\tau} \ln\left(\frac{\pi^{L\prime}_{n,k|\mathcal{K}_1,\tau}}{\psi^C_{n,k,\tau}}\right).$$

L5 $\forall n, \tau$

$$N^{M,U\prime}_{n,\tau} = \varpi^U_{n,\tau} \bar{L}_{n,\tau} m^{U\prime}_{n,\tau}, \quad N^{M,C\prime}_{n,\tau} = \varpi^C_{n,\tau} \bar{L}_{n,\tau} \pi^{L\prime}_{n,\mathcal{K}_1,\tau} m^{C\prime}_{n,\tau}, \quad N^{M\prime}_n = \sum_{\tau \in \mathcal{T}} (N^{M,U\prime}_{n,\tau} + N^{M,C\prime}_{n,\tau}).$$

CL1 $\forall n, \tau, k \in \mathcal{K}_1$

$$\widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau} = \frac{\exp[\alpha_2 R_{n,k,\tau}(\widehat{R}_{n,k,\tau} - 1)]}{\sum_{\ell \in \mathcal{K}_1} \pi^L_{n,\ell|\mathcal{K}_1,\tau} \exp[\alpha_2 R_{n,\ell,\tau}(\widehat{R}_{n,\ell,\tau} - 1)]}.$$

CL2 $\forall n, \tau, g \in \mathcal{G}^L$

$$\widehat{\pi}^L_{n,g,\tau} = \frac{\exp[\alpha_1 R_{n,g,\tau}(\widehat{R}_{n,g,\tau} - 1)]}{\sum_{m \in \mathcal{G}^L} \pi^L_{n,m,\tau} \exp[\alpha_1 R_{n,m,\tau}(\widehat{R}_{n,m,\tau} - 1)]}.$$

CL3 $\forall n, k$

$$\widehat{Q}_{n,k} = \begin{cases} \sum_{\tau \in \mathcal{T}} \dfrac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,\mathcal{K}_1,\tau} \widehat{\pi}^L_{n,k|\mathcal{K}_1,\tau}, & k \in \mathcal{K}_1, \\ \sum_{\tau \in \mathcal{T}} \dfrac{Q_{n,k,\tau}}{Q_{n,k}} \widehat{\hbar}_{n,k} \widehat{E}_{n,k,\tau} \widehat{\pi}^L_{n,k,\tau}, & k \in \mathcal{K}_2 \cup \mathcal{K}_3. \end{cases}$$

F.4. Remaining Equilibrium Conditions: Exact-Change Equations

F1 $\forall n,k,\tau$

$$\widehat{p}_{n,k} = \widehat{c}_{n,k,\tau}(q) = \widehat{R}_{n,k,\tau}(q)^{\gamma^L_{n,k}} \widehat{W}_n^{\gamma^N_{n,k}} (\widehat{P}^M_{n,k})^{\gamma^M_{n,k}} \widehat{e}_{n,k,\tau}(q)^{-\gamma^L_{n,k}}, \quad \text{Fréchet.}$$

F2 $\forall n,k,\tau$

$$\widehat{R}_{n,k,\tau} = \widehat{E}_{n,k,\tau}\widehat{h}_{n,k}, \quad \widehat{h}_{n,k} = \widehat{p}_{n,k}\widehat{\hbar}_{n,k}, \quad \widehat{\hbar}_{n,k} = \left(\frac{\widehat{W}_n}{\widehat{p}_{n,k}}\right)^{-\gamma^N_{n,k}/\gamma^L_{n,k}} \left(\frac{\widehat{P}^M_{n,k}}{\widehat{p}_{n,k}}\right)^{-\gamma^M_{n,k}/\gamma^L_{n,k}}.$$

F3 $\forall n,\tau$

$$L'_{n,g,\tau} = \pi^{L'}_{n,g,\tau}\bar{L}_{n,\tau}, \qquad L'_{n,k,\tau} = \pi^{L'}_{n,\mathcal{K}_1,\tau}\pi^{L'}_{n,k|\mathcal{K}_1,\tau}\bar{L}_{n,\tau}, \quad k \in \mathcal{K}_1.$$

F4 $\forall n,k$

$$\widehat{Q}_{n,k} = \widehat{A}_{n,k}\widehat{N}_{n,k}^{\gamma^N_{n,k}}\widehat{M}_{n,k}^{\gamma^M_{n,k}}, \qquad k \in \mathcal{E}\cup\mathcal{J}.$$

F5 $\forall n, k \in \mathcal{E}\cup\mathcal{J}$

$$\widehat{c}_{n,k} = \widehat{A}^{-1}_{n,k}\widehat{W}_n^{\gamma^N_{n,k}}(\widehat{P}^M_{n,k})^{\gamma^M_{n,k}}.$$

F6 $\forall n,k$

$$\widehat{p}_{n,k} = \widehat{c}_{n,k}, \qquad k \in \mathcal{E}\cup\mathcal{J}.$$

F7 $\forall n,k$

$$\widehat{P}^p_{nk,e} = \left[\omega^{e,p}_{nk,\text{bio}}\widehat{P}^{1-\sigma^{e,p}}_{n,\text{bio}} + \omega^{e,p}_{nk,\text{other}}\widehat{P}^{1-\sigma^{e,p}}_{n,\text{other}}\right]^{1/(1-\sigma^{e,p})}, \quad \widehat{P}^M_{n,k} = (\widehat{P}^p_{nk,e})^{\gamma^X_{n,ke}} \prod_{\ell\in\mathcal{G}'\setminus\{e\}} \widehat{P}_{n,\ell}^{\gamma^X_{n,k\ell}}.$$

F8 $\forall n,k$

$$\widehat{\omega}^{e,p}_{nk,\text{bio}} = \left(\frac{\widehat{P}_{n,\text{bio}}}{\widehat{P}^p_{nk,e}}\right)^{1-\sigma^{e,p}}, \qquad \widehat{\omega}^{e,p}_{nk,\text{other}} = \left(\frac{\widehat{P}_{n,\text{other}}}{\widehat{P}^p_{nk,e}}\right)^{1-\sigma^{e,p}}.$$

T1 $\forall n,i,j$

$$\widehat{P}_{ni,j} = \widehat{\kappa}_{ni,j}\widehat{p}_{i,j}.$$

T2 $\forall n,j$

$$\widehat{P}_{n,j} = \left[\sum_i \lambda_{ni,j}\widehat{P}^{1-\sigma_j}_{ni,j}\right]^{1/(1-\sigma_j)}.$$

T3 $\forall n,i,j$

$$\widehat{\lambda}_{ni,j} = \frac{\widehat{P}^{1-\sigma_j}_{ni,j}}{\sum_m \lambda_{nm,j}\widehat{P}^{1-\sigma_j}_{nm,j}}.$$

C1 $\forall n$

$$\widehat{P}^c_{n,e} = \left[\omega^{e,c}_{n,\text{bio}}((\widehat{1-\tau^c_{n,\text{bio}}})\widehat{P}_{n,\text{bio}})^{1-\sigma^{e,c}} + \omega^{e,c}_{n,\text{other}}\widehat{P}^{1-\sigma^{e,c}}_{n,\text{other}}\right]^{1/(1-\sigma^{e,c})}.$$

C2 $\forall n$

$$\widehat{\omega}^{e,c}_{n,\text{bio}} = \left(\frac{(\widehat{1-\tau^c_{n,\text{bio}}})\widehat{P}_{n,\text{bio}}}{\widehat{P}^c_{n,e}} \right)^{1-\sigma^{e,c}}, \quad \widehat{\omega}^{e,c}_{n,\text{other}} = \left(\frac{\widehat{P}_{n,\text{other}}}{\widehat{P}^c_{n,e}} \right)^{1-\sigma^{e,c}}.$$

C3 $\forall n,\ j \in \mathcal{G}' \setminus \{e\}$

$$\widehat{P}^C_n = (\widehat{P}^c_{n,e})^{\alpha^C_{n,e}} \prod_{j \in \mathcal{G}' \setminus \{e\}} \widehat{P}^{\alpha^C_{n,j}}_{n,j}, \quad \widehat{P}^c_{n,e}\widehat{C}_{n,e} = \widehat{P}^C_n \widehat{C}_n, \quad \widehat{P}_{n,j}\widehat{C}_{n,j} = \widehat{P}^C_n \widehat{C}_n.$$

C4 $\forall n$

$$(\widehat{1-\tau^c_{n,\text{bio}}})\widehat{P}_{n,\text{bio}}\widehat{C}_{n,\text{bio}} = \widehat{\omega}^{e,c}_{n,\text{bio}}\widehat{P}^C_n \widehat{C}_n, \quad \widehat{P}_{n,\text{other}}\widehat{C}_{n,\text{other}} = \widehat{\omega}^{e,c}_{n,\text{other}}\widehat{P}^C_n \widehat{C}_n.$$

C5 $\forall n$

$$T^{c\prime}_n = \tau^{c\prime}_{n,\text{bio}} P'_{n,\text{bio}} C'_{n,\text{bio}}.$$

C6 $\forall n$

$$P^{C\prime}_n C'_n = W'_n N_n + \text{NLR}'_n - T^{c\prime}_n + D'_n.$$

C7 $\forall n$

$$D'_n = -\phi_n(W'_n N_n + \text{NLR}'_n) + \frac{N_n}{\sum_m N_m} \sum_m \phi_m (W'_m N_m + \text{NLR}'_m), \qquad \sum_n D'_n = 0.$$

E1 $\forall n, i, j$

$$X'_{ni,j} = P'_{ni,j} Q'_{ni,j} = \lambda'_{ni,j} X'_{n,j}, \qquad X'_{n,j} = \sum_i X'_{ni,j} = P'_{n,j} Q'_{n,j}.$$

E2 $\forall n$

$$\begin{aligned} X'_{n,\text{bio}} &= \frac{\omega^{e,c\prime}_{n,\text{bio}} \alpha^C_{n,e} P^{C\prime}_n C'_n}{1-\tau^{c\prime}_{n,\text{bio}}} + \sum_{k \in \mathcal{G}} \gamma^M_{n,k} \gamma^X_{n,ke} \omega^{e,p\prime}_{nk,\text{bio}} Y'_{n,k}, \\ X'_{n,\text{other}} &= \omega^{e,c\prime}_{n,\text{other}} \alpha^C_{n,e} P^{C\prime}_n C'_n + \sum_{k \in \mathcal{G}} \gamma^M_{n,k} \gamma^X_{n,ke} \omega^{e,p\prime}_{nk,\text{other}} Y'_{n,k}, \\ X'_{n,j} &= \alpha^C_{n,j} P^{C\prime}_n C'_n + \sum_{k \in \mathcal{G}} \gamma^M_{n,k} \gamma^X_{n,kj} Y'_{n,k}, \quad j \in \mathcal{G}' \setminus \{e\}. \end{aligned}$$

E3 $\forall n, j$

$$Y'_{n,j} = \sum_i \lambda'_{in,j} X'_{i,j}.$$

E4 $\forall n$

$$\sum_i \sum_j X'_{ni,j} = \sum_i \sum_j X'_{in,j} + D'_n.$$

E5 $\forall n$

$$D'_n = -\phi_n(W'_n N_n + \text{NLR}'_n) + \frac{N_n}{\sum_m N_m} \sum_m \phi_m (W'_m N_m + \text{NLR}'_m), \qquad \sum_n D'_n = 0.$$

E6 $\forall n, \tau$

$$N^{M,U\prime}_{n,\tau} = \varpi^{U}_{n,\tau} \bar{L}_{n,\tau} m^{U\prime}_{n,\tau}, \quad N^{M,C\prime}_{n,\tau} = \varpi^{C}_{n,\tau} \bar{L}_{n,\tau} \pi^{L\prime}_{n,\mathcal{K}_1,\tau} m^{C\prime}_{n,\tau}, \quad N^{M\prime}_{n} = \sum_{\tau\in\mathcal{T}} (N^{M,U\prime}_{n,\tau} + N^{M,C\prime}_{n,\tau}).$$

E7 $\forall n$

$$W'_n N_n = \begin{cases} \sum_{k\in\mathcal{G}} \gamma^N_{n,k} Y'_{n,k} + W'_n \sum_{\tau\in\mathcal{T}} S'_{n,\text{agr},\tau}, & \text{Fréchet/ACET/CET/Classical-Logit,} \\ \sum_{k\in\mathcal{G}} \gamma^N_{n,k} Y'_{n,k} + W'_n \sum_{\tau\in\mathcal{T}} S'_{n,\text{agr},\tau} + W'_n N^{M\prime}_n, & \text{Entropy-Logit.} \end{cases}$$

E8 $\forall n$

$$S'_{n,\text{agr}} = \begin{cases} \displaystyle\sum_{\tau\in\mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau} \left[1 - (\pi^{L\prime}_{n,0,\tau})^{(\nu_1-1)/\nu_1}\right], & \text{Fréchet,} \\ \displaystyle\sum_{\tau\in\mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau} \sum_{g\in\{\mathcal{K}_1,\mathcal{K}_2,\mathcal{K}_3\}} \pi^{L\prime}_{n,g,\tau}, & \text{CET/ACET/Entropy-Logit/Classical-Logit.} \end{cases}$$

E9 $\forall n$

$$\text{NLR}'_n = \begin{cases} \displaystyle\sum_{\tau\in\mathcal{T}} \sum_{k\in\{0\}\cup\mathcal{K}} \mathbb{E}[R'_{n,k,\tau}(q) \mid q \in \Omega_{n,k,\tau}] L'_{n,k,\tau} - W'_n \sum_{\tau\in\mathcal{T}} \mathbb{E}[e_{n,0,\tau}(q)] \bar{L}_{n,\tau}, & \text{Fréchet,} \\ \displaystyle\sum_{\tau\in\mathcal{T}} \sum_{k\in\{0\}\cup\mathcal{K}} R'_{n,k,\tau} L'_{n,k,\tau} - W'_n \sum_{\tau\in\mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau}, & \text{ACET/CET/Classical-Logit,} \\ \displaystyle\sum_{\tau\in\mathcal{T}} \sum_{k\in\{0\}\cup\mathcal{K}} R'_{n,k,\tau} L'_{n,k,\tau} - W'_n \sum_{\tau\in\mathcal{T}} E_{n,0,\tau} \bar{L}_{n,\tau} - W'_n N^{M\prime}_n, & \text{Entropy-Logit.} \end{cases}$$

F.5. Counterfactual Solution

We solve the counterfactual equilibrium using nested fixed-point iterations. Following Alvarez and Lucas (2007), we normalize world value added and iterate on its distribution across countries and factors. Given a candidate distribution of factor payments and a trial U.S. final-consumption biofuel subsidy, the factor-market conditions determine the corresponding factor prices and, where factor allocation is endogenous, the allocation of the factor across uses. Conditional on these factor prices and allocations, we solve an inner fixed point for sectoral price indexes. The resulting prices determine trade shares, expenditures, sectoral output, and the factor payments implied by the equilibrium. We update the candidate distribution until it coincides with the distribution implied by these equilibrium outcomes. The equations governing production, household demand, trade, and market clearing are common across the five specifications; each uses its own land-allocation equations.

F.5.1. Counterfactual Closure

We impose the U.S. biofuel output requirement

$$\widehat{Q}^{p}_{\text{USA,bio}} = \widehat{Q}^{p,*}_{\text{USA,bio}},$$

where

$$\widehat{Q}^{p,*}_{\text{USA,bio}} = 56.7/6.55 \simeq 8.656. \tag{F.1}$$

The U.S. final-consumption biofuel subsidy $\tau^{c}_{\text{USA,bio}}$ adjusts endogenously to produce this output level in all five land-allocation specifications.

F.5.2. Numerical Solution Algorithm

For a trial value of $\tau^{c}_{\text{USA,bio}}$, we solve the equilibrium using the nested fixed-point procedure summarized in Algorithm 1. Let $\bar{V}^{W}$ denote normalized world value added, ε_W and ε_P the convergence tolerances for the value-added and price iterations, and v_W and v_R the corresponding damping parameters. After the equilibrium converges for a given trial subsidy, we update the subsidy and resolve the equilibrium until U.S. biofuel production reaches the required level.

Algorithm 1 Counterfactual Equilibrium

1: Choose one of the five land-allocation specifications and fix a trial value of $\tau^{c}_{\text{USA,bio}}$. Guess the counterfactual shares of world value added accruing to production labor and land in each active use, $\{s^{VA\prime}_{Nn}, s^{VA\prime}_{kn}\}_{n,k\in\mathcal{K}}$, and repeat until $\max_n \left\{ \left| \dfrac{\widetilde{VA}'_{Nn} - VA^{tar\prime}_{Nn}}{EX'_n} \right|, \max_{k\in\mathcal{K}} \left| \dfrac{\widetilde{VA}'_{kn} - VA^{tar\prime}_{kn}}{EX'_n} \right| \right\} < \varepsilon_W$.

(a) Construct the candidate factor payments: $VA^{tar\prime}_{Nn} = \bar{V}^{W} s^{VA\prime}_{Nn}, \qquad VA^{tar\prime}_{kn} = \bar{V}^{W} s^{VA\prime}_{kn}, \quad k \in \mathcal{K}$.

(b) Given $\{VA^{tar\prime}_{Nn}, VA^{tar\prime}_{kn}\}_{n,k\in\mathcal{K}}$, use the factor-market conditions to determine $\{\widehat{W}_n, \widehat{h}_{n,k}\}$.

(b.1) Together with the land-allocation equations, obtain

$$\{\widehat{W}_n, \widehat{h}_{n,k}\} \xrightarrow[\text{F2-F3, E7-E8}]{F\text{:H0-H4, }A\text{:A1-A3, }C\text{:C1-C3, }EL\text{:L1-L5, }CL\text{:CL1-CL3}} \left\{ \widehat{R}_{n,k,\tau}, \widehat{\pi}^{L}_{n,k,\tau}, L'_{n,k,\tau}, S'_{n,\text{agr},\tau} \right\}.$$

For Entropy Logit, $\{\text{L4} - \text{L5},\ \text{E6} - \text{E8}\} \longrightarrow \left\{ m^{U\prime}_{n,\tau}, m^{C\prime}_{n,\tau}, N^{M,U\prime}_{n,\tau}, N^{M,C\prime}_{n,\tau}, N^{M\prime}_{n} \right\}$.

(b.2) Guess $\{\widehat{P}_{n,j}\}$, and repeat until $\max_{n,j} \left| \dfrac{\widehat{P}^{new}_{n,j} - \widehat{P}_{n,j}}{\widehat{P}_{n,j}} \right| < \varepsilon_P$:

(b.2.a) Given factor prices, land returns, and the current sectoral price indexes, compute

$$\{\widehat{W}, \widehat{R}, \widehat{P}\} \xrightarrow{\text{F1/F1}', \text{F5-F8, T1-T3, Household C1-C5}} \left\{ \widehat{c}, \widehat{p}, \widehat{P}^{M}, \widehat{P}_{ni}, \widehat{\lambda}, \widehat{P}^{new} \right\}.$$

(b.2.b) Set $\widehat{P} \leftarrow \widehat{P}^{new}$ and repeat.

(b.3) Given the converged prices, trade shares, and land allocations, recover expenditures, trade flows, and sectoral output: $\left\{\widehat{W}, \widehat{R}, \widehat{P}, \widehat{\lambda}, \widehat{\pi}^L, L'\right\} \xrightarrow{\text{Household C6–C7, E1–E5, E9}} \left\{\text{NLR}'_n, D'_n, X'_{n,j}, X'_{ni,j}, Y'_{n,j}\right\}$.

(b.4) Compute the factor payments implied by sectoral output:
$\widetilde{VA}'_{Nn} = \sum_{j \in \mathcal{G}} \gamma^N_{n,j} Y'_{n,j}, \qquad \widetilde{VA}'_{kn} = \gamma^L_{n,k} Y'_{n,k}, \quad k \in \mathcal{K}.$

(c) Compute the differences between the implied and candidate factor payments:
$r^{VA\prime}_{Nn} = \widetilde{VA}'_{Nn} - VA^{tar\prime}_{Nn}, \qquad r^{VA\prime}_{kn} = \widetilde{VA}'_{kn} - VA^{tar\prime}_{kn}, \quad k \in \mathcal{K}.$

(d) Update the candidate factor payments: $VA^{new\prime}_{Nn} = VA^{tar\prime}_{Nn} + v_W r^{VA\prime}_{Nn}, \qquad VA^{new\prime}_{kn} = VA^{tar\prime}_{kn} + v_R r^{VA\prime}_{kn}, \quad k \in \mathcal{K}.$

(e) Renormalize: $s^{VA,new\prime}_{Nn} = \dfrac{VA^{new\prime}_{Nn}}{\sum_m \left(VA^{new\prime}_{Nm} + \sum_{k \in \mathcal{K}} VA^{new\prime}_{km} \right)},$
$s^{VA,new\prime}_{kn} = \dfrac{VA^{new\prime}_{kn}}{\sum_m \left(VA^{new\prime}_{Nm} + \sum_{\ell \in \mathcal{K}} VA^{new\prime}_{\ell m} \right)}, \qquad k \in \mathcal{K}.$

(f) Set $s^{VA\prime}_{Nn} \leftarrow s^{VA,new\prime}_{Nn}, \qquad s^{VA\prime}_{kn} \leftarrow s^{VA,new\prime}_{kn}$, and repeat **(a)–(f)**.

2: For the converged value-added distribution, return factor prices, sectoral price indexes, land returns and allocations, trade shares, expenditures, sectoral output, net land revenue, transfers, and $\widehat{Q}^p_{\text{USA,bio}}$.

For each trial value of $\tau^c_{\text{USA,bio}}$, the procedure above delivers the corresponding counterfactual equilibrium and U.S. biofuel production. We update the subsidy and repeat the equilibrium calculation until

$$\widehat{Q}^p_{\text{USA,bio}} = \widehat{Q}^{p,*}_{\text{USA,bio}}.$$

The converged subsidy and the associated equilibrium are used in the quantitative analysis.

F.6. Model Dimensions and Concordances

The model contains 18 regions, 10 production sectors, eight land-use categories, and 18 GTAP-BIO agro-ecological-zone (AEZ) land-source types. The upper land nest contains idle land, cropland, pasture/livestock land, and managed forest. Conditional on cropland, the lower land nest allocates land across five crop uses.

Table F.2 defines the principal indices used below.

Table F.2. Dimension Conventions

Index	**Meaning**	**Size**	**Value**
n	Country / region.	N	18
i	Source / seller country in bilateral trade matrices.	N	18
j	Production sector.	J	10
J_r	Reduced sector set after the two energy goods are treated as one energy composite.	$J-1$	9
k	Land-use category, including idle and active land uses.	K	8
$k-1$	Active land-use categories, excluding idle land.	$K-1$	7
τ	GTAP-BIO AEZ land-source type.	K_τ	18

The 18 model regions are listed in Table F.3. The same regional classification is used throughout the benchmark construction.

Table F.3. Country Groups

No.	Code	Region
1	USA	United States.
2	CAN	Canada.
3	EU27	European Union, 27-country aggregate.
4	BRAZIL	Brazil.
5	JAPAN	Japan.
6	CHIHKG	China and Hong Kong.
7	INDIA	India.
8	LAEEX	Latin American energy exporters.
9	RoLAC	Rest of Latin America and the Caribbean.
10	EEFSUEX	Eastern Europe and former Soviet Union energy exporters.
11	RoE	Rest of Europe.
12	MEASTNAEX	Middle East and North Africa energy exporters.
13	SSAEX	Sub-Saharan Africa energy exporters.
14	RoAFR	Rest of Africa.
15	SASIAEEX	South and Southeast Asian energy exporters.
16	RoHIA	Rest of high-income Asia.
17	RoASIA	Rest of Asia.
18	Oceania	Oceania.

The ten production sectors are reported in Table F.4. The first five are crop sectors. Livestock and Forest are the remaining active land-using sectors. biofuel, OtherEnergy, and OtherGoods do not use land directly.

Table F.4. Model Sectors

No.	Sector	Description
1	CrGrains	Coarse grains, including corn/maize.
2	Oilseeds	Oilseed crops.
3	Sugarcane	Sugar cane and sugar beet.
4	OthGrains	Other grains, including paddy rice and wheat.
5	OthAgri	Other agricultural crops and agricultural products not included in the preceding crop categories.
6	Livestock	Livestock production and the associated pasture-related land use.
7	Forest	Forestry production associated with managed forest land.
8	biofuel	biofuel products, including sugarcane-based ethanol, corn/coarse-grain ethanol, and biodiesel fuel.
9	OtherEnergy	Non-biofuel energy and energy-intensive sectors, including coal, crude oil, natural gas, petroleum and coal products, electricity, and energy-intensive industries.
10	OtherGoods	Remaining goods and activities, including other food products, processed livestock products, other primary sectors, other industry and services, capital goods, and the biofuel byproducts DDGS and BDBP.

Using the notation of the model, let $\mathcal{K}_1$ denote the five crop sectors, $\mathcal{K}_2$ Livestock, and $\mathcal{K}_3$ Forest. Then

$$\mathcal{K} = \mathcal{K}_1 \cup \mathcal{K}_2 \cup \mathcal{K}_3$$

is the set of active land-using sectors. Let

$$\mathcal{E} = \{\text{bio}, \text{other}\}$$

denote biofuel and OtherEnergy, and let $\mathcal{J} = \{\text{OtherGoods}\}$. The complete production-sector set is

$$\mathcal{G} = \mathcal{K} \cup \mathcal{E} \cup \mathcal{J}.$$

F.7. Commodity and Activity Concordances

The GTAP-BIO database distinguishes commodities from production activities, and we construct the model concordance separately along these two dimensions. The commodity classification is used for bilateral trade and final expenditures, while the activity classification is used for production and primary-factor payments. Intermediate-input purchases link the two dimensions: inputs are classified by commodity and their users by production activity.

F.7.1. Commodity Concordance

Table F.5 reports the commodity concordance used to aggregate the 22 GTAP-BIO commodities into the ten model sectors. The same concordance is applied to bilateral trade, private and government final demand, and intermediate inputs on the commodity dimension.

Table F.5. Mapping from GTAP-BIO Commodities to the Ten-Sector Model

New No.	**New Sector**	GTAP No.	**GTAP-BIO Code**	**Description**
1	CrGrains	1	`CrGrains`	Coarse grains, including corn/maize.
2	Oilseeds	3	`Oilseeds`	Oilseed crops.
3	Sugarcane	4	`Sugarcane`	Sugar cane and sugar beet.
4	OthGrains	2	`OthGrains`	Other grains, including paddy rice and wheat.
5	OthAgri	10	`OthAgri`	Other agricultural goods.
6	Livestock	5	`Livestock`	Livestock products.
7	Forest	6	`Forestry`	Forestry products.
8	biofuel	7	`Ethanol2`	Sugarcane-based ethanol.
8	biofuel	19	`Ethanol1`	Corn/coarse-grain ethanol.
8	biofuel	21	`Biodieself`	Biodiesel fuel.
9	OtherEnergy	12	`Coal`	Coal.
9	OtherEnergy	13	`Oil`	Crude oil.
9	OtherEnergy	14	`Gas`	Natural gas.
9	OtherEnergy	15	`Oil_Pcts`	Petroleum and coal products.
9	OtherEnergy	16	`Electricity`	Electricity.
9	OtherEnergy	17	`En_Int_Ind`	Energy-intensive industries.
10	OtherGoods	8	`OthFoodPdts`	Other food products.
10	OtherGoods	9	`ProcLivestoc`	Processed livestock products.
10	OtherGoods	11	`OthPrimSect`	Other primary sectors.
10	OtherGoods	18	`Oth_Ind_Se`	Other industry and services.
10	OtherGoods	20	`DDGS`	Byproduct of corn-ethanol production.
10	OtherGoods	22	`BDBP`	Byproduct of biodiesel production.

F.7.2. Activity Concordance

Table F.6 reports the corresponding concordance for the 21 GTAP-BIO production activities. Most activities map directly into one model sector. The two joint-production activities, `EthanolC` and `Biodiesel`, require an additional allocation because each activity produces a fuel together with a byproduct. We use the GTAP-BIO revenue shares `REVE` and `REVB` to separate these outputs before aggregating them to the model sectors.

Table F.6. Mapping from GTAP-BIO Activities to the Ten-Sector Model

New No.	**New Sector**	GTAP No.	**GTAP-BIO Code**	**Description**
1	CrGrains	1	`CrGrains`	Coarse-grain activity, including corn/maize.
2	Oilseeds	3	`Oilseeds`	Oilseed activity.
3	Sugarcane	4	`Sugarcane`	Sugar cane and sugar beet activity.
4	OthGrains	2	`OthGrains`	Other-grain activity.
5	OthAgri	12	`OthAgri`	Other agricultural activity.
6	Livestock	5	`Livestock`	Livestock activity.
7	Forest	6	`Forestry`	Forestry activity.
8	biofuel	8	`Ethanol2`	Sugarcane-based ethanol activity.
8 / 10	biofuel / OtherGoods	7	`EthanolC`	Split by `REVE`: Ethanol1 enters biofuel and DDGS enters OtherGoods.
8 / 10	biofuel / OtherGoods	9	`Biodiesel`	Split by `REVB`: Biodieself enters biofuel and BDBP enters OtherGoods.
9	OtherEnergy	14	`Coal`	Coal activity.
9	OtherEnergy	15	`Oil`	Crude-oil activity.
9	OtherEnergy	16	`Gas`	Natural-gas activity.
9	OtherEnergy	17	`Oil_Pcts`	Petroleum and coal products activity.
9	OtherEnergy	18	`Electricity`	Electricity activity.
9	OtherEnergy	19	`En_Int_Ind`	Energy-intensive industries.
10	OtherGoods	10	`OthFoodPdts`	Other food products activity.
10	OtherGoods	11	`ProcLivestoc`	Processed livestock products.
10	OtherGoods	13	`OthPrimSect`	Other primary sectors.
10	OtherGoods	20	`Oth_Ind_Se`	Other industry and services.
10	OtherGoods	21	`CGDS`	Capital goods.

For `EthanolC`, `REVE` allocates activity revenue between Ethanol1 and DDGS; for `Biodiesel`, `REVB` allocates activity revenue between Biodieself and BDBP. The fuel outputs are assigned to biofuel, while DDGS and BDBP are assigned to OtherGoods. This activity concordance is used to aggregate production, primary-factor payments, and intermediate-input use by producing activity.

F.8. Land-Source and Land-Use Classifications

The index τ identifies the GTAP-BIO AEZ source from which land is drawn, whereas k identifies its economic use. The 18 source types combine three climate zones with six length-of-growing-period (LGP) intervals.

Table F.7. GTAP-BIO Land-Source Types

No.	AEZ	Climate zone	LGP range	Description
1	AEZ1	Tropical	0–60 days	Tropical land with a 0–60 day growing period.
2	AEZ2	Tropical	60–120 days	Tropical land with a 60–120 day growing period.
3	AEZ3	Tropical	120–180 days	Tropical land with a 120–180 day growing period.
4	AEZ4	Tropical	180–240 days	Tropical land with a 180–240 day growing period.
5	AEZ5	Tropical	240–270 days	Tropical land with a 240–270 day growing period.
6	AEZ6	Tropical	270–360 days	Tropical land with a 270–360 day growing period.
7	AEZ7	Temperate	0–60 days	Temperate land with a 0–60 day growing period.
8	AEZ8	Temperate	60–120 days	Temperate land with a 60–120 day growing period.
9	AEZ9	Temperate	120–180 days	Temperate land with a 120–180 day growing period.
10	AEZ10	Temperate	180–240 days	Temperate land with a 180–240 day growing period.
11	AEZ11	Temperate	240–270 days	Temperate land with a 240–270 day growing period.
12	AEZ12	Temperate	270–360 days	Temperate land with a 270–360 day growing period.
13	AEZ13	Boreal	0–60 days	Boreal land with a 0–60 day growing period.
14	AEZ14	Boreal	60–120 days	Boreal land with a 60–120 day growing period.
15	AEZ15	Boreal	120–180 days	Boreal land with a 120–180 day growing period.
16	AEZ16	Boreal	180–240 days	Boreal land with a 180–240 day growing period.
17	AEZ17	Boreal	240–270 days	Boreal land with a 240–270 day growing period.
18	AEZ18	Boreal	270–360 days	Boreal land with a 270–360 day growing period.

AEZ denotes agro-ecological zone and LGP denotes length of growing period. The AEZ dimension is included in both the `COVR` and `AREA` physical land accounts.

The eight economic land-use categories are reported separately in Table F.8.

Table F.8. Land-Use Types

No.	Land use	Description
1	Idle land	Land not allocated to active production.
2	CrGrains land	Land allocated to coarse-grain production.
3	Oilseeds land	Land allocated to oilseed production.
4	Sugarcane land	Land allocated to sugar cane and sugar beet production.
5	OthGrains land	Land allocated to other-grain production.
6	OthAgri land	Land allocated to other agricultural crop production.
7	Livestock land	Land allocated to pasture/livestock use.
8	Managed forest land	Land allocated to managed forestry.

G. Environmental Outcome Accounting

We report one-time indirect land-use-change (ILUC) carbon-stock effects separately from annual production-side CO_2 emissions. The former arise from changes in physical land cover; the latter from changes in sectoral output. Combining them requires an explicit accounting horizon. A prime denotes a counterfactual level and $\widehat{x} \equiv x'/x$.

Table G.1. Mapping of carbon factors to model land uses

Land use	Loss factor	Gain factor	Interpretation
Idle land, 0	0	0	No direct accounted carbon stock.
Crop uses, $k \in \mathcal{K}_1$	$\texttt{ECR}_{\tau n}$	$\texttt{ECR}_{\tau n}$	Common cropland factor for all five crops.
Livestock, $k \in \mathcal{K}_2$	$\texttt{EPS}_{\tau n}$	$\texttt{EPS}_{\tau n}$	Pasture/livestock-land factor.
Managed forest, $k \in \mathcal{K}_3$	$\texttt{EFL}_{\tau n}$	$\texttt{EFG}_{\tau n}$	Distinct factors for forest loss and forest gain.

G.1. Carbon Factors, Land Uses, and Units

The active land uses are those in $\mathcal{K}$ defined in equation (A.1). For environmental accounting, it is convenient to augment this set with idle land:

$$\mathcal{K}^0 \equiv \{0\} \cup \mathcal{K}, \tag{G.1}$$

where 0 denotes idle land, $\mathcal{K}_1$ contains the five crop uses, $\mathcal{K}_2 = \{\text{Livestock}\}$, and $\mathcal{K}_3 = \{\text{ManagedForest}\}$.

The GTAP-BIO carbon-factor objects are

$$\texttt{EFL}_{\tau n}, \qquad \texttt{EFG}_{\tau n}, \qquad \texttt{ECR}_{\tau n}, \qquad \texttt{EPS}_{\tau n}, \tag{G.2}$$

where $\tau \in \mathcal{T}$ indexes the AEZ source type and $n \in \mathcal{N}$ indexes the country. Each object is a positive magnitude measured in MgCO_2e per hectare. These are one-time carbon-stock factors, not annual emissions rates. Recall that one Mg is one metric ton and one Mt is 10^6 Mg.

For each n, τ, and $k \in \mathcal{K}^0$, let $e^{\text{loss}}_{n,k,\tau}$ be the carbon released when one hectare is removed from use k, and let $e^{\text{gain}}_{n,k,\tau}$ be the carbon stored when one hectare is added to use k. Table G.1 gives the mapping from the raw GTAP-BIO objects to the model land uses.

We assign zero direct carbon stock to idle land. Equation (D.20) maps that alternative from the `unmngland` input category, so this assumption must not be interpreted as excluding unmanaged land from the modeled endowment. The aggregate does not distinguish carbon stocks within that category. The zero factor is a baseline accounting convention, not an estimate that those stocks are zero. All five crop uses receive the same cropland factor, so reallocation among crops has no direct land-cover carbon effect after aggregation. Forest loss and forest gain use separate factors, $\texttt{EFL}_{\tau n}$ and $\texttt{EFG}_{\tau n}$, which can take different values.

G.2. Physical Land Changes and ILUC

For Fréchet, ACET, Classical Logit, and Entropy Logit, we apply carbon factors to physical land quantities. CET is treated separately below. Let $L_{n,k,\tau}$ and $L'_{n,k,\tau}$ denote benchmark and counterfactual land in country n, use k, and AEZ source type τ, measured in hectares. The benchmark is the common physical land allocation constructed from the GTAP-BIO land-cover and harvested-area data:

$$L_{n,k,\tau} = L^{data}_{n,k,\tau}, \qquad k \in \mathcal{K}^0. \tag{G.3}$$

For every land-allocation specification, the environmental module uses the corresponding $L'_{n,k,\tau}$ returned by the equilibrium solver directly. No additional normalization or specification-specific transformation is applied. In particular, carbon factors are applied to the individual land-use quantities rather than to an upper- or lower-level land composite.

Define the net physical land change by

$$\Delta L_{n,k,\tau} \equiv L'_{n,k,\tau} - L_{n,k,\tau}, \qquad \sum_{k \in \mathcal{K}^0} \Delta L_{n,k,\tau} = 0. \tag{G.4}$$

Let $[x]_+ \equiv \max\{x, 0\}$. Physical losses from and gains to land use k are

$$O_{n,k,\tau} = [-\Delta L_{n,k,\tau}]_+, \qquad G_{n,k,\tau} = [\Delta L_{n,k,\tau}]_+. \tag{G.5}$$

We use a net-change accounting convention: a use in a source cell has either net gains or net losses. Simultaneous gross clearing and regrowth within that use are not recovered from net areas. Because physical area is fixed within each cell,

$$\sum_{k \in \mathcal{K}^0} O_{n,k,\tau} = \sum_{k \in \mathcal{K}^0} G_{n,k,\tau}.$$

To show how net changes map into conversion emissions, consider a conceptual source–destination matrix $M_{n,\tau,ab}$, where $a, b \in \mathcal{K}^0$ and $M_{n,\tau,ab}$ is the number of hectares converted from source use a to destination use b. Its margins satisfy

$$\sum_{b \in \mathcal{K}^0} M_{n,\tau,ab} = O_{n,a,\tau}, \qquad \sum_{a \in \mathcal{K}^0} M_{n,\tau,ab} = G_{n,b,\tau}, \qquad M_{n,\tau,aa} = 0. \tag{G.6}$$

The carbon factor for conversion from a to b is separable into the carbon lost at the source and the carbon gained at the destination:

$$\Gamma_{n,\tau,ab} = e^{\text{loss}}_{n,a,\tau} - e^{\text{gain}}_{n,b,\tau}. \tag{G.7}$$

Thus, the matrix-based emissions in an (n, τ) cell collapse exactly to an expression involving only net land changes:

$$\begin{aligned} E^{\text{ILUC},M}_{n,\tau} &= \sum_{a \in \mathcal{K}^0} \sum_{b \in \mathcal{K}^0} M_{n,\tau,ab} \Gamma_{n,\tau,ab} \\ &= \sum_{a \in \mathcal{K}^0} e^{\text{loss}}_{n,a,\tau} O_{n,a,\tau} - \sum_{b \in \mathcal{K}^0} e^{\text{gain}}_{n,b,\tau} G_{n,b,\tau} \equiv E^{\text{ILUC}}_{n,\tau}. \end{aligned} \tag{G.8}$$

Under this net-change convention, the net area changes suffice for the calculation without imputing the full transition matrix. This does not establish that arbitrary gross transition matrices with the same net area changes have equal emissions. Gross clearing and regrowth can matter when loss and gain factors are unequal. Under the separable carbon-factor structure in equation (G.7), every matrix with the same source losses and destination gains produces the same aggregate emissions. This equivalence would fail if conversion factors were genuinely source–destination specific and nonseparable.

Summing equation (G.8) over countries and AEZ source types gives global ILUC:

$$E^{\mathrm{ILUC}} = \sum_{n\in\mathcal{N}} \sum_{\tau\in\mathcal{T}} E^{\mathrm{ILUC}}_{n,\tau}. \tag{G.9}$$

Using the mapping in Table G.1, the implemented formula is

$$\begin{aligned} E^{\mathrm{ILUC}} = \sum_{n\in\mathcal{N}} \sum_{\tau\in\mathcal{T}} \Bigg[& -\mathtt{ECR}_{\tau n} \sum_{k\in\mathcal{K}_1} \Delta L_{n,k,\tau} - \mathtt{EPS}_{\tau n} \Delta L_{n,\mathrm{Livestock},\tau} \\ & + \mathtt{EFL}_{\tau n} [-\Delta L_{n,\mathrm{ManagedForest},\tau}]_+ - \mathtt{EFG}_{\tau n} [\Delta L_{n,\mathrm{ManagedForest},\tau}]_+ \Bigg]. \end{aligned} \tag{G.10}$$

Idle land does not appear directly because its loss and gain factors are zero. Since ΔL is measured in hectares and the carbon factors are measured in $\mathrm{MgCO_2e}$ per hectare, E^{ILUC} is measured in $\mathrm{MgCO_2e}$. We also report

$$E^{\mathrm{ILUC}}_{\mathrm{Mt}} \equiv \frac{E^{\mathrm{ILUC}}}{10^6}, \tag{G.11}$$

in $\mathrm{MtCO_2e}$. A positive value denotes a one-time net carbon release, whereas a negative value denotes net sequestration or a carbon credit.

G.3. *CET branch-based accounting*

The CET solver returns transformed land services $B_{n,k,\tau}$, initialized in benchmark-hectare units. The reported carbon calculation applies the same factors to $\Delta B_{n,k,\tau}$ in place of $\Delta L_{n,k,\tau}$ in (G.10). We label this object $E^{\mathrm{CET,proxy}}$. It does not satisfy the physical balance used in (G.4); thus, the transition-matrix interpretation above does not apply to it.

In the final-consumption experiment, the reported global CET branch changes sum to approximately 6.26 million benchmark units. Cropland branches expand by 9.47 million units, while the other branches decline by 3.21 million. Although the residual is small relative to the initial worldwide endowment, it is substantial relative to the conversion being evaluated. A physical carbon estimate from CET would require an explicit, empirically justified mapping from productive services to hectares. We do not impose an ex post rescaling to manufacture that balance.

G.4. *Annual Production-Side CO_2 Emissions*

Annual production-side emissions are constructed from the GTAP-BIO object $\mathtt{CO2}_{n,c}$, where c indexes an original GTAP-BIO activity. This object is measured in Mt of carbon per year, rather than Mt of CO_2. Let $\chi_{n,cj}$ denote the activity-side concordance weight assigning original activity c to model sector $j \in \mathcal{G}$. The concordance is the same as that used for production and factor payments in Appendix F.7; in particular, the joint-product biofuel activities are split using the corresponding revenue shares. Benchmark carbon mass in model dimensions is

$$E^{\mathrm{C}}_{n,j} = \sum_{c} \chi_{n,cj} \mathtt{CO2}_{n,c}, \tag{G.12}$$

and benchmark CO_2 mass is

$$E^{\mathrm{CO_2}}_{n,j} = \frac{44}{12} E^{\mathrm{C}}_{n,j}, \tag{G.13}$$

measured in $MtCO_2$ per year. The ratio 44/12 converts carbon mass to CO_2 mass.

Because $Y_{n,j}$ is nominal production value, define production-side real output by

$$Y_{n,j} = c_{n,j} Q^p_{n,j}, \qquad \widehat{Q}^p_{n,j} = \frac{\widehat{Y}_{n,j}}{\widehat{c}_{n,j}}. \tag{G.14}$$

The superscript p distinguishes domestic production from the Armington absorption quantity. For biofuel, $c_{n,\text{bio}} = (1 + \omega^p_{n,\text{bio}}) p_{n,\text{bio}}$; for sectors without a producer wedge, unit cost equals the producer price.

Holding the benchmark emissions intensity of each country–sector cell fixed, counterfactual annual emissions and their change are

$$E^{CO_2\prime}_{n,j} = E^{CO_2}_{n,j} \widehat{Q}^p_{n,j}, \tag{G.15}$$

$$\Delta E^{CO_2}_{n,j} = E^{CO_2}_{n,j} \left(\widehat{Q}^p_{n,j} - 1 \right). \tag{G.16}$$

The global annual change is therefore

$$\Delta E^{CO_2}_{\text{annual}} = \sum_{n \in \mathcal{N}} \sum_{j \in \mathcal{G}} E^{CO_2}_{n,j} \left(\widehat{Q}^p_{n,j} - 1 \right), \tag{G.17}$$

measured in $MtCO_2$ per year. A positive value denotes an increase in annual production-side emissions, and a negative value denotes an annual emissions reduction. Equation (G.17) holds benchmark emissions intensities fixed; changes in combustion technology or fuel-specific emissions intensities are not inferred from changes in sectoral output.

G.5. Monetary Accounting

We express the one-time land-use carbon effect in monetary terms using the social cost of carbon (SCC). Let p^{SCC} denote the SCC in 2020 U.S. dollars per metric ton of CO_2. Moore et al. (2024) construct a synthetic distribution of SCC estimates and report a median value of

$$p^{\text{SCC}} = 185 \qquad \text{2020 U.S. dollars per } tCO_2. \tag{G.18}$$

We use this value for the baseline monetary accounting.

Because one $MgCO_2e$ equals one metric ton of CO_2e, the SCC-equivalent value of global ILUC is

$$\Delta \mathcal{C}^{\text{ILUC}} = p^{\text{SCC}} E^{\text{ILUC}}, \tag{G.19}$$

measured in U.S. dollars when E^{ILUC} is measured in $MgCO_2e$. Equivalently, using the $MtCO_2e$ measure defined in equation (G.11),

$$\Delta \mathcal{C}^{\text{ILUC}} = p^{\text{SCC}} E^{\text{ILUC}}_{\text{Mt}} \times 10^6, \tag{G.20}$$

in U.S. dollars, or

$$\Delta \mathcal{C}^{\text{ILUC}}_{\text{million}} = p^{\text{SCC}} E^{\text{ILUC}}_{\text{Mt}} = 185\, E^{\text{ILUC}}_{\text{Mt}}, \tag{G.21}$$

in millions of 2020 U.S. dollars. This multiplication is a conditional monetary accounting exercise. It treats the reported CO_2-equivalent stock change as a CO_2 pulse at the stated valuation date and does not model the timing or gas composition of emissions. It is not equivalent variation, a net lifecycle benefit, or a complete welfare calculation. The CET monetary figure inherits the service-proxy qualification.

G.6. Energy normalization

For comparison with emissions intensities, we divide the one-time stock loss by an assumed 30 years of incremental fuel energy. With the quantity change $56.7 - 6.55 = 50.15$ billion liters per year and an assumed lower heating value of 21.2 MJ per liter,

$$I_{30} = \frac{10^{12} E^{\mathrm{ILUC}}_{\mathrm{Mt}}}{30 \times 50.15 \times 10^{9} \times 21.2}. \tag{G.22}$$

The units are gCO_2e/MJ. This is an undiscounted normalization of the reported stock loss, conditional on a constant annual increment for 30 years. It does not add cultivation, processing, transport, or fuel-use emissions. The accompanying data file records the denominator, horizon, and heating value for each conversion.

H. Additional Quantitative Results

H.1. Global land and U.S. coarse grains

Tables H.1 and H.2 report land-cover changes and the U.S. coarse-grains response to the final-consumption subsidy. Physical-land specifications and CET service quantities are labeled separately. The geographic results below use the country aggregation of the benchmark accounts.

Table H.1. Global land-use changes: final-consumption subsidy

Land use	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
Coarse grains	17.94	9.68	5.19	5.18	10.29
Oilseeds	-1.23	-0.70	0.75	0.74	-0.27
Sugarcane	0.21	0.11	0.16	0.15	0.12
Other grains	-1.53	-0.95	0.63	0.63	-0.42
Other agriculture	-1.14	-0.68	-0.19	-0.18	-0.25
Pasture	-4.52	-2.02	-1.76	-1.67	-0.80
Managed forest	-6.93	-3.14	-3.62	-3.58	-1.56
Idle land	-2.79	-2.32	-1.15	-1.27	-0.85
Sum of branches	0.01	-0.02	0.01	-0.00	6.26

Notes: Units are million hectares for the physical-land specifications and million benchmark service units for CET. The sum uses rounded entries. Physical-land specifications conserve area within each source cell. †CET constrains a composite of productive land services rather than total physical area.

Table H.2. U.S. coarse-grains responses: final-consumption subsidy

Specification	Output	Land	Yield	Price	Exports	Imports
Fréchet	30.67	32.24	-1.19	4.09	-7.56	71.00
ACET	33.18	17.82	13.04	2.45	-4.66	67.61
Classical Logit	31.36	9.55	19.91	3.62	-6.78	70.02
Entropy Logit	31.38	9.53	19.95	3.62	-6.77	70.02
CET†	33.42	19.01	—	2.30	-4.36	67.19

Notes: Entries are percentage changes. Yield is computed as $100[(1+\Delta Q/100)/(1+\Delta L/100)-1]$ from rounded output and acreage responses; it includes input-intensity and composition effects. †CET land denotes transformed services, so a physical yield is not reported. Export and import changes follow the corresponding country-sector figure data.

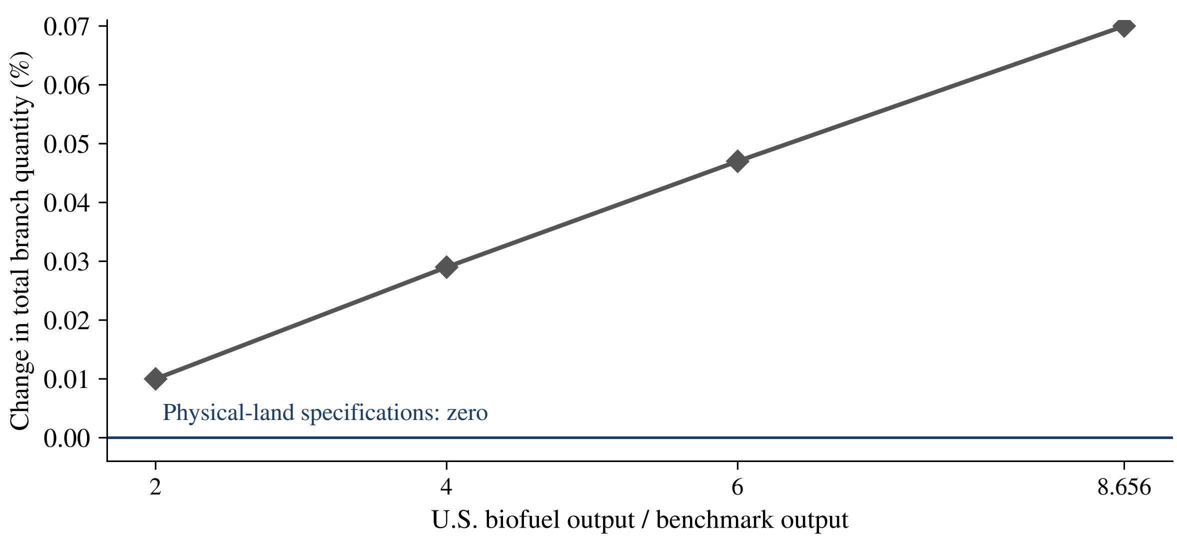

Figure H.1. Non-additivity of CET branches as biofuel production expands

Notes: The vertical axis is the percentage change in the arithmetic sum of CET branch quantities. The zero line records area conservation in the four physical-land specifications. A nonzero CET residual is not physical land creation. Markers correspond to separately solved biofuel expansions.

H.2. Production-subsidy experiment

We use a producer subsidy to obtain the same U.S. biofuel output. Tables H.3–H.5 report the land, U.S. coarse-grains, and carbon outcomes. The physical-land specifications preserve their baseline ordering in land-use carbon. The annual production-based CO_2 response is smaller than under the final-consumption subsidy.

Table H.3. Global land-use changes: production subsidy

Land use	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
Coarse grains	17.81	9.61	5.14	5.14	10.22
Oilseeds	-1.22	-0.69	0.73	0.74	-0.26
Sugarcane	-0.07	-0.04	-0.01	-0.01	-0.03
Other grains	-1.53	-0.95	0.60	0.62	-0.42
Other agriculture	-1.09	-0.64	-0.21	-0.16	-0.22
Pasture	-4.32	-1.90	-1.52	-1.61	-0.59
Managed forest	-6.66	-2.98	-3.45	-3.44	-1.17
Idle land	-2.91	-2.40	-1.28	-1.27	-0.87
Sum of branches	0.01	0.01	-0.00	0.01	6.66

Notes: Units are million hectares for the physical-land specifications and million benchmark service units for CET. The sum uses rounded entries. Physical-land specifications conserve area within each source cell. †CET constrains a composite of productive land services rather than total physical area.

Table H.4. U.S. coarse-grains responses: production subsidy

Specification	Output	Land	Yield	Price	Exports	Imports
Fréchet	30.66	32.18	-1.15	4.06	-7.63	71.25
ACET	33.16	17.77	13.07	2.43	-4.73	67.78
Classical Logit	31.35	9.48	19.98	3.60	-6.86	70.27
Entropy Logit	31.36	9.51	19.95	3.60	-6.85	70.26
CET†	33.40	18.96	—	2.28	-4.43	67.36

Notes: Entries are percentage changes. Yield is computed as $100[(1+\Delta Q/100)/(1+\Delta L/100)-1]$ from rounded output and acreage responses; it includes input-intensity and composition effects. †CET land denotes transformed services, so a physical yield is not reported. Export and import changes follow the corresponding country-sector figure data.

Table H.5. Carbon effects of the production subsidy

Specification	Land-use carbon ($MtCO_2e$)	30-year intensity (gCO_2e/MJ)	Annual CO_2 (Mt/year)
Fréchet	5,133	160.9	-21.2
ACET	2,338	73.3	-10.0
Classical Logit	2,696	84.5	-8.7
Entropy Logit	2,653	83.2	-7.5
CET†	978	30.7	-19.0

Notes: Land-use carbon is a one-time stock loss. Annual CO_2 is the change in production-based fossil-fuel emissions. The intensity divides the stock loss by 30 years of the additional 50.15 billion liters, at an assumed 21.2 MJ per liter. This conversion is not a lifecycle estimate. †CET applies the same carbon factors to transformed branch quantities; it is a diagnostic proxy, not a physically balanced conversion estimate.

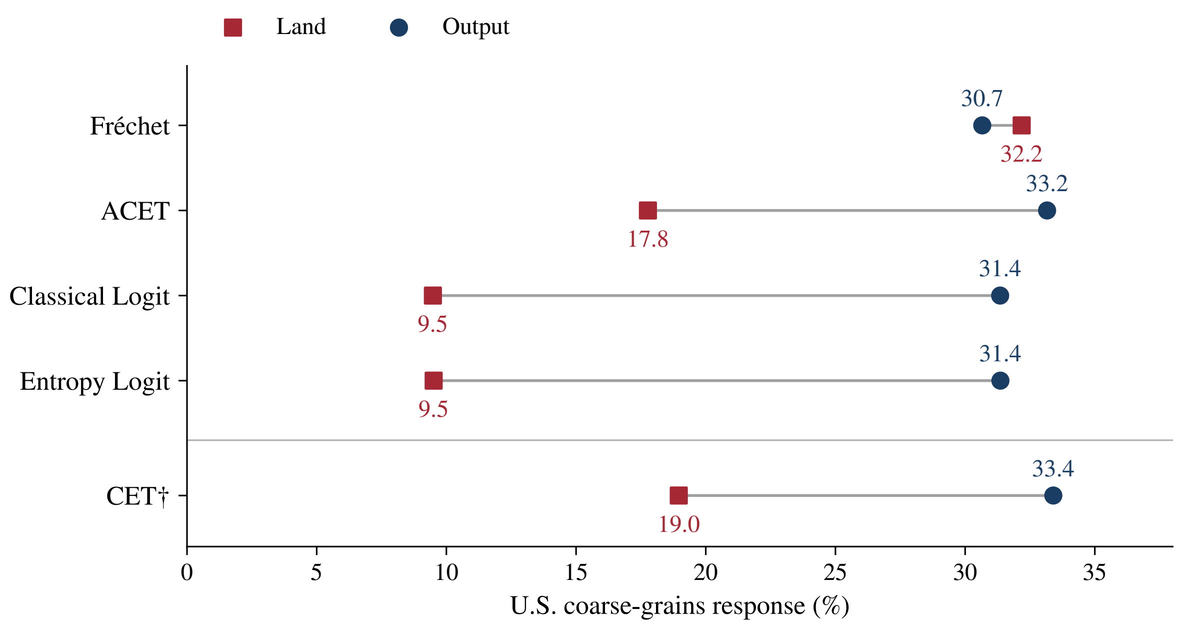

Figure H.2. U.S. coarse-grains output and land under the production subsidy

Notes: Percentage changes. CET land denotes transformed services. U.S. biofuel production is held at the same level.

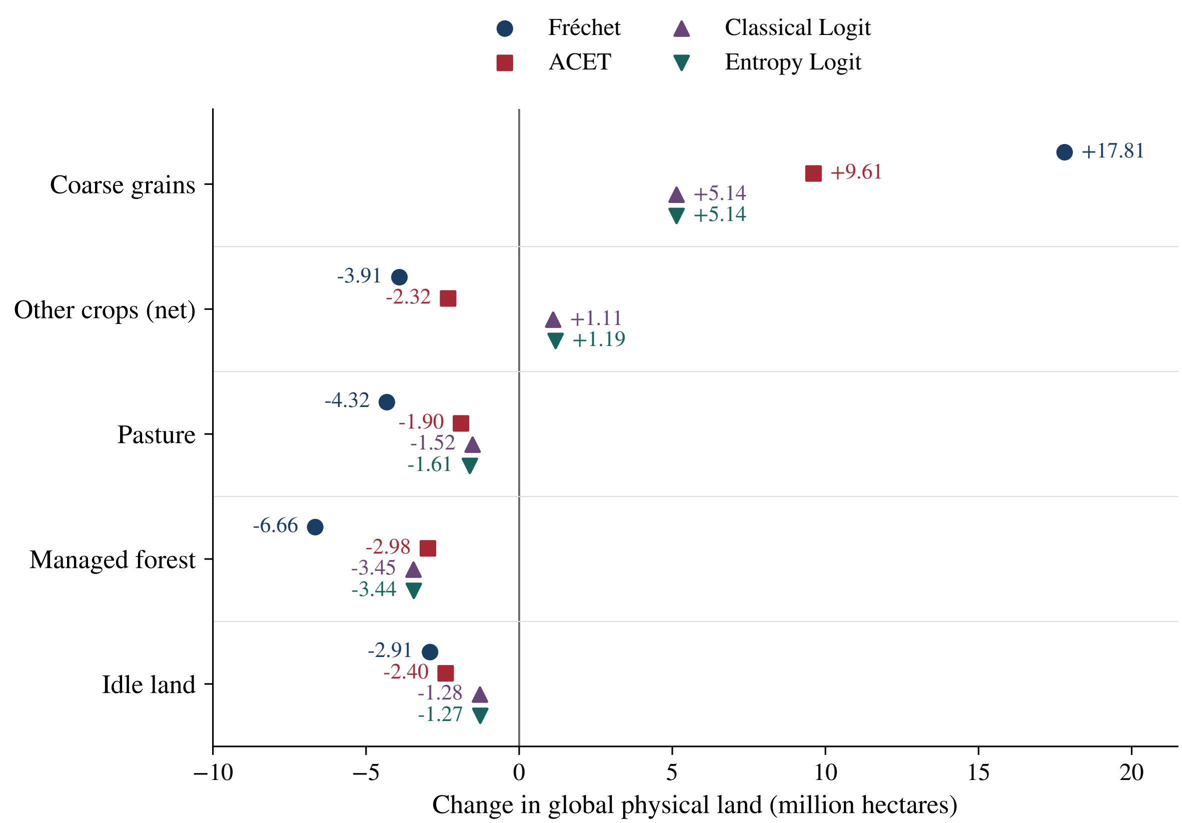

Figure H.3. Physical land reallocation under the production subsidy

Notes: Million hectares. Other cropland sums the four crop categories other than coarse grains. Positive values denote expansion. CET is excluded because its branch quantities do not conserve physical area.

H.3. Comparison with the published benchmark

Table H.6. U.S. coarse-grains responses and the Hertel et al. reference

Specification	Output change (%)	Land change (%)
Hertel et al. (2010)	17.00	16.00
Fréchet	30.67	32.24
ACET	33.18	17.82
Classical Logit	31.36	9.55
Entropy Logit	31.38	9.53
CET†	33.42	19.01

Notes: The reference row reports the values used in the comparison with Hertel et al. (2010). The model rows use the final-consumption-subsidy results. The common biofuel output level allows comparison of the associated commodity-market responses. †CET land denotes transformed services.

Table H.6 compares output and land responses at a common scale of biofuel expansion. Derived feedstock demand, input substitution, and land-cover conversion also depend on the remaining model assumptions, which are not held constant across these studies.

The approximately 800 gCO_2e per MJ of additional annual production reported by Hertel et al. (2010) corresponds to approximately 27 gCO_2e/MJ when divided over 30 years. At the denominator in (G.22), 800 g/MJ corresponds to approximately 851 $MtCO_2e$. Our larger physical-land estimates reflect a different commodity-market response as well as differences in land calibration and carbon factors. DDGS and biodiesel by-products are aggregated into OtherGoods (Online Appendix D); a separate joint-production and grain-feed substitution mechanism is absent from the counterfactual. The reference study attributes a 72 percent reduction in cropland conversion relative to feedstock land to market-mediated responses and by-product use jointly. Quantifying the contribution of the by-product treatment requires a matched counterfactual.

H.4. Country-level coarse-grains responses

The following figures report coarse grains for each region under both subsidy instruments. Every plotted value is labeled. The accompanying CSV contains all sectors represented in the source country-sector figures, including competing crops, livestock, forestry, and biofuel. Global rows are shown for land; market outcomes use the regional observations. Land and trade quantities are distinct from producer prices and production quantities.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
World	+17.94	+9.68	+5.19	+5.18	+10.29
United States	+15.65	+8.65	+4.64	+4.63	+9.23
Canada	+0.93	+0.49	+0.25	+0.25	+0.50
EU27	+0.17	+0.08	+0.04	+0.04	+0.09
Brazil	+0.09	+0.03	+0.03	+0.03	+0.02
Japan	0.00	0.00	0.00	0.00	0.00
China / Hong Kong	+0.14	+0.05	+0.02	+0.02	+0.05
India	0.00	0.00	0.00	0.00	0.00
Latin Am. energy exporters	+0.34	+0.13	+0.10	+0.10	+0.13
Other Latin Am. / Caribbean	+0.25	+0.13	+0.05	+0.05	+0.13
E. Europe / FSU energy exp.	+0.03	+0.01	+0.01	+0.01	+0.01
Other Europe	+0.04	+0.02	+0.01	+0.01	+0.02
MENA energy exporters	+0.09	+0.03	+0.01	+0.01	+0.03
Sub-Saharan energy exp.	+0.07	+0.03	+0.01	+0.01	+0.03
Other Africa	+0.06	+0.02	+0.02	+0.02	+0.02
S./SE Asian energy exp.	+0.02	+0.01	0.00	0.00	+0.01
Other high-income Asia	0.00	0.00	0.00	0.00	0.00
Other Asia	+0.01	0.00	0.00	0.00	0.00
Oceania	+0.04	+0.01	+0.01	+0.01	+0.01

Million hectares; CET: benchmark service units

Figure H.4. Coarse-grains land changes: final-consumption subsidy

Notes: Million hectares; CET uses million benchmark-hectare service units. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
World	+4.86	+2.62	+1.41	+1.41	+2.79
United States	+32.24	+17.82	+9.55	+9.53	+19.01
Canada	+10.33	+5.39	+2.81	+2.80	+5.60
EU27	+0.44	+0.21	+0.11	+0.11	+0.24
Brazil	+0.71	+0.20	+0.20	+0.23	+0.15
Japan	+3.89	+1.36	+0.40	+0.40	+1.32
China / Hong Kong	+0.45	+0.16	+0.06	+0.06	+0.16
India	+0.02	+0.01	0.00	0.00	+0.01
Latin Am. energy exporters	+1.31	+0.49	+0.37	+0.37	+0.50
Other Latin Am. / Caribbean	+3.12	+1.53	+0.67	+0.66	+1.54
E. Europe / FSU energy exp.	+0.05	+0.02	+0.02	+0.02	+0.02
Other Europe	+0.52	+0.18	+0.07	+0.07	+0.19
MENA energy exporters	+1.16	+0.42	+0.12	+0.12	+0.41
Sub-Saharan energy exp.	+0.09	+0.04	+0.02	+0.02	+0.04
Other Africa	+0.57	+0.21	+0.14	+0.14	+0.21
S./SE Asian energy exp.	+0.29	+0.10	+0.03	+0.03	+0.11
Other high-income Asia	+1.88	+0.72	+0.02	+0.02	+0.69
Other Asia	+0.12	+0.04	0.00	+0.01	+0.04
Oceania	+0.97	+0.34	+0.29	+0.29	+0.32

Percentage change from the benchmark

Figure H.5. Coarse-grains land responses: final-consumption subsidy

Notes: Percentage changes in physical acreage, except CET transformed services. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	+4.09	+2.45	+3.62	+3.62	+2.30
Canada	+0.77	+0.42	+0.69	+0.69	+0.42
EU27	+0.07	+0.03	+0.05	+0.05	+0.04
Brazil	+0.15	+0.09	+0.11	+0.11	+0.11
Japan	+0.33	+0.12	+0.32	+0.32	+0.12
China / Hong Kong	+0.12	+0.04	+0.09	+0.09	+0.05
India	+0.03	0.00	0.00	0.00	+0.02
Latin Am. energy exporters	+0.30	+0.12	+0.21	+0.21	+0.12
Other Latin Am. / Caribbean	+0.59	+0.30	+0.53	+0.52	+0.30
E. Europe / FSU energy exp.	+0.02	0.00	0.00	0.00	+0.02
Other Europe	+0.10	+0.04	+0.08	+0.07	+0.05
MENA energy exporters	+0.11	+0.04	+0.08	+0.08	+0.05
Sub-Saharan energy exp.	+0.03	0.00	0.00	0.00	+0.02
Other Africa	+0.07	+0.02	+0.04	+0.03	+0.03
S./SE Asian energy exp.	+0.14	+0.05	+0.12	+0.11	+0.06
Other high-income Asia	+0.47	+0.20	+0.47	+0.46	+0.20
Other Asia	+0.07	+0.02	+0.05	+0.05	+0.03
Oceania	+0.11	+0.03	+0.06	+0.06	+0.04

Percentage change from the benchmark

Figure H.6. Coarse-grains producer prices: final-consumption subsidy

Notes: Percentage changes in producer prices. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	+30.67	+33.18	+31.36	+31.38	+33.42
Canada	+10.26	+9.88	+10.10	+10.10	+9.78
EU27	+0.46	+0.41	+0.44	+0.44	+0.41
Brazil	+0.72	+0.42	+0.65	+0.65	+0.37
Japan	+3.61	+2.37	+3.12	+3.12	+2.21
China / Hong Kong	+0.43	+0.28	+0.37	+0.37	+0.27
India	+0.02	+0.01	+0.01	+0.01	+0.02
Latin Am. energy exporters	+1.15	+0.83	+1.11	+1.11	+0.79
Other Latin Am. / Caribbean	+2.67	+2.54	+2.57	+2.58	+2.49
E. Europe / FSU energy exp.	+0.06	+0.04	+0.05	+0.05	+0.04
Other Europe	+0.48	+0.32	+0.43	+0.43	+0.30
MENA energy exporters	+1.11	+0.73	+1.00	+1.00	+0.69
Sub-Saharan energy exp.	+0.09	+0.08	+0.09	+0.09	+0.08
Other Africa	+0.58	+0.39	+0.53	+0.53	+0.37
S./SE Asian energy exp.	+0.20	+0.15	+0.16	+0.16	+0.15
Other high-income Asia	+1.44	+1.08	+1.14	+1.14	+1.03
Other Asia	+0.08	+0.07	+0.07	+0.07	+0.06
Oceania	+0.93	+0.60	+0.85	+0.85	+0.55

Percentage change from the benchmark

Figure H.7. Coarse-grains production: final-consumption subsidy

Notes: Percentage changes in domestic production quantities. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	-7.56	-4.66	-6.78	-6.77	-4.36
Canada	+23.72	+22.93	+23.44	+23.44	+22.79
EU27	+5.17	+4.58	+5.01	+5.01	+4.52
Brazil	+1.54	+0.90	+1.40	+1.40	+0.82
Japan	+3.86	+3.56	+3.62	+3.63	+3.51
China / Hong Kong	+1.98	+1.25	+1.77	+1.76	+1.17
India	+3.38	+2.98	+3.29	+3.28	+2.93
Latin Am. energy exporters	+1.50	+1.25	+1.51	+1.51	+1.22
Other Latin Am. / Caribbean	+23.28	+22.36	+22.93	+22.93	+22.20
E. Europe / FSU energy exp.	+1.53	+1.11	+1.41	+1.41	+1.07
Other Europe	+1.02	+0.68	+0.91	+0.91	+0.64
MENA energy exporters	+11.54	+10.78	+11.33	+11.33	+10.69
Sub-Saharan energy exp.	+7.01	+6.40	+6.85	+6.85	+6.34
Other Africa	+3.14	+2.10	+2.87	+2.86	+1.99
S./SE Asian energy exp.	+1.68	+1.38	+1.56	+1.57	+1.35
Other high-income Asia	+30.68	+29.32	+30.04	+30.04	+29.17
Other Asia	+1.50	+1.11	+1.39	+1.39	+1.08
Oceania	+1.45	+0.91	+1.33	+1.33	+0.85

Percentage change from the benchmark

Figure H.8. Coarse-grains exports: final-consumption subsidy

Notes: Percentage changes in export quantities. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	+71.00	+67.61	+70.02	+70.02	+67.19
Canada	-5.29	-2.56	-4.54	-4.52	-2.31
EU27	-1.66	-0.97	-1.46	-1.45	-0.92
Brazil	-0.78	-0.32	-0.65	-0.65	-0.29
Japan	-3.20	-1.97	-2.86	-2.85	-1.84
China / Hong Kong	-0.49	-0.27	-0.43	-0.42	-0.26
India	-2.61	-1.58	-2.35	-2.35	-1.47
Latin Am. energy exporters	-7.71	-4.81	-6.97	-6.96	-4.51
Other Latin Am. / Caribbean	-4.42	-2.70	-3.90	-3.90	-2.51
E. Europe / FSU energy exp.	-1.54	-0.94	-1.38	-1.38	-0.88
Other Europe	-2.77	-1.71	-2.48	-2.47	-1.61
MENA energy exporters	-2.70	-1.66	-2.41	-2.41	-1.56
Sub-Saharan energy exp.	-2.55	-1.54	-2.27	-2.27	-1.44
Other Africa	-2.77	-1.71	-2.49	-2.49	-1.59
S./SE Asian energy exp.	-1.08	-0.65	-0.95	-0.95	-0.60
Other high-income Asia	-1.78	-1.10	-1.58	-1.58	-1.03
Other Asia	-1.54	-0.93	-1.37	-1.37	-0.88
Oceania	-4.76	-2.95	-4.32	-4.31	-2.77

Percentage change from the benchmark

Figure H.9. Coarse-grains imports: final-consumption subsidy

Notes: Percentage changes in import quantities. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
World	+17.81	+9.61	+5.14	+5.14	+10.22
United States	+15.62	+8.63	+4.60	+4.62	+9.21
Canada	+0.82	+0.43	+0.22	+0.22	+0.44
EU27	+0.17	+0.08	+0.06	+0.04	+0.09
Brazil	+0.11	+0.04	+0.03	+0.03	+0.04
Japan	0.00	0.00	0.00	0.00	0.00
China / Hong Kong	+0.14	+0.05	+0.02	+0.02	+0.05
India	0.00	0.00	0.00	0.00	0.00
Latin Am. energy exporters	+0.34	+0.13	+0.10	+0.10	+0.13
Other Latin Am. / Caribbean	+0.25	+0.12	+0.05	+0.05	+0.12
E. Europe / FSU energy exp.	+0.02	+0.01	+0.01	+0.01	+0.01
Other Europe	+0.04	+0.02	+0.01	+0.01	+0.02
MENA energy exporters	+0.09	+0.03	+0.01	+0.01	+0.03
Sub-Saharan energy exp.	+0.06	+0.03	+0.01	+0.01	+0.02
Other Africa	+0.06	+0.02	+0.02	+0.02	+0.02
S./SE Asian energy exp.	+0.02	+0.01	0.00	0.00	+0.01
Other high-income Asia	0.00	0.00	0.00	0.00	0.00
Other Asia	+0.01	0.00	0.00	0.00	0.00
Oceania	+0.04	+0.01	+0.01	+0.01	+0.01

Million hectares; CET: benchmark service units

Figure H.10. Coarse-grains land changes: production subsidy

Notes: Million hectares; CET uses million benchmark-hectare service units. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
World	+4.83	+2.60	+1.39	+1.39	+2.77
United States	+32.18	+17.77	+9.48	+9.51	+18.96
Canada	+9.14	+4.74	+2.48	+2.48	+4.93
EU27	+0.44	+0.21	+0.14	+0.11	+0.24
Brazil	+0.84	+0.30	+0.22	+0.21	+0.30
Japan	+3.87	+1.35	+0.40	+0.40	+1.32
China / Hong Kong	+0.45	+0.16	+0.05	+0.06	+0.16
India	+0.01	+0.01	+0.01	0.00	+0.01
Latin Am. energy exporters	+1.31	+0.49	+0.38	+0.38	+0.50
Other Latin Am. / Caribbean	+3.10	+1.52	+0.66	+0.67	+1.53
E. Europe / FSU energy exp.	+0.05	+0.02	+0.01	+0.02	+0.02
Other Europe	+0.52	+0.18	+0.09	+0.07	+0.19
MENA energy exporters	+1.16	+0.42	+0.13	+0.12	+0.41
Sub-Saharan energy exp.	+0.08	+0.04	+0.01	+0.02	+0.03
Other Africa	+0.57	+0.20	+0.14	+0.14	+0.21
S./SE Asian energy exp.	+0.29	+0.10	+0.03	+0.03	+0.11
Other high-income Asia	+1.87	+0.71	+0.01	+0.02	+0.68
Other Asia	+0.12	+0.05	0.00	0.00	+0.05
Oceania	+0.97	+0.33	+0.29	+0.29	+0.33

Percentage change from the benchmark

Figure H.11. Coarse-grains land responses: production subsidy

Notes: Percentage changes in physical acreage, except CET transformed services. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	+4.06	+2.43	+3.60	+3.60	+2.28
Canada	+0.66	+0.35	+0.59	+0.58	+0.34
EU27	+0.05	+0.01	+0.02	+0.02	+0.02
Brazil	+0.05	-0.01	+0.01	+0.01	0.00
Japan	+0.32	+0.10	+0.30	+0.30	+0.11
China / Hong Kong	+0.10	+0.02	+0.07	+0.07	+0.03
India	0.00	-0.02	-0.03	-0.03	-0.01
Latin Am. energy exporters	+0.28	+0.10	+0.18	+0.18	+0.10
Other Latin Am. / Caribbean	+0.57	+0.27	+0.50	+0.50	+0.28
E. Europe / FSU energy exp.	-0.01	-0.03	-0.03	-0.03	-0.02
Other Europe	+0.08	+0.02	+0.05	+0.05	+0.02
MENA energy exporters	+0.08	+0.01	+0.05	+0.05	+0.02
Sub-Saharan energy exp.	-0.01	-0.04	-0.04	-0.04	-0.03
Other Africa	+0.04	-0.01	0.00	0.00	0.00
S./SE Asian energy exp.	+0.13	+0.04	+0.10	+0.10	+0.04
Other high-income Asia	+0.45	+0.19	+0.45	+0.44	+0.18
Other Asia	+0.06	+0.01	+0.04	+0.03	+0.02
Oceania	+0.08	+0.01	+0.04	+0.04	+0.02

Percentage change from the benchmark

Figure H.12. Coarse-grains producer prices: production subsidy

Notes: Percentage changes in producer prices. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	+30.66	+33.16	+31.35	+31.36	+33.40
Canada	+9.16	+8.75	+9.01	+9.00	+8.65
EU27	+0.46	+0.41	+0.45	+0.44	+0.41
Brazil	+0.85	+0.55	+0.77	+0.77	+0.52
Japan	+3.60	+2.36	+3.11	+3.11	+2.21
China / Hong Kong	+0.42	+0.28	+0.37	+0.37	+0.27
India	+0.01	+0.01	+0.01	+0.01	+0.01
Latin Am. energy exporters	+1.17	+0.85	+1.13	+1.13	+0.81
Other Latin Am. / Caribbean	+2.67	+2.54	+2.58	+2.58	+2.49
E. Europe / FSU energy exp.	+0.05	+0.04	+0.05	+0.05	+0.03
Other Europe	+0.49	+0.32	+0.44	+0.43	+0.31
MENA energy exporters	+1.11	+0.74	+1.01	+1.00	+0.70
Sub-Saharan energy exp.	+0.09	+0.08	+0.09	+0.09	+0.08
Other Africa	+0.58	+0.39	+0.53	+0.53	+0.37
S./SE Asian energy exp.	+0.20	+0.16	+0.16	+0.16	+0.15
Other high-income Asia	+1.43	+1.07	+1.14	+1.14	+1.03
Other Asia	+0.09	+0.07	+0.07	+0.07	+0.07
Oceania	+0.93	+0.60	+0.85	+0.85	+0.56

Percentage change from the benchmark

Figure H.13. Coarse-grains production: production subsidy

Notes: Percentage changes in domestic production quantities. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	-7.63	-4.73	-6.86	-6.85	-4.43
Canada	+24.01	+23.11	+23.71	+23.71	+22.97
EU27	+5.17	+4.57	+5.01	+5.00	+4.51
Brazil	+1.76	+1.11	+1.61	+1.60	+1.05
Japan	+3.83	+3.54	+3.60	+3.60	+3.48
China / Hong Kong	+1.98	+1.24	+1.77	+1.77	+1.17
India	+3.38	+2.98	+3.30	+3.29	+2.94
Latin Am. energy exporters	+1.49	+1.25	+1.52	+1.52	+1.22
Other Latin Am. / Caribbean	+23.14	+22.23	+22.80	+22.81	+22.07
E. Europe / FSU energy exp.	+1.53	+1.12	+1.42	+1.42	+1.08
Other Europe	+1.00	+0.66	+0.90	+0.89	+0.63
MENA energy exporters	+11.52	+10.76	+11.31	+11.31	+10.67
Sub-Saharan energy exp.	+7.03	+6.42	+6.86	+6.87	+6.36
Other Africa	+3.15	+2.11	+2.89	+2.88	+2.00
S./SE Asian energy exp.	+1.67	+1.37	+1.55	+1.55	+1.34
Other high-income Asia	+30.64	+29.29	+30.01	+30.01	+29.13
Other Asia	+1.49	+1.10	+1.37	+1.38	+1.07
Oceania	+1.45	+0.91	+1.33	+1.33	+0.86

Percentage change from the benchmark

Figure H.14. Coarse-grains exports: production subsidy

Notes: Percentage changes in export quantities. Regional codes follow Table F.3. Values are reproduced at their reported precision.

	Fréchet	ACET	Classical Logit	Entropy Logit	CET†
United States	+71.25	+67.78	+70.27	+70.26	+67.36
Canada	-7.26	-4.50	-6.50	-6.50	-4.26
EU27	-1.59	-0.91	-1.41	-1.40	-0.86
Brazil	-0.91	-0.45	-0.78	-0.78	-0.43
Japan	-3.18	-1.95	-2.85	-2.84	-1.83
China / Hong Kong	-0.42	-0.23	-0.36	-0.36	-0.22
India	-2.63	-1.59	-2.37	-2.36	-1.48
Latin Am. energy exporters	-7.69	-4.79	-6.95	-6.95	-4.50
Other Latin Am. / Caribbean	-4.40	-2.69	-3.89	-3.89	-2.50
E. Europe / FSU energy exp.	-1.55	-0.95	-1.39	-1.39	-0.89
Other Europe	-2.74	-1.69	-2.46	-2.46	-1.59
MENA energy exporters	-2.69	-1.66	-2.40	-2.40	-1.55
Sub-Saharan energy exp.	-2.58	-1.58	-2.31	-2.31	-1.48
Other Africa	-2.78	-1.72	-2.50	-2.50	-1.61
S./SE Asian energy exp.	-1.07	-0.63	-0.93	-0.93	-0.59
Other high-income Asia	-1.75	-1.06	-1.55	-1.55	-0.99
Other Asia	-1.47	-0.87	-1.30	-1.30	-0.81
Oceania	-4.74	-2.93	-4.30	-4.29	-2.75

Percentage change from the benchmark

Figure H.15. Coarse-grains imports: production subsidy

Notes: Percentage changes in import quantities. Regional codes follow Table F.3. Values are reproduced at their reported precision.

I. Additional Land-Response and Carbon Calculations

I.1. Land-response coefficients

Table I.1 changes the broad-land coefficient while keeping the crop coefficient at 1.38. Fréchet's carbon loss falls from 5,287 to 5,250 $MtCO_2e$ as the upper coefficient rises to 1.38. ACET's rises from 2,423 to 2,639 $MtCO_2e$.

Table I.1. Responses to the broad-land coefficient

		U.S. coarse-grains acreage (%)		Carbon loss ($MtCO_2e$)	
ν_1	m_1	Fréchet	ACET	Fréchet	ACET
1.10	0.091	32.24	17.82	5,287	2,423
1.18	0.153	32.28	17.97	5,282	2,492
1.28	0.219	32.33	18.16	5,270	2,571
1.38	0.275	32.37	18.32	5,250	2,639

Notes: The crop coefficient is 1.38 throughout. The broad-land coefficient takes the value in the first column in each specification. $m_1 = (\nu_1 - 1)/\nu_1$ is the Fréchet conditional marginal-to-average productivity ratio. Carbon losses use the baseline factors, including zero direct carbon for idle land. All calculations use the same U.S. biofuel expansion and final-consumption subsidy.

Table I.2 reports the joint coefficient changes under both specifications. Fréchet at $(2.10, 2.38)$ and baseline ACET satisfy $\nu_m^F - 1 = \nu_m^A$ at each nest. Their U.S. coarse-grains output responses are within 0.06 percentage points, but Fréchet converts 15.10 million hectares to cropland against ACET's 7.47 million hectares. Their carbon ratio is 2.03. Comparing the two specifications at common allocation coefficients instead gives ratios of 2.18 at $(1.10, 1.38)$, 1.91 at $(1.50, 1.66)$, and 1.67 at $(2.10, 2.38)$. Moving between coefficient pairs changes both allocation responsiveness and the strength of Fréchet selection.

The two new Fréchet exports identify the active specification but omit the coefficient values. We assign them to the two requested pairs using the implied upper-to-lower nesting ratio in their reported land shares. The data documentation records the assignment and its verification.

Table I.2. Joint coefficient changes under Fréchet and ACET

	Fréchet			ACET		
	Baseline	Intermediate	Higher	Baseline	Intermediate	Higher
Broad-land coefficient	1.10	1.50	2.10	1.10	1.50	2.10
Crop coefficient	1.38	1.66	2.38	1.38	1.66	2.38
Broad-land marginal/average ratio	0.091	0.333	0.524	–	–	–
Crop marginal/average ratio	0.275	0.398	0.580	–	–	–
U.S. coarse-grains output (%)	30.67	31.74	33.12	33.18	33.57	34.20
U.S. coarse-grains acreage (%)	32.24	32.75	33.48	17.82	19.73	22.78
U.S. coarse-grains price (%)	4.09	3.38	2.49	2.45	2.20	1.81
Global coarse-grains expansion (Mha)	17.94	18.01	18.12	9.68	10.67	12.22
Global cropland expansion (Mha)	14.25	14.66	15.10	7.47	8.74	10.17
Global managed-forest loss (Mha)	6.93	6.75	6.35	3.14	3.48	3.73
Global pasture loss (Mha)	4.52	4.34	4.13	2.02	2.24	2.44
Global idle-land loss (Mha)	2.79	3.57	4.62	2.32	3.02	4.01
Land-use carbon loss ($MtCO_2e$)	5,287	5,174	4,916	2,423	2,707	2,935
Annual CO_2 change ($MtCO_2$/year)	-70.7	-70.1	-70.0	-59.2	-60.3	-61.7

Notes: All land quantities are physical hectares. Cropland expansion adds signed changes across the five crops. Losses are positive amounts. The ratio rows apply to Fréchet and hold the other nest and input intensity fixed. Comparing higher-coefficient Fréchet with baseline ACET implements $\nu_m^F - 1 = \nu_m^A$; comparing the two higher-coefficient columns instead holds their allocation coefficients equal.

I.2. Positive carbon factors for idle land

We apply positive idle-land carbon factors to the baseline physical allocations. The pasture case uses the country–AEZ pasture factor for both land losses and gains. For a forest weight w, the mixture uses $(1-w)\texttt{EPS} + w\texttt{EFL}$ for losses and $(1-w)\texttt{EPS} + w\texttt{EFG}$ for gains, with $w = 0.25$ and $w = 0.50$. All other land-cover factors are unchanged. These weights are accounting assumptions rather than measured land-cover shares within idle land.

Table I.3. Land-use carbon under positive idle-land factors

Idle-land carbon assumption	Fréchet	ACET	Classical Logit	Entropy Logit
Zero direct carbon	5,287	2,423	2,743	2,719
Pasture factors	5,575	2,666	2,869	2,853
75% pasture + 25% forest factors	5,974	3,008	3,059	3,047
50% pasture + 50% forest factors	6,373	3,351	3,249	3,242

Notes: One-time carbon losses in $MtCO_2e$. Every row uses the baseline land allocation, production responses, and coefficients $(1.10, 1.38)$. Only the idle-land carbon factors change. Pasture factors use `EPS` for both losses and gains. The mixtures use `EFL` for the forest share of losses and `EFG` for the forest share of gains, by country and AEZ. The mixture weights are accounting assumptions, not estimates of the ecological composition of idle land. CET is excluded because its branch-based calculation uses productive services rather than physical hectares.

Under the 50–50 mixture, ACET's carbon loss exceeds both Logit estimates. Fréchet is the largest at 6,373 $MtCO_2e$, compared with 3,242 $MtCO_2e$ under Entropy Logit, a ratio of 1.97. Physical acreage, commodity-market outcomes, and annual fossil-fuel emissions are unchanged. These accounting cases are separate from the higher-coefficient Fréchet runs.

I.3. Shock size, within-cropland responses, and trade

Figure I.1 reports the acreage responses associated with the carbon paths in the main text. Figure I.2 changes only the within-cropland coefficient, with the upper coefficient fixed at 1.10. Table I.4 gives the trade parameters used for Figure I.3.

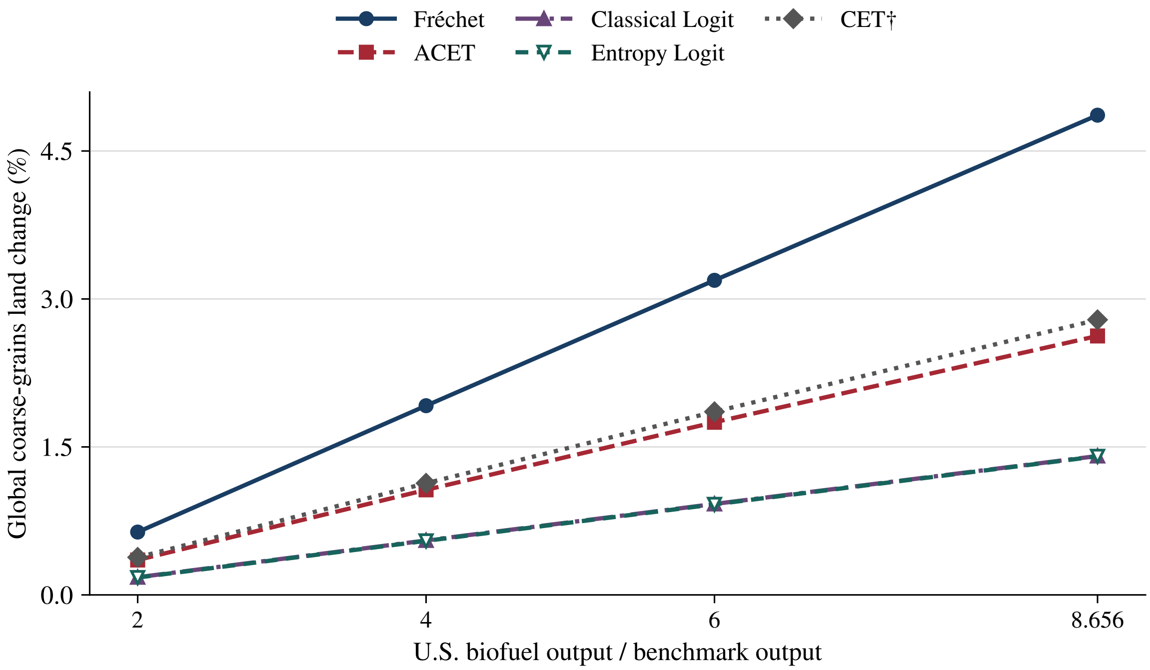

Figure I.1. Coarse-grains land under alternative biofuel expansions

Notes: Each marker is a separately solved final-consumption-subsidy counterfactual. All parameters are fixed. †CET denotes productive land-service quantities; the other specifications report physical acreage.

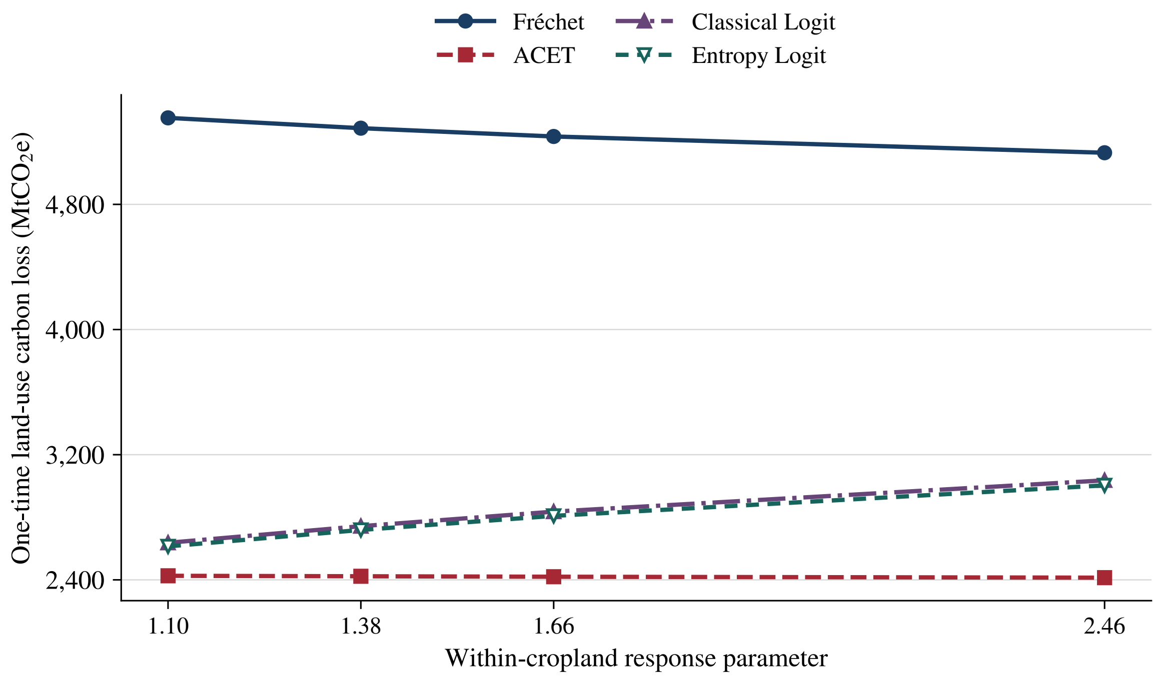

Figure I.2. Land-use carbon and the within-cropland response parameter

Notes: The upper-nest coefficient remains 1.10. The baseline crop coefficient is 1.38. Markers show the four reported calibrations, ordered by their numerical parameter values. Physical-land specifications only.

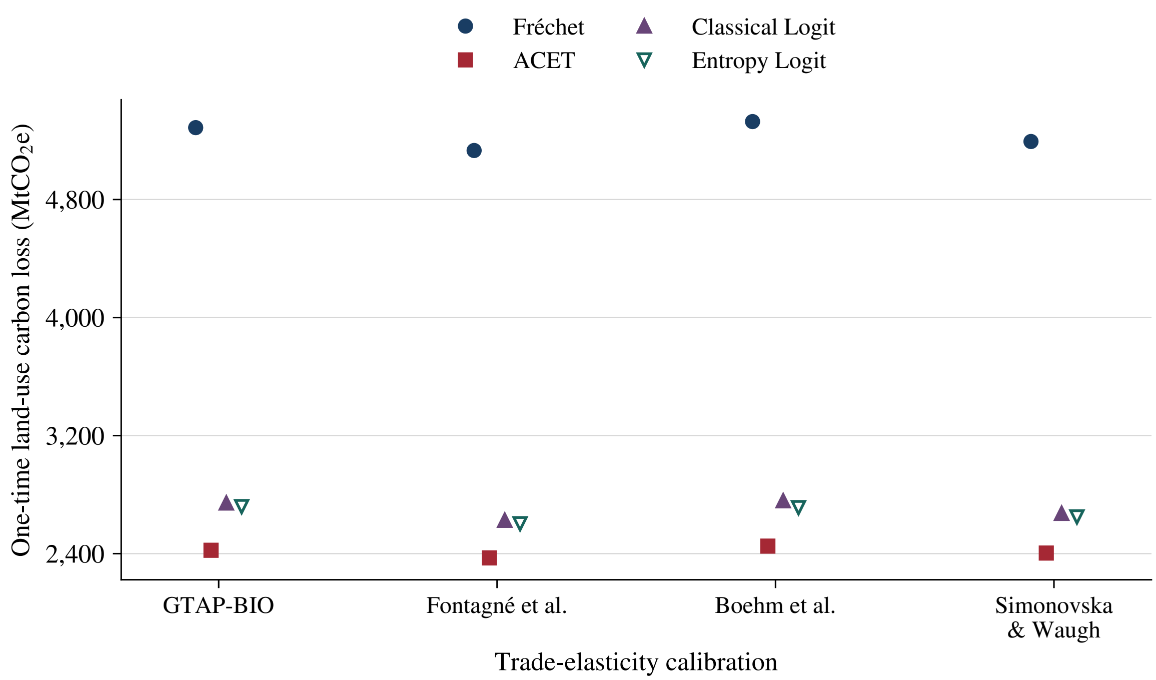

Figure I.3. Land-use carbon under alternative trade calibrations

Notes: Each marker is a separate calibration. Discrete alternatives are not connected by lines. Physical-land specifications only. All use the baseline biofuel expansion and land-response coefficients.

Table I.4. Alternative CES sourcing parameters

Sector	GTAP-BIO	Fontagné et al.	Boehm et al.	Simonovska–Waugh
Coarse grains	2.60	6.12*	3.12	5.14
Oilseeds	4.90	3.05	3.12	5.14
Sugarcane	5.40	3.33	3.12	5.14
Other grains	9.06	6.12	3.12	5.14
Other agriculture	4.14	4.89	3.12	5.14
Livestock	4.17	7.39	3.12	5.14
Forestry	5.00	3.53	3.12	5.14
Biofuel	5.78	6.12*	3.12	5.14
Other energy	7.29	8.88	3.12	5.14
Other goods	6.63	6.17	3.12	5.14

Notes: Entries are CES sourcing parameters σ_j. We use $\sigma = 1 + \theta$, where θ is the magnitude of the trade-flow elasticity: $1 + 2.12 = 3.12$ for Boehm et al. and $1 + 4.14 = 5.14$ for Simonovska–Waugh. *Coarse grains uses the other-grains estimate; biofuel uses the grain-ethanol estimate. Sources: Fontagné et al. (2022); Boehm et al. (2023); Simonovska and Waugh (2014) and the GTAP-BIO calibration.

References

Alvarez, F., Lucas, Robert E., J., 2007. General equilibrium analysis of the eaton–kortum model of international trade. Journal of Monetary Economics 54, 1726–1768. doi:10.1016/j.jmoneco.2006.07.006.

Armington, P.S., 1969. A theory of demand for products distinguished by place of production. IMF Staff Papers 16, 159–178.

Birur, D.K., Hertel, T.W., Tyner, W.E., 2008. Introducing Liquid Biofuels into the GTAP Data Base. GTAP Research Memorandum 11. Center for Global Trade Analysis, Purdue University.

Boehm, C.E., Levchenko, A.A., Pandalai-Nayar, N., 2023. The long and short (run) of trade elasticities. American Economic Review 113, 861–905. doi:10.1257/aer.20210225.

Carpentier, A., Letort, É., 2014. Multicrop production models with multinomial logit acreage shares. Environmental and Resource Economics 59, 537–559. doi:10.1007/s10640-013-9748-6.

Costinot, A., Donaldson, D., Smith, C.B., 2016. Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. Journal of Political Economy 124, 205–248. doi:10.1086/684719.

Dekle, R., Eaton, J., Kortum, S., 2008. Global rebalancing with gravity: Measuring the burden of adjustment. IMF Staff Papers 55, 511–540. doi:10.1057/imfsp.2008.17.

Dimaranan, B.V. (Ed.), 2006. Global Trade, Assistance, and Production: The GTAP 6 Data Base. Center for Global Trade Analysis, Purdue University, West Lafayette, IN.

Farrokhi, F., Pellegrina, H.S., 2023. Trade, technology, and agricultural productivity. Journal of Political Economy 131, 2509–2555. doi:10.1086/724319.

Feenstra, R.C., Inklaar, R., Timmer, M.P., 2015. The next generation of the Penn World Table. American Economic Review 105, 3150–3182. doi:10.1257/aer.20130954.

Fontagné, L., Guimbard, H., Orefice, G., 2022. Tariff-based product-level trade elasticities. Journal of International Economics 137, 103593. doi:10.1016/j.jinteco.2022.103593.

Fujimori, S., Hasegawa, T., Masui, T., Takahashi, K., 2014. Land use representation in a global CGE model for long-term simulation: CET vs. Logit functions. Food Security 6, 685–699. doi:10.1007/s12571-014-0375-z.

Golub, A.A., Hertel, T.W., 2012. Modeling land-use change impacts of biofuels in the GTAP-BIO framework. Climate Change Economics 3, 1250015. doi:10.1142/S2010007812500157.

Hertel, T.W., Golub, A.A., Jones, A.D., O'Hare, M., Plevin, R.J., Kammen, D.M., 2010. Effects of U.S. maize ethanol on global land use and greenhouse gas emissions: Estimating market-mediated responses. BioScience 60, 223–231. doi:10.1525/bio.2010.60.3.8.

Hertel, T.W., Tsigas, M.E., 1988. Tax policy and U.S. agriculture: A general equilibrium analysis. American Journal of Agricultural Economics 70, 289–302. doi:10.2307/1242069.

Keeney, R., Hertel, T.W., 2009. The indirect land use impacts of United States biofuel policies: The importance of acreage, yield, and bilateral trade responses. American Journal of Agricultural Economics 91, 895–909. doi:10.1111/j.1467-8276.2009.01308.x.

Moore, F.C., Drupp, M.A., Rising, J., Dietz, S., Rudik, I., Wagner, G., 2024. Synthesis of evidence yields high social cost of carbon due to structural model variation and uncertainties. Proceedings of the National Academy of Sciences 121, e2410733121. doi:10.1073/pnas.2410733121.

Sands, R.D., Leimbach, M., 2003. Modeling agriculture and land use in an integrated assessment framework. Climatic Change 56, 185–210. doi:10.1023/A:1021344614845.

Simonovska, I., Waugh, M.E., 2014. The elasticity of trade: Estimates and evidence. Journal of International Economics 92, 34–50. doi:10.1016/j.jinteco.2013.10.001.

Sotelo, S., 2020. Domestic trade frictions and agriculture. Journal of Political Economy 128, 2690–2738. doi:10.1086/706859.

Taheripour, F., Zhao, X., Horridge, M., Farrokhi, F., Tyner, W.E., 2020. Land use in computable general equilibrium models. Journal of Global Economic Analysis 5, 63–109. doi:10.21642/JGEA.050202AF.

Train, K.E., 2009. Discrete Choice Methods with Simulation. 2 ed., Cambridge University Press, Cambridge.

Zhao, X., Calvin, K.V., Wise, M.A., 2020a. The critical role of conversion cost and comparative advantage in modeling agricultural land use change. Climate Change Economics 11, 2050004. doi:10.1142/S2010007820500049.

Zhao, X., van der Mensbrugghe, D.Y., Keeney, R.M., Tyner, W.E., 2020b. Improving the way land use change is handled in economic models. Economic Modelling 84, 13–26. doi:10.1016/j.econmod.2019.03.003.