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The Length and Structure of Norwegian Production Chains: Evidence from Global Input–Output Networks

Mohamed Badr

mhbadr94@gmail.com

NTNU: Norges teknisk-naturvitenskapelige universitet https://orcid.org/0009-0006-4714-3350

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The Length and Structure of Norwegian Production Chains

Evidence from Global Input–Output Networks

Mohamed Badr*

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Abstract

Global production networks create economic dependencies that extend beyond direct trading relationships. This study examines the length and geographical structure of Norwegian production chains using the OECD Inter-Country Input–Output database for 1995 and 2022. Average propagation length (APL) is combined with Leontief multipliers, hypothetical extraction, and intermediary decomposition to assess Norway's upstream production dependencies. The results reveal a modest lengthening of production chains, with 37 of the 49 comparable industries recording an increase in APL. This development was consistent with the broader trend among 12 comparison economies, although Norway experienced considerably less lengthening compared to similar mainland Nordic economies, while China and Iceland recorded reductions. Production-chain length and the magnitude of upstream requirements nevertheless capture distinct characteristics, as reflected in their declining correlation from 0.450 in 1995 to 0.156 in 2022. The EU-27 exhibits the largest aggregate structural contribution among the regional groups examined, with its hypothetical extraction reducing Norwegian upstream requirements by 26.47% in 2022. China has become a substantially more important source of upstream requirements, while its production connections with Norway involve more intermediate stages than those associated with the EU-27 or the United States. Intermediary analysis further reveals that Norway's international production connections extend through several other economies, including European countries linking Norwegian and Chinese production. These findings demonstrate that direct trade relationships and conventional linkage measures provide an incomplete account of international

*Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU). Corresponding author. Email: mhbadr94@gmail.com.

production dependencies. APL offers a complementary perspective on their length and geographical structure, with implications for assessing economic exposure and supply-chain resilience.

Keywords: Average propagation length; Input–output analysis; Production networks; Global value chains; Norway; Hypothetical extraction.

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1. Introduction

The increasing integration of national economies within global production networks has strengthened interdependencies between industries and countries. While international trade provides access to a wider range of suppliers, it also creates channels through which economic disturbances may spread across borders and successive stages of production. Understanding these interdependencies requires examining both the magnitude of economic linkages and the structure and length of the production chains through which they operate (Acemoglu et al. 2012; Baldwin and Venables 2013; Barrot and Sauvagnat 2016).

Conventional input–output analysis provides an established framework for examining these relationships. Direct input coefficients describe immediate production requirements, while the Leontief inverse captures cumulative direct and indirect requirements (Leontief 1974; Miller and Blair 2009). However, these measures do not explicitly distinguish between dependencies operating through few production stages and those involving several intermediate industries. Similarly, conventional trade statistics provide limited information about the upstream production networks underlying imported inputs.

Average propagation length (APL) addresses this distinction by measuring the average number of production steps connecting industries. Introduced by Dietzenbacher, Luna, et al. (2005) and subsequently applied in an interregional framework by Dietzenbacher and Romero (2007), APL incorporates direct and indirect production linkages to describe economic distance. Combined with conventional linkage measures, it distinguishes the length of production connections from their economic magnitude. Simply put, a higher APL indicates that a change in final demand for industry j affects the output of industry i through a greater number of production stages on average, reflecting greater economic distance between the two industries.

APL has been applied to identify production chains, examine interregional dependencies, and investigate production fragmentation and the position of industries within global networks (Yao 2026; Franco et al. 2011; Banouei and Fahimi 2021). Subsequent developments have extended the measure to groups of industries and countries and enabled the identification of intermediary contributions (Chen 2014). Applications also include the analysis of embodied emissions and environmental pressures (Fang et al. 2020), as well as error propagation through the Leontief production structure (Badr and Stadler 2026).

In parallel, Norwegian supply-chain dependencies have received increasing attention in recent years. Blöchliger (2026) examines Norway's exposure to global

value-chain disruptions and potential policy responses, while other studies investigate the effects of COVID-19 on food and pharmaceutical supply chains (Bø et al. 2023) and seafood exports (Veylit et al. 2025). Supply-chain resilience has also been examined in relation to Nordic security of supply and crisis preparedness (Mikael et al. 2022). Particularly relevant is the network analysis by Oliveira Paes et al. (2024), which identifies Norwegian strategic dependencies within global supply networks. The present study complements this research by examining the number of production stages underlying these dependencies and distinguishing their length from their economic magnitude.

Related approaches have been developed to measure industry positions within international production networks. Antràs et al. (2012) measure the average distance of industries from final use, while Miller and Temurshoev (2017) examine upstreamness and downstreamness across 40 countries using the World Input–Output Database. Although conceptually related to APL, these indicators describe different aspects of production-chain position. The present analysis instead focuses on the length of Norwegian industries' upstream production connections, combining APL with conventional Leontief linkages, hypothetical extraction, and intermediary decomposition.

Using the OECD Inter-Country Input–Output (ICIO) database (OECD 2026), the study addresses three questions. First, which Norwegian industries exhibit the longest production chains, and how do these compare with conventional Leontief linkages? Second, which foreign economies and industries contribute most substantially to Norway's production structure? Third, how are Norwegian industries connected to China, the EU-27, and the United States through successive production stages, and which intermediary economies contribute to these connections?

The analysis covers 1995 and 2022 and includes a comparison with 12 selected economies, including Norway's Nordic neighbours and major international production centres, to assess whether changes in Norwegian production-chain lengths reflect broader international patterns. Together, these analyses provide an assessment of the length, geographical composition, and development of Norway's upstream production dependencies.

2. Data and methods

2.1 Data

The analysis employs the OECD Inter-Country Input–Output (ICIO) database for 1995 and 2022 (OECD 2026). The database provides harmonised interindustry transaction tables covering domestic production and international intermediate trade, thereby

allowing production dependencies to be traced across national boundaries.

The analysis uses the regular ICIO classification, comprising 81 producing regions and 50 industries per region, corresponding to 4,050 country–industry combinations. Both years are analysed using the same industry classification to ensure comparability. Norway is treated as the focal economy, while all other regions remain within the global production network when calculating direct and indirect requirements.

To examine Norway's principal international connections, foreign economies are grouped into China, the European Union (EU-27), the United States, and the remaining regions. EU membership is held constant at its 2022 composition for both years. This ensures that observed differences between 1995 and 2022 reflect changes in production linkages rather than changes in the composition of the regional group.

2.2 Input–output framework

Let $\mathbf{Z}$ denote the matrix of interindustry transactions, where z_{ij} represents the monetary value of intermediate inputs supplied by industry i to industry j. Let $\mathbf{x}$ denote the vector of gross industry outputs and $\mathbf{y}$ the vector of total final demand. The standard input–output identity is expressed as

$$\mathbf{x} = \mathbf{Z}\mathbf{1} + \mathbf{y}, \tag{1}$$

where $\mathbf{1}$ is a summation vector of ones.

The technical coefficient matrix $\mathbf{A}$ is calculated as

$$\mathbf{A} = \mathbf{Z}\widehat{\mathbf{x}}^{-1}, \tag{2}$$

where $\widehat{\mathbf{x}}$ is the diagonal matrix of gross outputs. Each element a_{ij} represents the intermediate input required from industry i per unit of output produced by industry j.

The Leontief inverse is subsequently obtained as

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}, \tag{3}$$

where $\mathbf{I}$ is the identity matrix. Its power-series expansion is given by

$$\mathbf{L} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \cdots. \tag{4}$$

The successive terms represent the initial production effect, direct input requirements, and higher-order indirect requirements. The elements of $\mathbf{L}$ therefore measure the total production requirements associated with a unit change in final demand, while the elements of $\mathbf{A}$ capture direct requirements alone.

The matrices are calculated using the pymrio Python package (Stadler 2021). The Leontief inverse and direct input coefficients are subsequently retained as conventional linkage measures against which the APL results are compared.

2.3 Average propagation length

Interindustry relationships can be characterised by two distinct dimensions: the strength of economic linkages and the distance over which they operate. While conventional input–output measures capture the magnitude of these relationships, average propagation length (APL) provides a measure of economic distance. Following Dietzenbacher and Romero (2007), the APL between industries i and j is defined as the weighted average number of production steps through which a change in final demand for industry j affects the output of industry i.

Using the power-series expansion of the Leontief inverse, the APL is expressed as

$$APL_{ij} = \frac{a_{ij} + 2(\mathbf{A}^2)_{ij} + 3(\mathbf{A}^3)_{ij} + \cdots}{a_{ij} + (\mathbf{A}^2)_{ij} + (\mathbf{A}^3)_{ij} + \cdots}. \tag{5}$$

The numerator weights each production-stage contribution by the number of steps involved, while the denominator represents the total effect associated with positive-length production paths. The zero-step initial effect is excluded.

Since

$$\sum_{k=1}^{\infty} k\mathbf{A}^k = \mathbf{L}(\mathbf{L} - \mathbf{I}), \tag{6}$$

the complete matrix of bilateral propagation lengths can be calculated as

$$\mathbf{APL} = \frac{\mathbf{L}(\mathbf{L} - \mathbf{I})}{\mathbf{L} - \mathbf{I}}, \tag{7}$$

where division is performed element-wise. The measure is defined for industry pairs with positive-length production linkages.

To obtain an industry-level measure for Norway, bilateral APL values are aggregated using the monetary value of intermediate transactions as weights, following Dietzenbacher and Romero (2007). The weighted backward APL for Norwegian industry j is calculated as

$$\overline{APL}_j^B = \frac{\sum_i z_{ij} APL_{ij}}{\sum_i z_{ij}}. \tag{8}$$

The weighting is based on direct intermediate transactions, giving greater importance to economically substantial deliveries. However, the corresponding bilateral

APL values capture both direct and indirect production linkages, allowing the weighted average to reflect the length of upstream production chains beyond immediate suppliers.

The measure is calculated for each Norwegian industry using all global suppliers, and separately for domestic and foreign supplying industries. The resulting values are used to rank Norwegian industries according to their upstream production-chain lengths. Changes between 1995 and 2022 are calculated as

$$\Delta\overline{APL}_j^B = \overline{APL}_{j,2022}^B - \overline{APL}_{j,1995}^B. \tag{9}$$

To assess the additional information provided by APL, the industry rankings are compared with conventional backward Leontief multipliers and direct input requirements. These comparisons distinguish the length of a production linkage from its economic magnitude.

2.4 Hypothetical extraction

The structural importance of foreign economies and industries is examined using the hypothetical extraction method (Dietzenbacher and Romero 2007; Dietzenbacher, Van Burken, et al. 2019). The method evaluates how the production structure of a remaining economic system changes when selected industries or regions are excluded.

Let K denote the set of extracted country–industry nodes and R the remaining nodes. The reduced technical coefficient matrix is obtained by retaining the principal submatrix of $\mathbf{A}$ corresponding to R:

$$\mathbf{A}^{(-K)} = \mathbf{A}_{RR}. \tag{10}$$

The corresponding Leontief inverse is

$$\mathbf{L}^{(-K)} = (\mathbf{I}_R - \mathbf{A}_{RR})^{-1}. \tag{11}$$

The APL matrix is recalculated for the reduced system using Equation 7. The effect of extraction on Norway's production-chain structure is then measured as

$$\Delta APL_K = \overline{APL}_{\text{NOR}}^{(-K)} - \overline{APL}_{\text{NOR}}, \tag{12}$$

where the aggregate Norwegian APL is obtained by weighting Norwegian industry-level values by their baseline intermediate purchases. For comparability, the original intermediate transaction weights of retained supplier–industry pairs are held constant following extraction.

The analysis considers three categories of extraction: individual foreign economies and regional groups, industry groups across foreign economies, and individual foreign country–industry combinations.

In addition to changes in propagation length, the effect of extraction on the magnitude of Norwegian upstream linkages is measured using the sum of positive-length Leontief requirements. Let $\mathcal{N}$ denote the set of Norwegian industries and $\mathcal{V}$ the set of all producing industries. The baseline indicator is defined as

$$R_{\mathrm{NOR}} = \sum_{j \in \mathcal{N}} \sum_{i \in \mathcal{V}} (l_{ij} - \delta_{ij}), \tag{13}$$

where δ_{ij} denotes the Kronecker delta. Following extraction of the nodes in K, the corresponding indicator is recalculated for the reduced production network. The percentage change is then expressed as

$$\Delta R_K(\%) = 100 \frac{R_{\mathrm{NOR}}^{(-K)} - R_{\mathrm{NOR}}}{R_{\mathrm{NOR}}}. \tag{14}$$

This indicator measures the aggregate direct and indirect production requirements associated with unit final-demand changes across Norwegian industries, excluding the initial production effect. It is a dimensionless structural linkage measure and should not be interpreted as the monetary value of imports, observed production losses, or an output-weighted national economic aggregate. Together, the two indicators distinguish the effects of extraction on the average length of Norwegian production chains from its effects on the magnitude of upstream production requirements.

The extraction experiments are interpreted as structural counterfactuals. They do not incorporate substitution between suppliers, changes in production technologies, or adjustments in final demand, and should therefore not be interpreted as estimates of economic losses following an actual supply disruption.

2.5 International production linkages and intermediary industries

To examine the geographical structure of Norwegian production chains, bilateral APL analysis is extended to groups of producing industries, consistent with the methodology of Chen (2014). This enables propagation lengths to be calculated between Norwegian industries and foreign economic regions rather than between individual industry pairs alone.

Let P denote a group of supplying industries, and let $\boldsymbol{s}_P$ be a selection vector with elements equal to one for industries belonging to P and zero otherwise. Let $\boldsymbol{f}_G$ denote a normalised final-product vector for the target group G. For an individual Norwegian

target industry j, the final-product vector $\boldsymbol{f}_G$ is defined as a unit selection vector with a value of one for industry j and zero elsewhere. For the aggregate Norwegian target, the vector is constructed from total final demand for Norwegian-produced products, irrespective of the geographical origin of final demand. Negative final-demand totals, if present, are set to zero for the purpose of constructing the weights, which are subsequently normalised to sum to one across Norwegian industries. The source selection vector $\boldsymbol{s}_P$ identifies the supplying industries belonging to the foreign region under examination.

The group-wise average propagation length is calculated as

$$APL_{PG} = \frac{\boldsymbol{s}_P^{\mathsf{T}}\mathbf{L}(\mathbf{L}-\mathbf{I})\boldsymbol{f}_G}{\boldsymbol{s}_P^{\mathsf{T}}\mathbf{L}\boldsymbol{f}_G}. \tag{15}$$

The group-wise measure is distinct from the transaction-weighted backward APL in Equation 8. The latter averages bilateral propagation lengths using direct intermediate transactions as weights, whereas the group-wise measure aggregates length-weighted production requirements across the selected supplying industries. The two measures therefore describe different sets of production relationships and should not be compared as alternative estimates of the same average. Unlike the conventional bilateral measure in Equation 7, this formulation includes the initial production effect in its denominator, following Chen (2014)'s group-wise definition.

The analysis calculates group-wise APL between Norwegian industries and China, the EU-27, and the United States. Differences between 1995 and 2022 are used to examine changes in the length and geographical composition of Norway's international production linkages.

To identify the industries contributing to these linkages, the length-weighted propagation matrix is decomposed as

$$\mathbf{L}(\mathbf{L}-\mathbf{I}) = \mathbf{L}\mathbf{W}, \qquad \mathbf{W} = \mathbf{L}-\mathbf{I}. \tag{16}$$

The contribution associated with an intermediary industry k is then expressed as

$$c_{k,PG} = \left(\sum_{i\in P} l_{ik}\right)\left(\sum_{j\in G} w_{kj} f_j\right), \tag{17}$$

where w_{kj} is the corresponding element of $\mathbf{W}$. The contributions sum to the numerator of Equation 15.

These contributions are aggregated by industry and country to identify important nodes within the production networks connecting Norway to the selected foreign regions. For the analysis of third-country intermediaries, industries located in

Norway and the corresponding source region are excluded from the intermediary-country rankings.

The decomposition captures the contribution of industry-node visits to the length-weighted production requirements. It does not identify unique physical supply routes, since production paths may revisit the same industry.

Together, these measures provide three complementary perspectives on Norwegian production networks: the average length of upstream dependencies, the structural importance of individual economies and industries, and the geographical composition of the production stages connecting Norway to its principal international partners.

3. Results

This section examines the structure of Norwegian production chains and their development between 1995 and 2022. The analysis begins by identifying industries with the longest production chains and comparing their propagation lengths with conventional Leontief multipliers. It then examines the structural importance of foreign economies and industries through hypothetical extraction, followed by an assessment of Norway's connections with China, the EU-27, and the United States. Following that, the intermediary economies contributing to these international production linkages are identified. Finally, the Norwegian findings are benchmarked against 12 selected economies, including the other Nordic countries and major industrial economies, to assess whether changes in Norway's production-chain lengths are consistent with broader international trends.

3.1 Average propagation lengths of Norwegian industries

As defined in Equation 8, the transaction-weighted backward APL represents the average number of production stages connecting an industry to its upstream suppliers, with greater weight assigned to economically important intermediate transactions. Higher values therefore indicate longer upstream production connections, rather than necessarily greater economic dependence. Figure 1 compares these values for Norwegian industries in 1995 and 2022.

The results suggest a general, albeit modest, lengthening of Norwegian production chains. Across the 49 industries with comparable values, the arithmetic mean of industry-level APL increased from 1.656 in 1995 to 1.687 in 2022. This development was relatively widespread, with 37 industries recording an increase and 12 experiencing a decrease. Nevertheless, the differences between industries remain considerably larger than the overall change, suggesting that developments in

production-chain length have not been uniform across the Norwegian economy.

Food products, beverages and tobacco (C10T12) exhibited the longest average production chains in 2022, with an APL of 1.803, followed by construction (F, 1.793), accommodation and food services (I, 1.787), mining support activities (B09, 1.775), and agriculture (A01, 1.773). The presence of both primary and service industries among those with the highest values indicates that relatively long upstream production connections are not confined to manufacturing. Rather, they are found across industries with different positions and functions within the Norwegian economy.

The evolution of individual industries further illustrates this variation. Forestry (A02) recorded the largest increase, from 1.439 to 1.628 production steps, while postal and courier activities (H53) and oil and gas extraction (B06) experienced increases of 0.127 and 0.122 steps, respectively. In contrast, coke and refined petroleum products (C19) recorded a reduction from 1.549 to 1.350 steps, while basic non-ferrous metals (C24B) and chemicals (C20) also experienced shorter average propagation lengths. The complete industry-level results are provided in Supplementary Table S2.

Taken together, these findings indicate a gradual lengthening of upstream production connections across much of the Norwegian economy, although this was accompanied by substantial sectoral variation. The changes suggest a reorganisation of production relationships over time rather than a uniform movement towards longer chains across all industries.

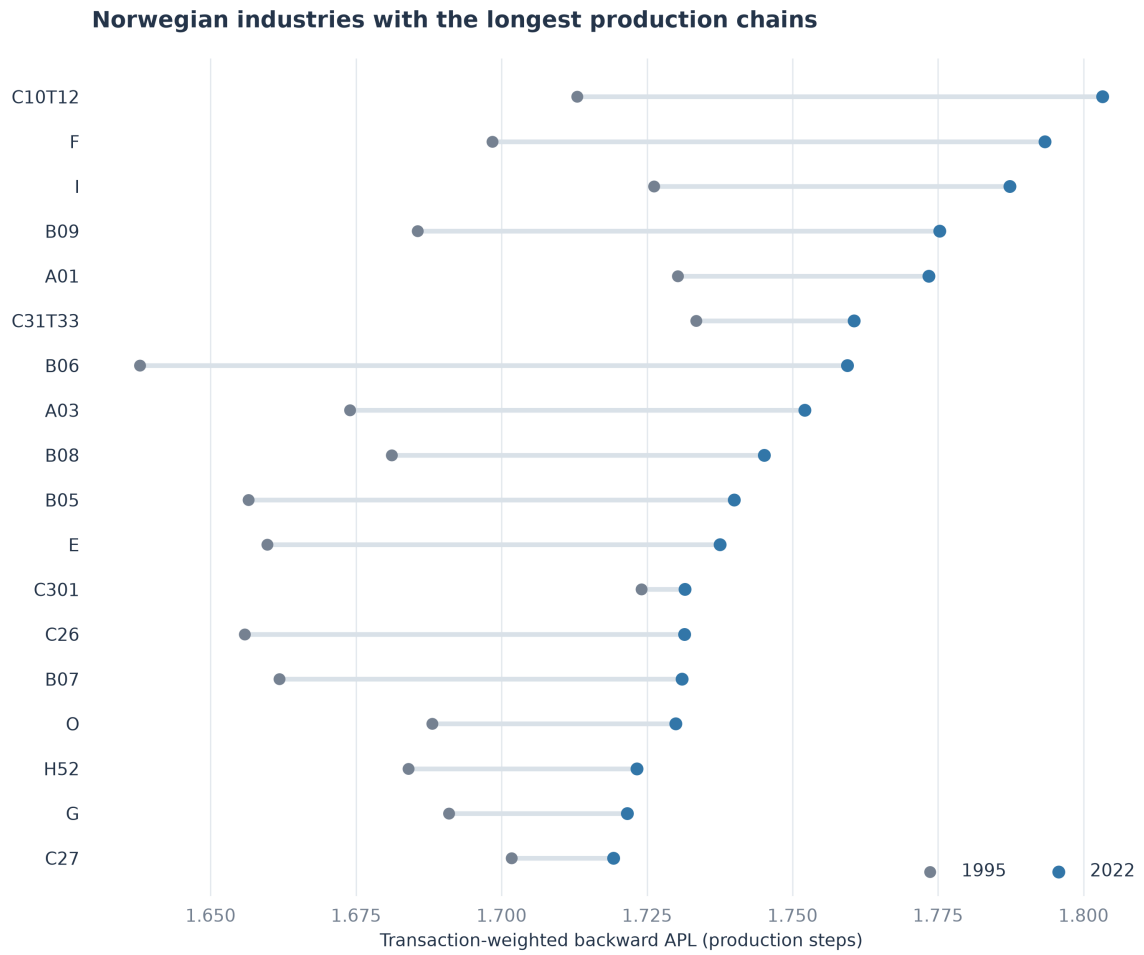


FIGURE 1. Transaction-weighted backward average propagation lengths of selected Norwegian industries in 1995 and 2022. Industries are ranked according to their 2022 values. Industry classifications are provided in Supplementary Table S1

3.2 *Average propagation length and conventional Leontief linkages*

While APL measures the average length of production connections, the Leontief inverse in Equation 3 describes the magnitude of direct and indirect production requirements. Comparing the two measures allows an assessment of whether industries with stronger upstream linkages are also those connected through longer production chains. Figure 2 presents this relationship for 1995 and 2022.

The relationship between the two measures was relatively weak, particularly in 2022. Their correlation declined from 0.450 in 1995 to 0.156 in 2022, indicating that longer production chains were increasingly less closely associated with larger total production requirements. The distinction is apparent among industries with relatively high APL values. Food products, beverages and tobacco (C10T12), for example, combined an APL of 1.803 with a Leontief multiplier of 2.958 in 2022,

whereas oil and gas extraction (B06) exhibited a similarly long APL of 1.759 despite having a substantially smaller multiplier of 1.196. Construction (F) also exhibited a relatively high APL of 1.793, with a Leontief multiplier of 2.510.

These differences indicate that the magnitude of upstream requirements provides only a partial description of the underlying production structure. Industries with comparatively small total requirements may nevertheless depend on production relationships extending through several intermediate stages. Conversely, relatively large production requirements need not imply similarly long chains. The weaker relationship observed in 2022 suggests that these dimensions of Norwegian production networks have become more distinct over time.

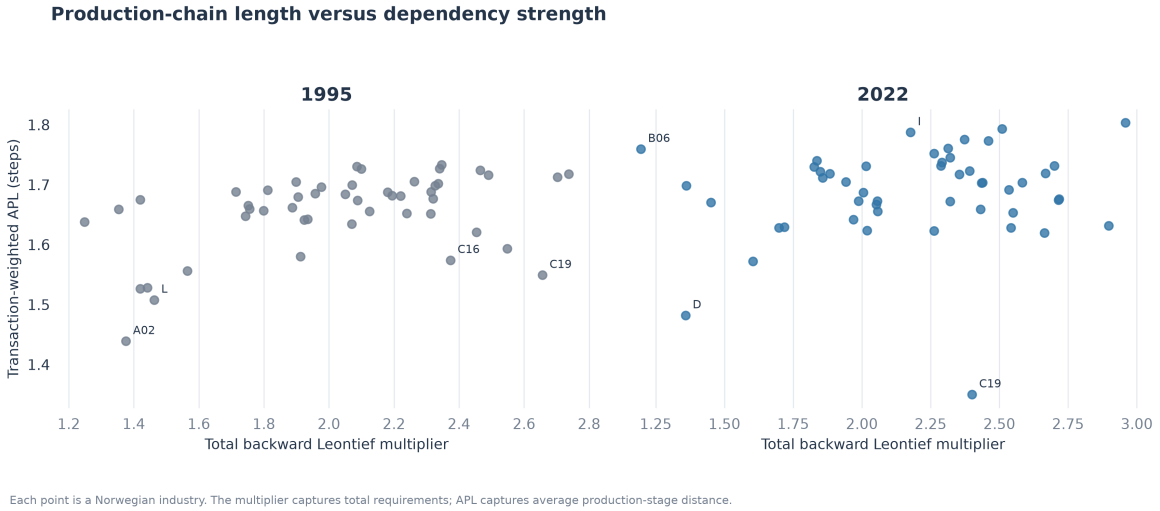


FIGURE 2. Relationship between transaction-weighted backward APL and conventional backward Leontief multipliers for Norwegian industries in 1995 and 2022.

3.3 Structural importance of foreign economies and industries

The hypothetical extraction method, described in Equations 10–12, examines how Norway's production-network structure changes when selected foreign economies or industries are removed. Larger reductions in upstream production requirements indicate stronger structural dependencies on the extracted nodes, while changes in APL reflect their contribution to the average length of the remaining production connections.

Figure 3 shows that the EU-27 has the largest structural contribution among the regional groups examined. Its extraction in 2022 reduces Norwegian upstream production requirements by 26.47% and aggregate weighted APL by 5.60%, compared with reductions of 24.48% and 4.84% in 1995. The somewhat larger effects in 2022 indicate that the EU-27 became more consequential to the measured structure of Norway's upstream production network over the period.

The importance of European connections is also apparent at the country level. Sweden and Germany remain among the leading individual economies, with their extraction reducing upstream requirements by 6.14% and 4.92% in 2022, respectively. Their corresponding APL reductions were 1.30% and 1.03%. Both countries were similarly prominent in 1995, suggesting a persistent role for neighbouring and major European economies within Norway's production network.

China and the United States also make substantial contributions, although their individual extraction effects are smaller than those associated with the EU-27 as a whole. Removing China reduces upstream requirements by 6.17% and APL by 1.23% in 2022, compared with 4.52% and 0.88%, respectively, for the United States. China therefore exhibits a larger individual structural contribution than the United States under both measures, illustrating its importance within Norway's indirect international production connections.

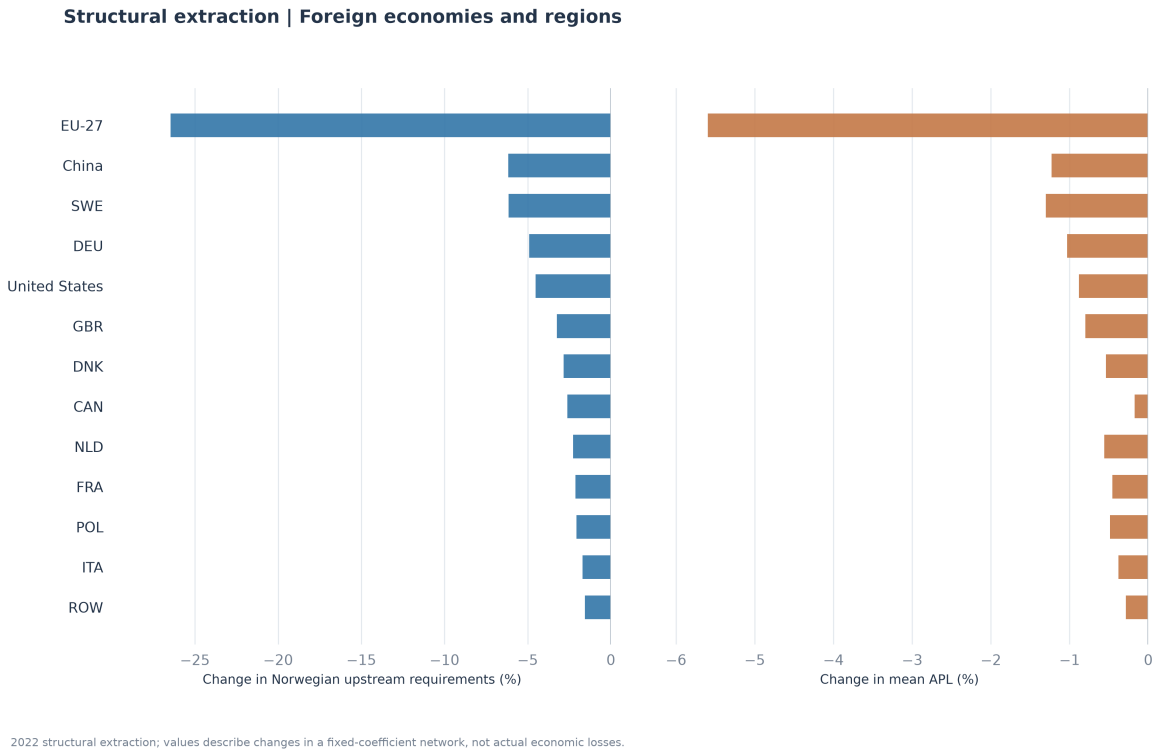


FIGURE 3. Percentage changes in Norwegian aggregate weighted APL and total positive-length production requirements following the hypothetical extraction of foreign economies and regional groups in 2022.

The extraction of foreign industry groups reveals that Norway's production structure also depends on activities that connect different stages of production, rather than exclusively on major manufacturing industries. As shown in Figure 4, wholesale and retail trade (G) produces the largest reduction in upstream requirements (8.47%) and APL (2.31%). Chemicals (C20) also have a substantial effect, reducing upstream

requirements by 6.54% and APL by 1.27%. Professional, scientific and technical activities (M), meanwhile, produce a larger reduction in APL (1.46%) than chemicals, despite their smaller contribution to total upstream requirements (4.19%).

The differences between these indicators suggest that the industries most important to the magnitude of Norway's upstream dependencies are not necessarily those contributing most strongly to their length. The prominent role of trade and professional services also indicates that international production connections extend beyond the industries directly responsible for transforming physical materials. Detailed extraction results for foreign industry groups and individual country–industry combinations are provided in Supplementary Tables S3 and S4, respectively.

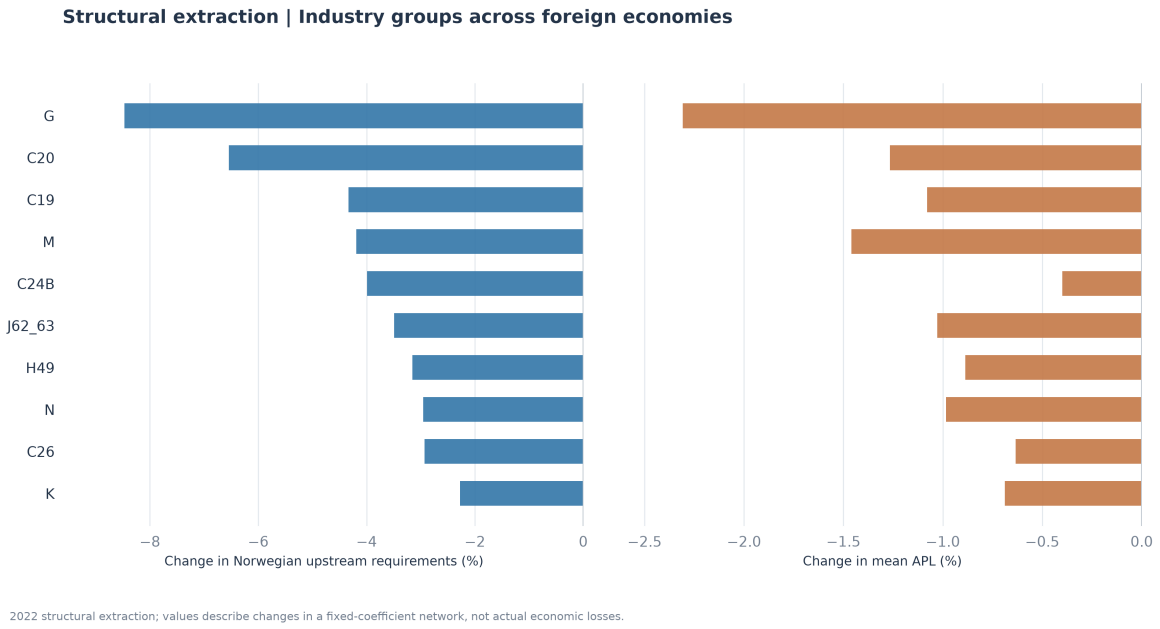


FIGURE 4. Percentage changes in Norwegian aggregate weighted APL and total positive-length production requirements following the hypothetical extraction of selected foreign industry groups in 2022. Industry codes are defined in Supplementary Table S1.

3.4 Norway's production linkages with China, the EU-27, and the United States

The group-wise APL measure in Equation 15 extends the analysis from individual industry pairs to connections between Norwegian industries and foreign economic regions. Higher values indicate that the associated production requirements operate through a greater number of intermediate production stages on average. Figure 5 shows how these connections changed between 1995 and 2022.

Norway's production connections with China are consistently longer than those with the EU-27 and the United States. Averaged across Norwegian industries, the group-wise APL associated with China was 3.683 in 1995 and 3.661 in 2022, compared with 2.662 and 2.645 for the EU-27 and 2.971 and 2.961 for the United

States. Thus, while average propagation lengths declined slightly for all three regions, the differences between them remained broadly unchanged. Norway's upstream connections with the EU-27 are the shortest among the three groups, whereas those associated with China involve the greatest number of production stages.

Beneath these relatively stable regional averages, however, the changes differed considerably across Norwegian industries. The propagation length connecting Chinese production with Norwegian mining support activities (B09) increased from 3.524 to 4.105 steps, while coke and refined petroleum products (C19) and oil and gas extraction (B06) recorded increases of 0.545 and 0.496 steps, respectively. Construction (F), by contrast, experienced a reduction of 0.223 steps. These contrasting developments suggest that changes in Norway's production connections with China were concentrated in particular industries rather than being uniformly distributed across the economy.

A different picture emerges when examining the magnitude of the underlying upstream requirements. The summed positive-length Leontief requirements associated with China increased from 0.215 in 1995 to 3.193 in 2022, compared with increases from 11.341 to 12.963 for the EU-27 and from 1.533 to 2.386 for the United States. These values describe structural requirements rather than bilateral monetary trade flows. Nevertheless, they indicate that China's contribution to Norway's upstream production requirements increased substantially, even as the average number of stages connecting the two economies remained relatively stable.

The findings therefore point to two distinct features of Norway's international production structure. European production remains associated with relatively short and economically important connections, while China represents a growing source of upstream production requirements that operates through longer chains. The United States occupies an intermediate position in terms of propagation length, with a smaller structural contribution than the EU-27 and China in the reported aggregate comparisons.

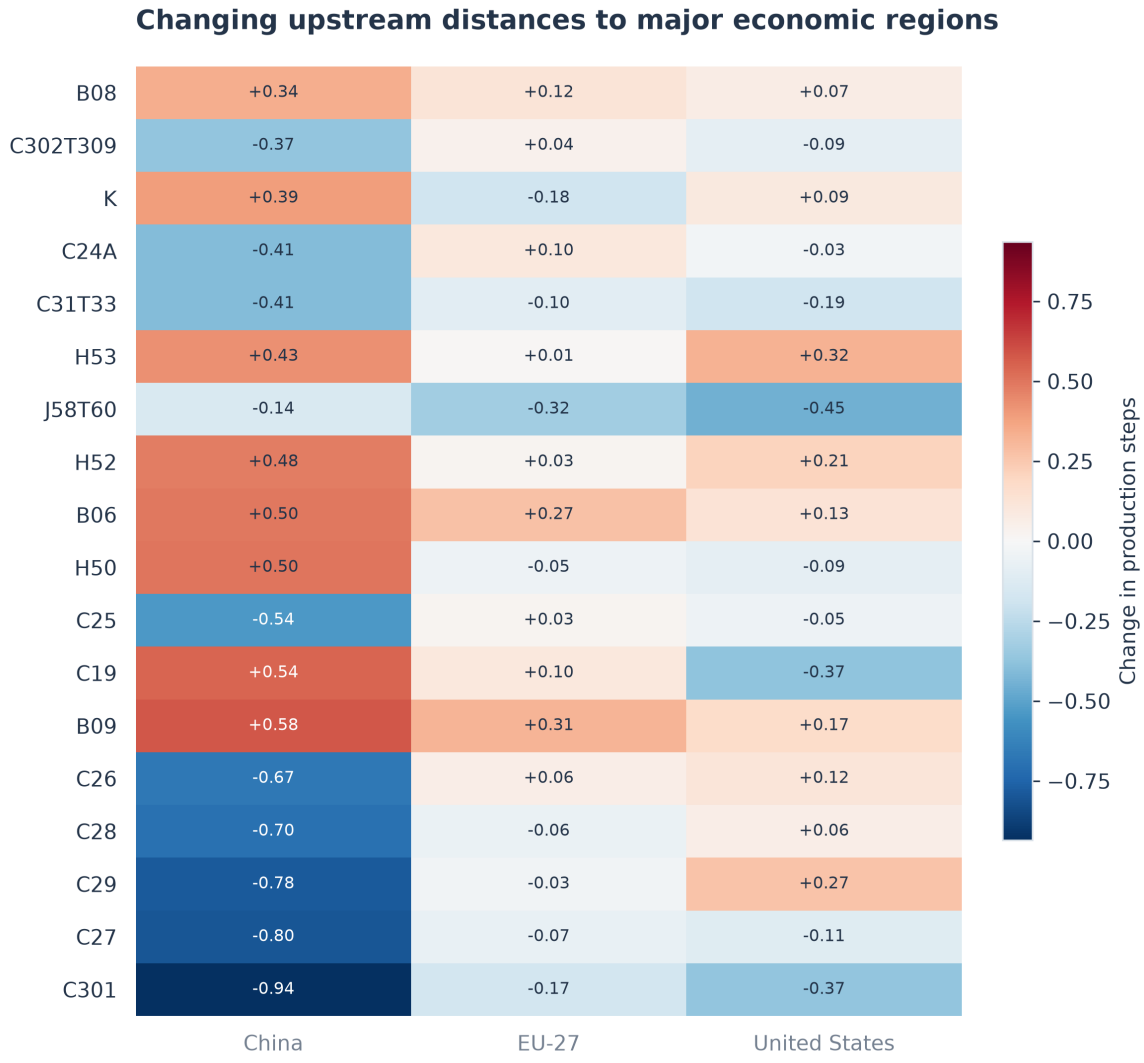


FIGURE 5. Changes in group-wise APL between Norwegian industries and selected foreign regional groups from 1995 to 2022. Positive values indicate longer average production chains in 2022.

3.5 *Intermediary economies in Norwegian production chains*

The intermediary decomposition in Equation 17 identifies the economies contributing to the length-weighted production connections between Norway and its international partners. Unlike bilateral trade statistics, these contributions reflect the importance of intermediate production stages within the wider network. Figure 6 presents the largest third-country intermediary contributions in 2022.

The connections between Norway and China involve several European economies as important intermediaries. Germany accounts for the largest share of non-endpoint intermediary contributions in 2022 (8.9%), followed by Sweden (6.9%), Poland (5.5%),

and Singapore (4.9%). This represents a change from 1995, when Denmark, Sweden, and South Korea were the largest contributors, accounting for 10.9%, 10.2%, and 10.0%, respectively. The presence of major European economies among the principal intermediaries indicates that production connections with China extend through networks involving Norway's other international partners.

A similar pattern of geographical interdependence is observed in the connections with the EU-27. The United Kingdom accounts for the largest share of third-country intermediary contributions in 2022 (23.6%), followed by Switzerland (12.3%) and China (11.6%). The United Kingdom's share was substantially higher in 1995, at 45.4%, indicating a change in the distribution of intermediary contributions. China's presence among the principal intermediaries also demonstrates that Norway's production connections with European industries involve upstream activity outside Europe.

For connections with the United States, the largest intermediary contributions in 2022 were associated with Ireland (10.7%), Sweden (9.2%), Canada (9.1%), and Germany (7.7%). In 1995, Canada, Sweden, and the United Kingdom made the largest contributions. As with the other regional connections, the geographical composition of intermediary activity therefore changed over time.

Overall, the intermediary analysis reveals that Norway's production connections with China, the EU-27, and the United States are not independent of one another. Rather, they are embedded within an international network in which several economies contribute to the production stages linking Norway with its major partners. This also helps explain why direct bilateral relationships alone provide an incomplete description of Norway's international production dependencies.

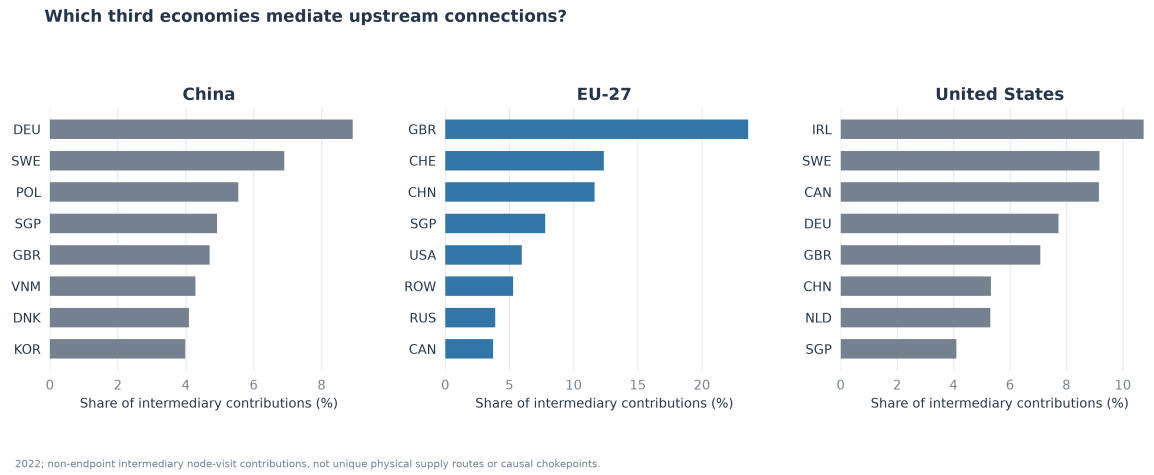


FIGURE 6. Leading third-country intermediary contributions to the length-weighted production connections between Norway and China, the EU-27, and the United States in 2022. Shares are calculated relative to total non-endpoint intermediary contributions for each regional group.

Taken together, the results indicate that Norwegian production chains have become moderately longer since 1995, while their international composition has changed considerably. The differences between APL and conventional linkage measures, together with the geographical extraction and intermediary results, show that the length, magnitude, and international organisation of upstream production connections represent distinct characteristics of Norway's production structure.

3.6 International comparison of production-chain lengths

To place the development of Norwegian production chains in an international context, the analysis was extended to 12 additional economies, including the other Nordic countries, major European trading partners, and selected large industrial economies in Asia and North America. These countries provide a comparison between Norway and economies with differing industrial structures and degrees of integration into international production networks.

As shown in Figure 7, the lengthening of production chains observed in Norway was part of a broader development across the selected economies. Between 1995 and 2022, 11 of the 13 countries recorded an increase in mean industry APL, suggesting that longer upstream production connections became more common over the period. However, the magnitude of these changes differed considerably. South Korea recorded the largest increase (0.200 production steps), followed by Germany (0.133), Finland (0.119), and Canada (0.111). China and Iceland were the only economies to experience a reduction in mean APL, both declining by approximately 0.100 steps.

Norway experienced a comparatively modest increase of 0.031 steps, ranking tenth among the 13 economies. This was substantially smaller than the increases observed in Sweden (0.066), Denmark (0.094), and Finland (0.119). The differences are also evident in the proportion of industries exhibiting longer production chains. While APL increased in 37 of Norway's 49 comparable industries, the corresponding figures were 43 of 49 in Sweden, 44 of 47 in Denmark, and 45 of 48 in Finland. Thus, although production chains lengthened across much of the Nordic region, the development was less pronounced in Norway than in its mainland Nordic neighbours.

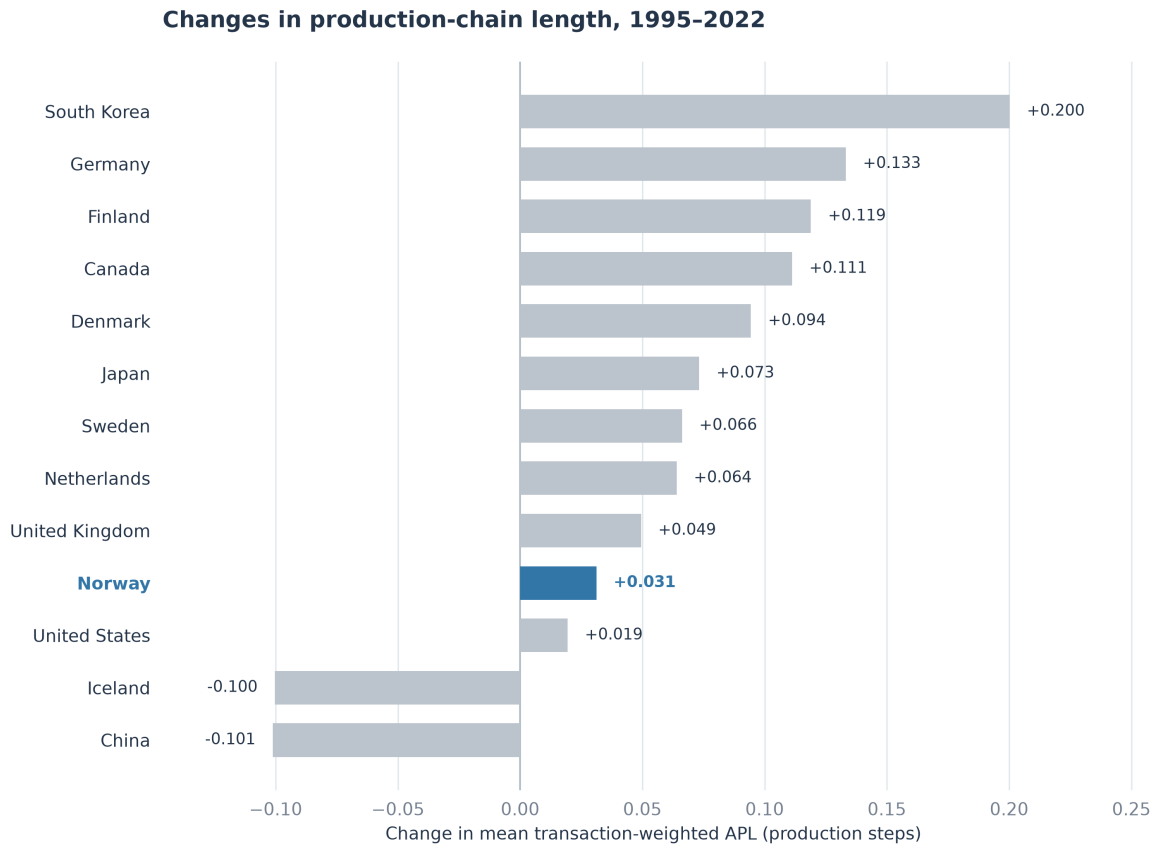


FIGURE 7. Change in mean transaction-weighted backward APL between 1995 and 2022 for Norway and 12 comparison economies. Norway is highlighted in blue.

Differences in the levels of APL provide further context for these developments (Figure 8). Despite experiencing the largest decline, China retained the longest mean production chains among the selected economies in 2022, with an APL of 1.988. South Korea followed at 1.857, having experienced the largest increase over the study period. Norway's mean APL reached 1.687 in 2022, remaining below those of Sweden, Finland, and Germany, although slightly above Denmark. These differences indicate that the direction of change alone does not necessarily reflect the relative length of a country's production chains.

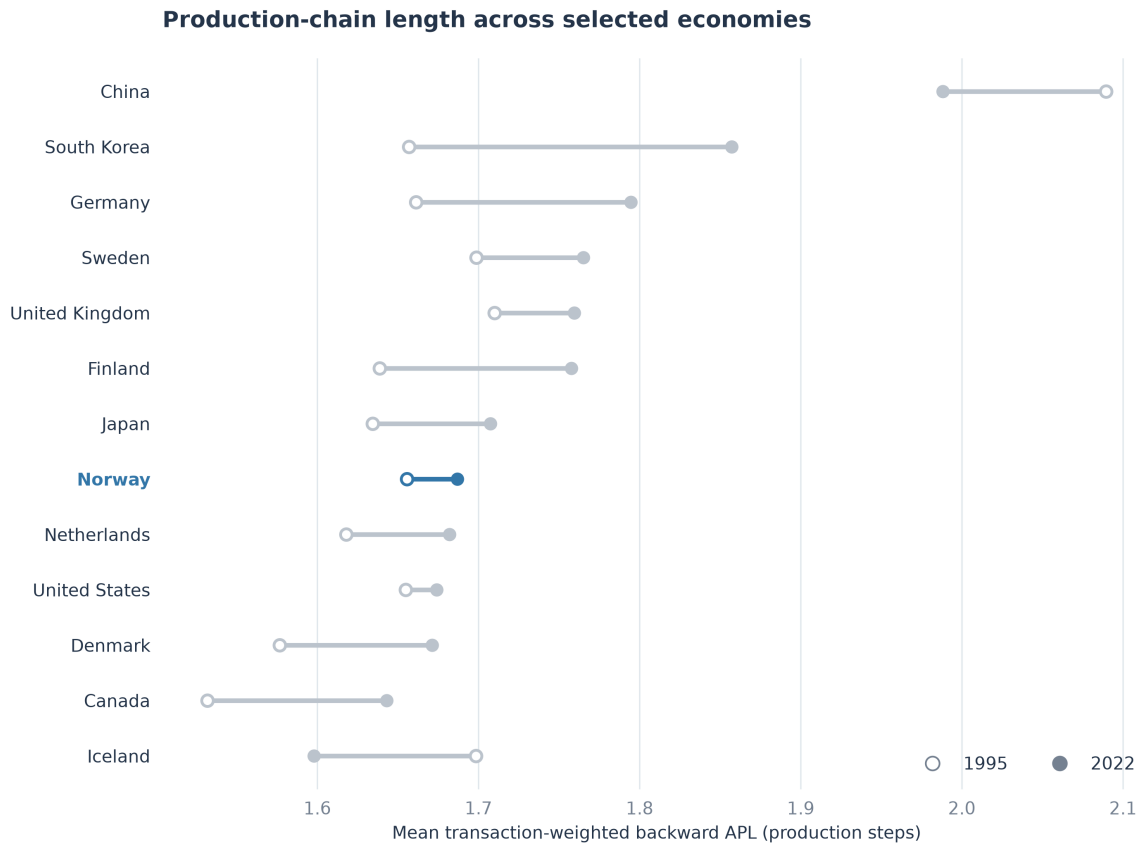


FIGURE 8. Mean transaction-weighted backward APL in 1995 and 2022 for the selected economies. Norway is highlighted in blue.

The comparison also provides context for the weakening relationship between APL and conventional Leontief multipliers observed in Norway. As illustrated in Figure 9, a declining correlation was also observed in Sweden, Germany, and the United States, whereas Finland and Denmark experienced an increase. This suggests that the relationship between production-chain length and the magnitude of upstream production requirements has evolved differently across national production structures, rather than following a uniform international trend.

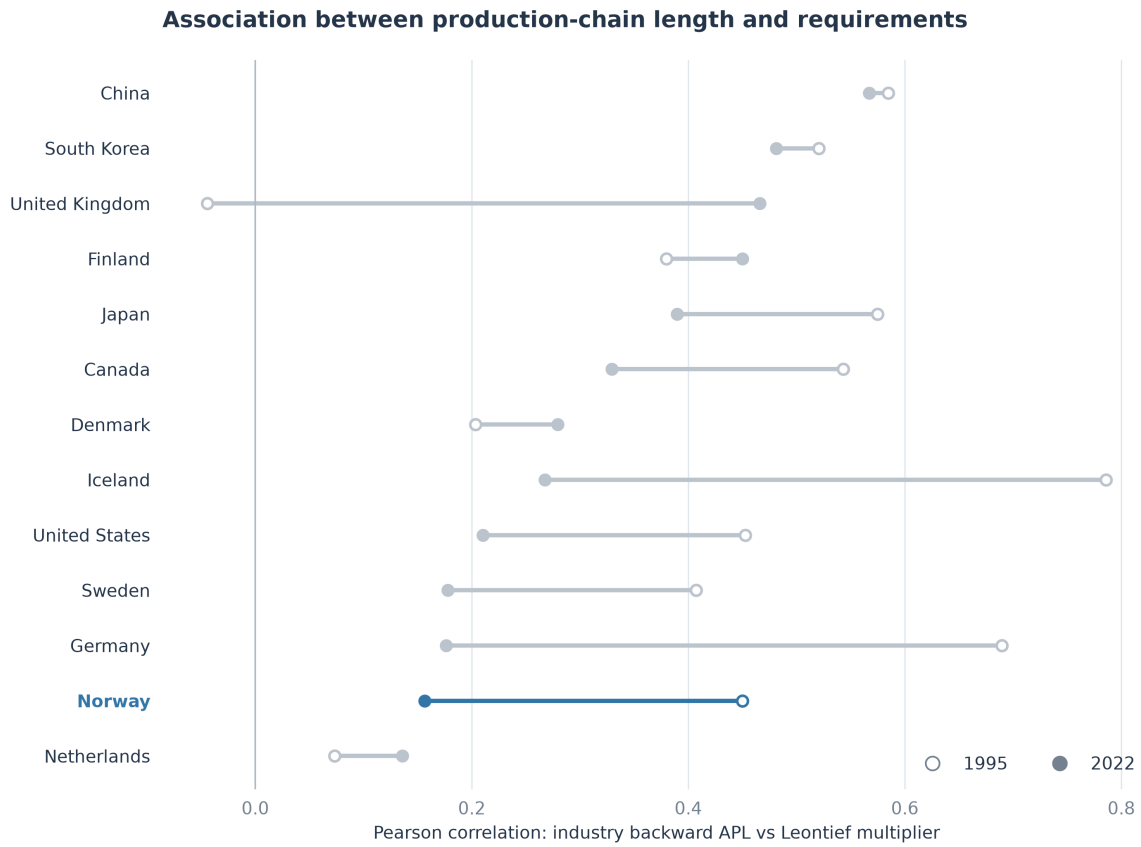


FIGURE 9. Correlation between industry-level transaction-weighted backward APL and Leontief multipliers in 1995 and 2022 across the selected economies. Norway is highlighted in blue.

Overall, the international comparison indicates that the lengthening of Norwegian production chains was not unique, but its magnitude was relatively limited among the economies examined. The widespread increases are consistent with a broader development towards more extended production relationships, although the contrasting experiences of China and Iceland demonstrate that this was not universal. Norway's comparatively small increase, particularly relative to Sweden, Denmark, and Finland, points to a more modest change in the average length of its upstream production connections. The complete country-level results are provided in Supplementary Table S5.

4. DISCUSSION

The gradual lengthening of Norwegian production chains between 1995 and 2022 suggests that upstream production relationships have become somewhat more extended, although the changes varied considerably across industries. This de-

velopment is consistent with the fragmentation and specialisation of production associated with economic globalisation, whereby intermediate goods and services pass through successive stages before reaching their final producers (Baldwin and Venables 2013; Timmer et al. 2014). Greater international integration may contribute to such changes by allowing industries to source inputs from increasingly specialised suppliers. However, longer production chains may also arise from changes in domestic production structures and do not necessarily indicate that a larger share of Norwegian production has moved abroad. The findings therefore point towards a modest change in the organisation of Norway's upstream production relationships rather than providing direct evidence of accelerating globalisation.

The international comparison places this development in a broader context. Most of the 13 economies examined experienced an increase in mean APL, suggesting that longer production connections became more common between 1995 and 2022. Norway's increase, however, was considerably smaller than those observed in Sweden, Denmark, and Finland, despite a majority of Norwegian industries recording longer production chains. South Korea recorded the largest increase, while China and Iceland experienced reductions. Interestingly, China retained the longest average production chains among the selected economies in 2022 despite their shortening over time. These contrasting developments indicate that changes in production-chain length have not followed a uniform international trajectory and may reflect differences in industrial specialisation, domestic sourcing, and the organisation of international production.

One possible explanation for Norway's relatively modest increase concerns differences in industrial specialisation. Compared with its mainland Nordic neighbours, Norway's economy has a greater orientation towards petroleum extraction and other resource-based activities, whereas Sweden, Finland, and Denmark have different manufacturing and service specialisations. Production fragmentation in manufacturing, particularly where intermediate inputs pass through successive stages of processing and assembly, may have contributed to the stronger lengthening observed in these economies (Røed Larsen 2005). Norway's production structure may therefore have been less affected by these particular developments. However, the international benchmark is based on an unweighted mean across industries, meaning that the economic importance of petroleum extraction cannot directly explain the difference. Rather, industrial specialisation may be associated with differences in how upstream relationships have evolved within individual sectors. This remains a working hypothesis, as identifying the underlying drivers would require a comparative decomposition of industry-level changes beyond the scope of the present analysis.

The comparison with conventional Leontief multipliers further illustrates why production-chain length should be considered separately from the magnitude of economic dependencies. The weakening correlation between the two measures indicates that Norwegian industries with longer production chains have become less consistently associated with larger upstream production requirements. Oil and gas extraction provides a notable example, combining a relatively long APL with a comparatively small Leontief multiplier. Similar declines in the correlation were observed in Sweden, Germany, and the United States, whereas Finland and Denmark experienced increases. This suggests that the relationship between economic dependence and production-chain length has evolved differently across national production structures.

One possible explanation for the weakening correlation is a change in the organisation of intermediate production. Greater industrial specialisation may extend production relationships through additional stages without a corresponding increase in total upstream requirements. Conversely, stronger dependence on intermediate inputs need not involve longer production chains. Such developments could explain why propagation length and conventional linkage measures have become less closely associated in Norway. The similar weakening observed in several other economies suggests that this pattern is not necessarily specific to Norway's petroleum-oriented production structure. Nevertheless, changes in the correlation may also reflect shifts in the distribution of industry-level values or the influence of particular sectors.

This distinction is consistent with earlier input–output research showing that conventional linkage measures, while informative about the magnitude of interindustry relationships, do not independently capture the economic distance over which these relationships operate (Dietzenbacher, Luna, et al. 2005; Dietzenbacher and Romero 2007).

The geographical results reflect Norway's position within European and global production networks. The substantial structural contribution of the EU-27, particularly Sweden and Germany, is consistent with geographical proximity, established trading relationships, and Norway's participation in the European Economic Area. European production connections are also relatively short compared with those involving China and the United States, suggesting that fewer intermediate stages separate Norwegian industries from upstream production within Europe. Nevertheless, the extraction results indicate that these relatively short connections account for a substantial share of Norway's total upstream production requirements. This demonstrates that geographical proximity and shorter production chains do not necessarily imply weaker economic dependencies.

China presents a different pattern. Its contribution to Norway's upstream production requirements increased considerably between 1995 and 2022, despite relatively little change in the average length of the corresponding production chains. This is consistent with China's growing importance within the international production networks supplying Norwegian industries. The intermediary analysis further identifies Germany, Sweden, and Poland among the economies contributing to Norway's production connections with China. Consequently, these dependencies are not confined to direct Norwegian–Chinese transactions but also operate through intermediate production elsewhere, particularly in Europe. The United States occupies an intermediate position in terms of propagation length, while its smaller extraction effects indicate a lower aggregate structural contribution than China under the measures examined. Taken together, these findings suggest that Norway's international production relationships differ not only in economic magnitude but also in the geographical organisation of their upstream connections.

The findings are broadly consistent with previous assessments of Norwegian supply-chain dependencies. Blöchliger (2026) identifies Norway as relatively less exposed to global value-chain disruptions than many other OECD economies, while highlighting dependencies on non-European economies. Similarly, Oliveira Paes et al. (2024) identifies strategic dependencies within global supply-chain networks that may not be apparent from aggregate trade relationships. The increasing contribution of China to Norwegian upstream production requirements is consistent with these concerns. The present analysis complements this literature by showing how such dependencies differ in production-chain length and involve intermediate production across several other economies.

These results also have implications for supply-chain resilience. Conventional assessments commonly consider supplier concentration, geographical diversification, substitutability, inventories, and the ability to absorb or recover from disruptions (Pettit et al. 2010; Barrot and Sauvagnat 2016; Tang 2006). Longer production chains may create additional points through which disturbances can affect downstream industries, particularly when intermediate inputs are difficult to substitute. However, they may also provide opportunities for alternative sourcing, and greater propagation length does not necessarily imply lower resilience. For Norway, the combination of substantial European dependencies and increasingly important upstream connections with China suggests that assessments based exclusively on direct trading partners may overlook relevant indirect relationships. Combining APL with conventional dependency measures may therefore help identify industries whose exposure extends beyond their immediate suppliers.

Several limitations remain. The analysis relies on a static input–output framework

and does not account for inventories, supplier substitution, production adjustments, or recovery following disruptions. Hypothetical extraction measures changes in production-network structure rather than actual economic losses, while APL represents production stages rather than the time required for disturbances to propagate. Furthermore, the OECD ICIO database does not identify individual firms or physical supply routes. The international benchmark is also limited to 13 selected economies and does not explain the underlying drivers of differences in production-chain length. Consequently, the results should be interpreted as measures of structural interdependence rather than direct indicators of economic vulnerability. Nevertheless, they demonstrate that examining both the length and magnitude of upstream production connections provides a more complete account of Norway's position within international production networks.

5. Conclusions

This study examined the length and international structure of Norwegian production chains between 1995 and 2022 using average propagation length, conventional Leontief linkages, hypothetical extraction, and intermediary decomposition. The results show a modest lengthening of production chains across most Norwegian industries, accompanied by substantial differences in the development of individual sectors. This trend was broadly consistent with developments in most of the 12 comparison economies, although Norway experienced considerably less lengthening compared to similar Nordic economies, while China and Iceland recorded reductions. The weakening relationship between APL and Leontief multipliers further indicates that the magnitude of upstream requirements and the number of production stages through which they operate describe distinct features of Norwegian production networks.

The EU-27 exhibits the largest aggregate structural contribution among the regional groups examined, although its extraction effect reflects the combined production linkages of 27 economies. China, meanwhile, has become a substantially more important source of upstream production requirements while remaining connected to Norwegian industries through relatively long production chains. The intermediary analysis further demonstrates that Norway's connections with its major international partners frequently involve production stages located in other economies.

These findings suggest that the development of Norwegian production networks cannot be understood through conventional measures of direct trade or total production requirements alone. APL provides a complementary perspective by revealing

the length and organisation of the production relationships underlying these dependencies. While longer production chains cannot be interpreted directly as evidence of lower resilience, understanding their structure may help identify indirect exposures that are otherwise difficult to observe. Integrating these measures with explicit disruption scenarios and information on substitution and adaptive capacity offers a potential direction for future research on the resilience of the Norwegian economy.

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Declarations

Availability of data and materials

The datasets supporting the conclusions of this article are publicly available from the OECD Inter-Country Input–Output (ICIO) database, 2025 edition (regular, non-extended version), at `www.oecd.org/en/data/datasets/inter-country-input-output-tables.html`. The Python code used to conduct the analysis and reproduce the results is available in the project's GitHub repository at `https://github.com/MohamedhBadr/APL_NO`.

Competing interests

The author declares that they have no competing interests.

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Contributions

M.B. was responsible for the conceptualization, methodology, data collection, software development, formal analysis, visualization, and writing of the manuscript, including its review and editing.

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Author information

M.B. holds a PhD in Industrial Ecology from the Norwegian University of Science and Technology (NTNU). His research focuses on quantitative economic and environmental modelling, particularly multi-regional input–output analysis, global production networks, and uncertainty assessment. His doctoral research examined uncertainty and its propagation in environmentally extended multi-regional input–output models. His broader research interests include economic interdependencies, supply-chain structures, and the application of quantitative methods to questions of economic sustainability and resilience.

771 # Supplementary Information

Table S1. OECD ICIO industry codes and descriptions used in the analysis.

Industry code	Description
A01	Crop and animal production, hunting and related service activities
A02	Forestry and logging
A03	Fishing and aquaculture
B05	Mining of coal and lignite
B06	Extraction of crude petroleum and natural gas
B07	Mining of metal ores
B08	Other mining and quarrying
B09	Mining support service activities
C10T12	Food products, beverages and tobacco products
C13T15	Textiles, wearing apparel, leather and related products
C16	Wood and products of wood and cork, except furniture
C17_18	Paper and paper products; printing and reproduction of recorded media
C19	Coke and refined petroleum products
C20	Chemicals and chemical products
C21	Basic pharmaceutical products and pharmaceutical preparations
C22	Rubber and plastics products
C23	Other non-metallic mineral products
C24A	Basic iron and steel
C24B	Basic precious and other non-ferrous metals
C25	Fabricated metal products, except machinery and equipment
C26	Computer, electronic and optical products
C27	Electrical equipment
C28	Machinery and equipment n.e.c.
C29	Motor vehicles, trailers and semi-trailers
C301	Building of ships and boats
C302T309	Other transport equipment
C31T33	Furniture; other manufacturing; repair and installation of machinery
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport

Continued on next page

TABLE S1. OECD ICIO industry codes and descriptions used in the analysis. (continued)

Industry code	Description
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58T60	Publishing, audiovisual and broadcasting activities
J61	Telecommunications
J62_63	IT and other information services
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
T	Activities of households as employers and for own use

TABLE S2. Transaction-weighted backward APL of Norwegian industries in 1995 and 2022, change in APL, and 2022 backward Leontief multiplier. Values are rounded to three decimals.

Industry	APL 1995	APL 2022	Change	L 2022
A01	1.730	1.773	0.043	2.460
A02	1.439	1.628	0.189	1.698
A03	1.674	1.752	0.078	2.263
B05	1.656	1.740	0.083	1.836
B06	1.638	1.759	0.122	1.196
B07	1.662	1.731	0.069	2.015
B08	1.681	1.745	0.064	2.321
B09	1.686	1.775	0.090	2.374
C10T12	1.713	1.803	0.090	2.958
C13T15	1.652	1.672	0.020	2.321
C16	1.574	1.692	0.118	2.535
C17_18	1.727	1.703	-0.023	2.583
C19	1.549	1.350	-0.199	2.400
C20	1.716	1.659	-0.057	2.432
C21	1.682	1.642	-0.040	1.969

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TABLE S2. Transaction-weighted backward APL of Norwegian industries in 1995 and 2022, change in APL, and 2022 backward Leontief multiplier. Values are rounded to three decimals. (continued)

Industry	APL 1995	APL 2022	Change	*L* 2022
C22	1.688	1.653	-0.035	2.549
C23	1.688	1.704	0.016	2.438
C24A	1.643	1.676	0.033	2.718
C24B	1.718	1.620	-0.098	2.664
C25	1.706	1.717	0.012	2.355
C26	1.656	1.731	0.076	2.288
C27	1.702	1.719	0.018	2.667
C28	1.677	1.703	0.026	2.435
C29	1.652	1.628	-0.023	2.543
C301	1.724	1.731	0.007	2.700
C302T309	1.580	1.623	0.043	2.262
C31T33	1.733	1.761	0.027	2.314
D	1.527	1.482	-0.045	1.358
E	1.660	1.738	0.078	2.291
F	1.698	1.793	0.095	2.510
G	1.691	1.722	0.031	1.849
H49	1.648	1.673	0.025	1.987
H50	1.593	1.674	0.081	2.715
H51	1.621	1.632	0.011	2.898
H52	1.684	1.723	0.039	2.391
H53	1.528	1.655	0.127	2.058
I	1.726	1.787	0.061	2.177
J58T60	1.700	1.673	-0.027	2.056
J61	1.634	1.667	0.032	2.052
J62_63	1.641	1.623	-0.018	2.019
K	1.556	1.572	0.016	1.604
L	1.508	1.629	0.121	1.717
M	1.680	1.712	0.032	1.857
N	1.696	1.718	0.022	1.883
O	1.688	1.730	0.042	1.826
P	1.659	1.699	0.040	1.361
Q	1.675	1.670	-0.005	1.451
R	1.665	1.687	0.022	2.005
S	1.705	1.705	-0.000	1.942
T	—	—	—	1.000

Note: An em dash indicates an unavailable or undefined result. Industry descriptions appear in Table S1.

TABLE S3. Hypothetical extraction of foreign industry groups in 2022. Changes are relative to the unextracted production network; negative values indicate reductions.

Extracted	Nodes	Δ APL (%)	Δ requirements (%)
G	80	-2.31	-8.47
C20	80	-1.27	-6.54
C19	80	-1.08	-4.33
M	80	-1.46	-4.19
C24B	80	-0.40	-3.99
J62_63	80	-1.03	-3.49
H49	80	-0.89	-3.16
N	80	-0.98	-2.95
C26	80	-0.63	-2.93
K	80	-0.69	-2.28

Note: The upstream requirements measure is the sum of positive-length Leontief requirements, not an estimate of output losses.

TABLE S4. Hypothetical extraction of individual foreign country–industry combinations in 2022. Changes are relative to the unextracted production network; negative values indicate reductions.

Extracted	Nodes	Δ APL (%)	Δ requirements (%)
CAN_C24B	1	-0.06	-1.93
CHN_C26	1	-0.34	-1.55
SWE_C19	1	-0.27	-1.11
CHN_C27	1	-0.20	-1.05
SWE_G	1	-0.27	-0.96
USA_G	1	-0.21	-0.91
IRL_J62_63	1	-0.21	-0.84
CHN_C20	1	-0.16	-0.84
DEU_C29	1	-0.12	-0.79
DEU_C20	1	-0.17	-0.79
DEU_G	1	-0.18	-0.73
CHN_G	1	-0.18	-0.67
USA_C20	1	-0.10	-0.62

Continued on next page

TABLE S4. Hypothetical extraction of individual foreign country–industry combinations in 2022. Changes are relative to the unextracted production network; negative values indicate reductions. (continued)

Extracted	Nodes	Δ APL (%)	Δ requirements (%)
BRA_C20	1	-0.10	-0.61
USA_M	1	-0.20	-0.61
USA_C302T309	1	-0.02	-0.60
CHN_C13T15	1	-0.13	-0.58
USA_B06	1	-0.10	-0.54
GBR_M	1	-0.20	-0.50
USA_K	1	-0.13	-0.39

Note: The upstream requirements measure is the sum of positive-length Leontief requirements, not an estimate of output losses.

TABLE S5. International benchmark of mean transaction-weighted backward average propagation length (APL), 1995–2022. Means are calculated over industries with valid values in both years for each economy.

Economy	Valid	1995 APL	2022 APL	Change	Increase	Decrease
South Korea	49	1.657	1.857	+0.200	49	0
Germany	48	1.661	1.794	+0.133	44	4
Finland	48	1.639	1.758	+0.119	45	3
Canada	49	1.532	1.643	+0.111	48	1
Denmark	47	1.577	1.671	+0.094	44	3
Japan	49	1.634	1.707	+0.073	44	5
Sweden	49	1.699	1.765	+0.066	43	6
Netherlands	47	1.618	1.682	+0.064	42	5
United Kingdom	48	1.710	1.759	+0.049	33	15
Norway	49	1.656	1.687	+0.031	37	12
United States	49	1.655	1.674	+0.019	32	17
Iceland	46	1.698	1.598	-0.100	19	27
China	49	2.089	1.988	-0.101	11	38

Notes: Valid denotes the number of industries with defined APL in both years. Increase and decrease indicate the number of industries with positive or negative changes in APL. National APL is the unweighted arithmetic mean of valid industry-level transaction-weighted backward APL values, rather than an economy-wide final-demand-weighted APL. All economies are calculated within the full global ICIO system.