

Narrower Portfolios, Shared Mills: Non-random Restructuring of Corporate Palm Oil Mill Disclosures

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Title

**Narrower Portfolios, Shared Mills: Non-random Restructuring of Corporate Palm Oil
Mill Disclosures**

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Abstract

Location-specific value-chain disclosure is expected to support corporate accountability,
nature-related decision-making, and industry-wide sustainability. This study analyzed mill
disclosures from 20 manufacturers that use palm oil; the findings showed that companies'
sourcing portfolios narrowed overall and became increasingly concentrated on widely
connected mills. This restructuring may improve oversight and reduce governance costs for
individual companies, while potentially shifting excluded mills toward less-scrutinized buyers
and limiting industry-wide sustainability gains.

Main text

Transforming business practices and supply chains is increasingly seen as essential to addressing environmental degradation. This shift reflects growing recognition of the limitations of approaches focused solely on regulating environmentally harmful activities^{1,2}. Consequently, emerging disclosure frameworks and due-diligence regulations require companies to identify environmental risks and impacts throughout their value chains. For example, the Taskforce on Nature-related Financial Disclosures (TNFD) recommends disclosing material nature-related dependencies, impacts, risks, and opportunities; at the same time, the European Union Deforestation Regulation (EUDR) requires traceability and due diligence for selected forest-risk commodities^{2,3}. Detailed disclosures remain concentrated among leading firms; however, their extensive supply chains provide considerable “network power” to propagate standards¹.

Environmental impacts often depend on where activities occur, and the broader shift towards value-chain accountability has therefore increased demand for spatially explicit information on operations and sourcing locations⁴. These demands may incentivize companies to simplify or restructure sourcing portfolios, for example by reducing exposure to environmentally or institutionally high-risk regions⁵. Consequently, corporate sourcing portfolios may contract and converge around suppliers that are easier to monitor, without necessarily improving sustainability across the overall industry⁵.

The oil palm industry provides a particularly relevant case for examining such changes. As in other land-based agricultural sectors, environmental impacts and dependencies in the oil palm industry can vary substantially across sourcing landscapes, making location-specific information particularly important. Oil palm accounts for more than one-third of global vegetable-oil production and remains a major driver of deforestation and biodiversity loss⁶;

consequently, palm oil has become a prominent focus of zero-deforestation commitments^{3,7}. Since approximately 2018, leading downstream companies have published lists of palm oil mills in their supply chains to improve transparency and demonstrate progress towards these commitments^{8,9}. Importantly, fresh fruit bunches must be processed within 24–48 hours of harvest, meaning that mill locations provide a geographically informative proxy for sourcing landscapes^{10,11}. These disclosures therefore provide a rare opportunity to examine how corporate sourcing networks change over time^{7,11}.

This study compared company–mill networks constructed from publicly disclosed mill lists for 20 manufacturing companies across two periods: 2020–2021 (P1) and 2023–2024 (P2) (Supplementary Table 1). For each period, we constructed a binary mill-by-company matrix in which each cell indicated whether a given mill appeared in a company’s disclosed mill list. We restricted the analysis to mills appearing in both periods, resulting in networks of 20 companies and 1,863 mills.

In the P1 network, each company was linked to an average of $1,273 \pm 287$ of the 1,863 mills, showing that individual company-mill lists were extensive and overlapped substantially. Conversely, in P2, the mean number of linked mills decreased by 17.0%, to $1,056 \pm 549$ (Supplementary Table 2). This decline was driven largely by 4 of the 20 companies that shortened their mill lists by more than 70% (Figures 1A–C). None of these companies reported a comparable reduction in palm oil consumption volume (Supplementary Table 1).

The extensive overlap in P1 may partly reflect the highly concentrated global palm oil trade, in which a small number of major traders aggregate supplies from numerous mills^{8,12}. Public mill lists of downstream companies often draw on information provided by traders and other intermediaries through which they source palm oil^{9,12}. In some cases, suppliers provide broader global mill lists rather than lists corresponding specifically to a company’s actual

supply, as explicitly reported by PZ Cussons (Supplementary Note 1). We therefore interpret network links as disclosed potential supply-chain connections, not necessarily transaction-specific mill-to-company flows^{9,12}.

Among these four companies, Mars and Unilever explicitly identified reductions in the number of mills as part of broader strategies to simplify their supply chains and strengthen sustainability governance. Together, their public statements describe shifts toward direct sourcing from selected mills, concentration of purchases among fewer suppliers, and the establishment of more segregated upstream pathways. Mars adopted the UniFuji 1:1:1 model, which exemplifies the latter approach; this model links a single plantation, mill, and refinery in a segregated supply chain rather than sourcing through a broad pool of mills (Supplementary Note 1).

While this trend is currently concentrated in only 4 of the 20 companies, and only 2 have explicitly confirmed it as a formal strategy, it may signal an emerging industry-wide trend. Such shifts may reduce both the costs of monitoring extensive supplier networks and the reputational risks associated with sustainability failures upstream¹³. Moreover, given strong mimetic pressures to resolve strategic uncertainty¹⁴ and practical pathways to simplify and strengthen control over upstream supply chains, such restructuring may spread across the sector as firms engage in selective mimicry to ensure supplier compliance¹⁵.

We quantified convergence in companies' sourcing networks using mill-side degree centralization to test whether the observed contraction of company–mill lists was accompanied by convergence around a smaller set of shared mills. A mill's degree is the number of companies linked to it; mill-side degree centralization measures the concentration of company–mill connections among a few high-degree mills¹⁶. In P1, mill-side degree centralization was 0.334 and did not differ significantly from the c0 null expectation. The c0

null model preserved matrix dimensions and each company's degree (null mean $\pm$ SD = 0.301 $\pm$ 0.026; empirical P = 0.373); however, in P2, degree centralization increased to 0.456 and was significantly higher than the null expectation (0.304 $\pm$ 0.031; empirical P = 0.001) (Supplementary Table 2).

The P2 network arose through changes to the P1 network; therefore, we additionally conducted a P1-to-P2 randomization analysis. Randomized P2 networks were generated by indiscriminately removing and adding links to the P1 network while maintaining each company's observed number of link losses and additions. Mean mill-side degree centralization across the randomized P2 networks was 0.334 $\pm$ 0.032, which was substantially lower than the observed P2 value (empirical P = 0.001). These results indicate that the observed restructuring was non-random and produced stronger convergence than anticipated under random link turnover. The mill degree-rank (Figure 1B) further shows a more polarized P2 degree distribution than expected from randomization, with more connected high-degree mills and less connected low-degree mills. Consistent with this link concentration among high-degree mills, companies that reduced their mill lists most sharply exhibited the largest increases in the proportion of high-degree mills (Spearman's ρ = -0.964, P < 0.0001; Figures 1C, D).

We fitted separate generalized linear mixed models for the retention of P1 connections and the addition of new connections in P2 to identify factors associated with the observed non-random link turnover. Models included company identity as a fixed effect and country and mill identity as random intercepts. Mill-level predictors were mill degree in P1, Roundtable on Sustainable Palm Oil (RSPO) certification status, recent deforestation within 20 km of the mill, and the biodiversity importance of the surrounding area, measured using the Species Threat Abatement and Restoration (STAR) metric¹⁷.

The findings were broadly consistent between the retention and addition models (Figure 2). Deforestation and STAR showed no association with link retention or addition, despite many companies committing publicly to reduce deforestation and biodiversity loss⁷. Environmental risk may influence mill addition only in extreme cases, as the observed proportions of link addition declined slightly at the highest values of both variables (Supplementary Figure 1). These conclusions were robust to alternative 10- and 50-km radii and to models separating country-level from within-country variation in deforestation, thereby testing whether country-level effects masked mill-level associations (Supplementary Tables 3–10).

Conversely, RSPO certification status and the supply-chain model showed clear associations with link turnover. In particular, mills certified under the RSPO Identity Preserved (IP) model had the highest predicted probabilities of being retained or newly added. This pattern aligns with corporate commitments to increase traceable, physically segregated sourcing. IP maintains physical separation and traceability to a specific certified mill and supply base; in contrast, the RSPO Mass Balance (MB) model allows certified and non-certified materials to be mixed¹⁸.

Mill degree was strongly positively associated with both link retention and addition, potentially because high degree captures unmeasured preferred mill attributes as well as information conveyed by existing buyer relationships. Mills with preferred characteristics may already have been more connected in P1 and more likely to retain or gain links in P2. Our model did not include some potentially important factors, such as human-rights or other compliance concerns. In addition, inclusion in other companies' sourcing portfolios may serve as an implicit screening signal, encouraging selective mimicry when firms face uncertainty about supplier compliance^{14,15}

Despite the perceived difficulty of major supply-chain transformation⁸, reinforced by geographic “stickiness” and infrastructure lock-in¹⁹, we observed substantial contraction and convergence over a relatively short period. These changes may contribute to a “twin-track system”⁵: traceability and oversight may improve within the disclosed segment, while mills excluded from these supply chains continue supplying markets where public mill-list disclosure is less widespread^{3,6,20}. Corporate disclosure remains important for clarifying private-sector responsibilities¹. However, improvements achieved by individual companies may not necessarily translate into industry-wide sustainability gains when disclosure and associated restructuring extend to only part of the sector.

Methods (up to 500 words)

Methodological details are provided in Supplementary Note 2.

P1 and P2 company–mill matrices

We compiled palm oil mill lists published by 20 manufacturing companies with broad international sourcing portfolios (Supplementary Table 1). Each list identifies mills reported by the company as part of its supply chain over a 6- or 12-month reporting interval, or at a snapshot, in 2020–2021 (P1) or 2023–2024 (P2) (Supplementary Table 11), yielding 110,044 raw mill records (Supplementary Figure 2). We matched mill identities using the January 2026 Universal Mill List (UML)²¹ and removed duplicates within each company and period before constructing binary matrices with companies as columns and mills as rows. For direct comparison, we retained the 1,863 mills that appeared in at least one company list in both P1 and P2, yielding two $1,863 \times 20$ matrices. These mills represented 78.2% of the 2,382 mills in the UML (Supplementary Table 12).

Network analysis

We classified links as dropped, retained, or newly added between P1 and P2 and compared their frequencies across companies. For the P1 and P2 networks, we calculated degree centralization separately for companies and mills—degree centralization measures the extent to which connections are concentrated among a subset of nodes¹⁶. We compared the observed values with those from 999 null matrices preserving matrix dimensions and company degrees (column sums). We also generated 999 randomized P2 matrices by randomly removing and adding links to P1 while preserving each company's observed link losses and additions. We then compared mill-side degree centralization and mill degree–rank relationships in these randomized matrices with those observed in P2.

Next, we calculated the proportion of high-degree mills in each company's list. We defined high-degree mills as the top 20% ranked by the number of connected companies within each period. Mills tied at the cutoff received fractional weights, so the weighted total equaled exactly 20% of all mills. We used Spearman's rank correlation to test the association between changes in this proportion and proportional changes in list length.

Factors associated with link retention and addition

We fitted separate binomial generalized linear mixed models with a logit link for retention and addition: the retention model distinguished links retained in P2 from those dropped after P1, and the addition model distinguished newly connected pairs in P2 from pairs unconnected in both periods. Predictors included mill degree in P1, RSPO certification status, deforested area during 2016–2020 within 20 km of each mill, and landscape biodiversity importance within 20 km (Supplementary Figure 3). Certification had four levels: IP, MB, both IP and MB, and uncertified¹⁸. Models included company identity as a fixed effect and country and mill identity as random intercepts.

We estimated deforestation using the deforestation-year layer of the Tropical Moist Forest dataset²². We measured biodiversity importance as the proportion of each buffer falling within the highest 10% of STAR values¹⁷. We natural-log-transformed mill degree and deforested areas. Sensitivity analyses separated country-level from within-country variation in deforestation and repeated the models using 10- and 50-km buffers.

Data availability

Original company–mill lists and the Universal Mill List were sourced from publicly available websites (URLs are presented in Supplementary Table 11). Integrated data and R codes are available at Zenodo (xxxxxx).

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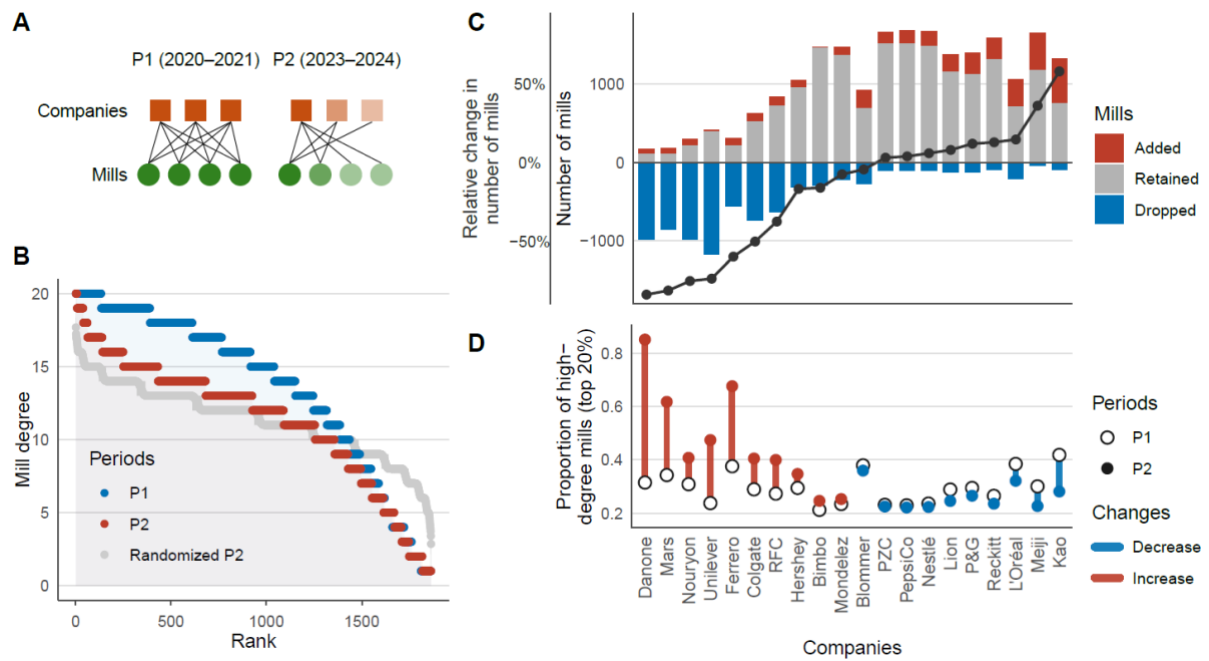


Figure 1. Changes in company–mill networks between P1 (2020–2021) and P2 (2023–2024). (A) Conceptual illustration of company–mill networks. Node shading indicates degree (number of connections). The P1 network is densely connected, whereas the P2 network illustrates contraction through link loss and convergence toward a smaller set of shared, high-degree mills. The diagram is conceptual and does not represent the observed networks quantitatively. (B) Mill degree, defined as the number of companies connected to each mill, plotted against rank in P1, P2, and randomized P2 networks. Randomized P2 networks were generated from P1 while preserving each company's observed numbers of dropped and added links between P1 and P2. The grey ribbon shows the 2.5th–97.5th percentile range across randomized networks. (C) Numbers of retained, dropped, and added company–mill links for each company between P1 and P2. Retained and added connections are shown above zero and dropped connections below zero. The black line shows the relative change in the total number of disclosed mills, calculated as $(P2 - P1)/P1$. (D) Proportion of high-degree mills in each company's disclosed mill list in P1 and P2. High-degree mills were defined as the top 20% of mills ranked by degree within each period, with mills tied at the cutoff fractionally weighted. Open and filled circles indicate P1 and P2, respectively; connecting lines are colored

281 according to whether the proportion increased or decreased. Companies in C and D are
282 ordered from the largest proportional decrease to the largest increase in the number of
283 disclosed mills.

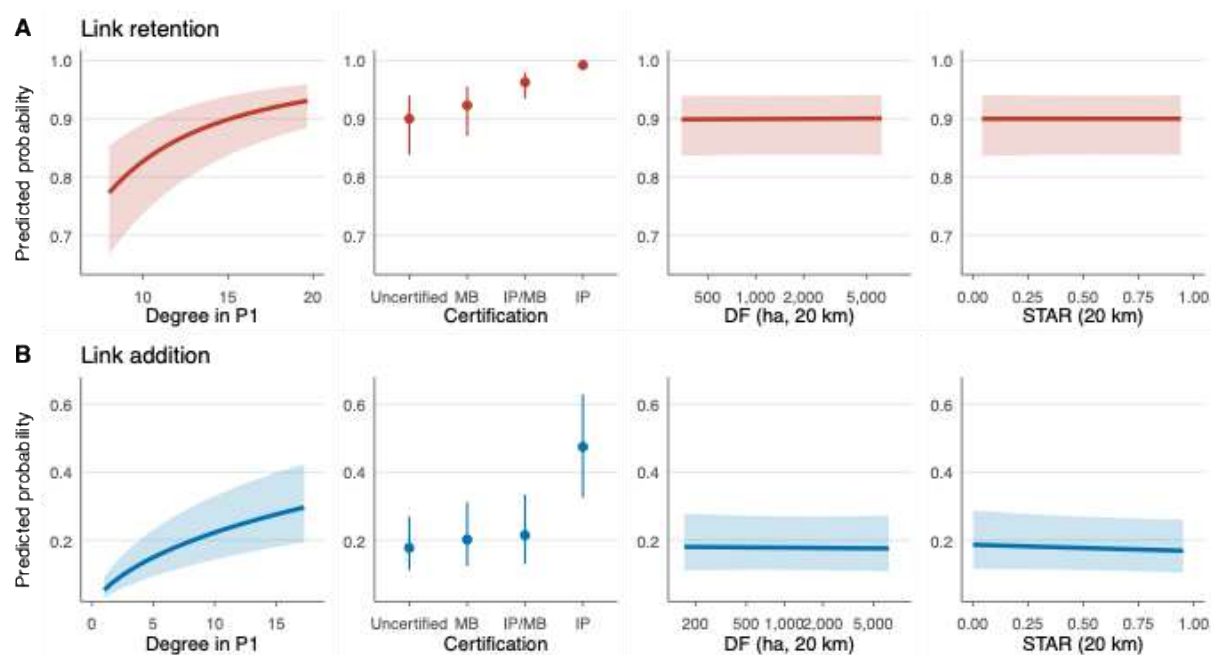


Figure 2. Predicted probabilities of retaining and adding disclosed company–mill links in relation to mill characteristics. (A) Predicted probability that a company–mill link present in P1 was retained in P2. (B) Predicted probability that a company–mill pair unconnected in P1 became connected in P2. Predictions were obtained from separate binomial generalized linear mixed models for link retention and addition (full model results are provided in Supplementary Tables 3 and 4) and are shown in relation to mill degree in P1, RSPO certification status, deforested area (DF) during 2016–2020 within 20 km of each mill, and the proportion of the 20-km buffer within the highest 10% of Species Threat Abatement and Restoration (STAR) values. Mill degree is the number of companies connected to a mill. Certification categories were uncertified, Mass Balance (MB), certification under both Identity Preserved and Mass Balance models (IP/MB), and Identity Preserved (IP). Lines and points show predicted probabilities, and shaded bands and error bars indicate 95% confidence intervals. Mill degree and deforested area were natural-log transformed in the models but are presented on their original scales. Models included company identity as a fixed effect, with P&G as the reference level, and country and mill identity as random intercepts.

Supplementary Files

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- [Supplementaryall.pdf](#)