

Industrial and Regional Trade Patterns in Zurich: A Structural Analysis

Export and Import Data of the Canton of Zurich, 2016–2024

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1 Data and Methodological Framework

1.1 Data Sources and Scope

1.1.1 Primary Trade Dataset

The primary dataset used in this project is “*Warenimporte und -exporte im Kanton Zürich*”, published on opendata.swiss by the Canton of Zurich. The dataset provides annual information on the value of goods imports and exports associated with the Canton of Zurich, disaggregated by partner country, industry classification, trade direction (import/export), and year.

Trade values are reported in Swiss francs (CHF) and cover the period from 2016 to 2024. This temporal range enables the analysis of both long-term structural patterns and shorter-term fluctuations in Zurich’s international trade relationships. Due to its relatively high level of aggregation, the dataset is particularly well suited for macro-level and structural exploratory analysis, allowing the identification of dominant trading partners, sectoral specialisation, hierarchical trade relationships, and shifts in Zurich’s global economic positioning over time.

1.1.2 Supplementary Economic Context

To provide additional economic context for selected comparative interpretations, country-level GDP data were incorporated as supplementary information. These data were used to support qualitative interpretation of trade volumes and growth patterns rather than as direct inputs into statistical modelling.

1.2 Analytical Workflow and Tooling

1.2.1 Data Processing and Transformation

All analytical procedures were implemented in the R programming environment, drawing primarily on the tidyverse ecosystem for structured data manipulation and ggplot2 for visualisation. The workflow was organised to enable multi-scale examination of Zurich’s trade system, integrating spatial mapping, sectoral aggregation, ranking dynamics, and temporal analysis within a unified reproducible pipeline.

1.2.2 Use of Computational Assistance

Large language models (ChatGPT and Gemini) were used exclusively as auxiliary tools for code debugging, language refinement, and text structuring. All analytical design choices, data transformations, visualisations, and interpretations were developed, implemented, and validated independently by the authors.

1.3 Research Design and Analytical Positioning

This study is explicitly exploratory and structural in nature. Rather than aiming for causal inference or econometric prediction, the analysis focuses on identifying persistent patterns, hierarchies, and asymmetries in Zurich’s trade architecture through descriptive metrics and comparative visualisation.

1.4 Methodology

1.4.1 Data Processing and Harmonisation

Prior to analysis, the raw trade dataset underwent systematic preprocessing to ensure internal consistency and comparability across visualisations. Country identifiers were standardised, sector classifications were

consolidated, numeric fields were validated, and missing or duplicate observations were resolved. Where multiple records existed for the same country–industry–year combination, trade values were aggregated to produce coherent analytical units.

Country names were harmonised to ensure consistency across data joins and visualisations, particularly when integrating geographic reference files for the world maps. Numeric fields were converted to appropriate data types, and missing values were handled systematically. Duplicate or incomplete observations were identified and removed where necessary. In cases where multiple records existed for the same country–industry–year combination, trade values were aggregated to obtain a single, coherent observation. Where required, auxiliary datasets, such as geographic world shapes, were joined to the trade data using standardised country identifiers.

1.4.2 Analytical Segmentation and Aggregation Strategy

To reduce visual clutter and improve interpretability, the dataset was segmented in several ways prior to visualisation. Exports and imports were analysed separately for the global trade maps in order to preserve directional differences in Zurich’s trade relationships. For comparative analyses, subsets of trading partners were selected based on cumulative trade volume, resulting in focused views such as the top-10 or top-30 partner countries.

Similarly, the most relevant industries were identified by total export value aggregated across the full observation period, allowing sectoral patterns to be highlighted without overloading the figures. Smaller country subsets were additionally used for detailed sector-level trend analyses.

Several derived tables were constructed to support different analytical perspectives, including country-level aggregates for exports and imports, sector-level time series by country, total trade volumes aggregated across years, and summary statistics used to characterise growth and volatility. This selective aggregation strategy enabled a balance between comprehensive global coverage and clear, readable visualisations, particularly in multi-facet plots.

1.4.3 Descriptive Metrics and Exploratory Modelling Approach

Rather than employing complex econometric models, the analysis focused on a set of interpretable descriptive measures designed to support exploratory comparison. These included average annual growth rates of trade volumes, volatility measured as the standard deviation of year-to-year growth, and relative rankings of trade partners over time. Log-scaled transformations were applied where necessary to account for substantial differences in absolute trade volumes across countries and industries.

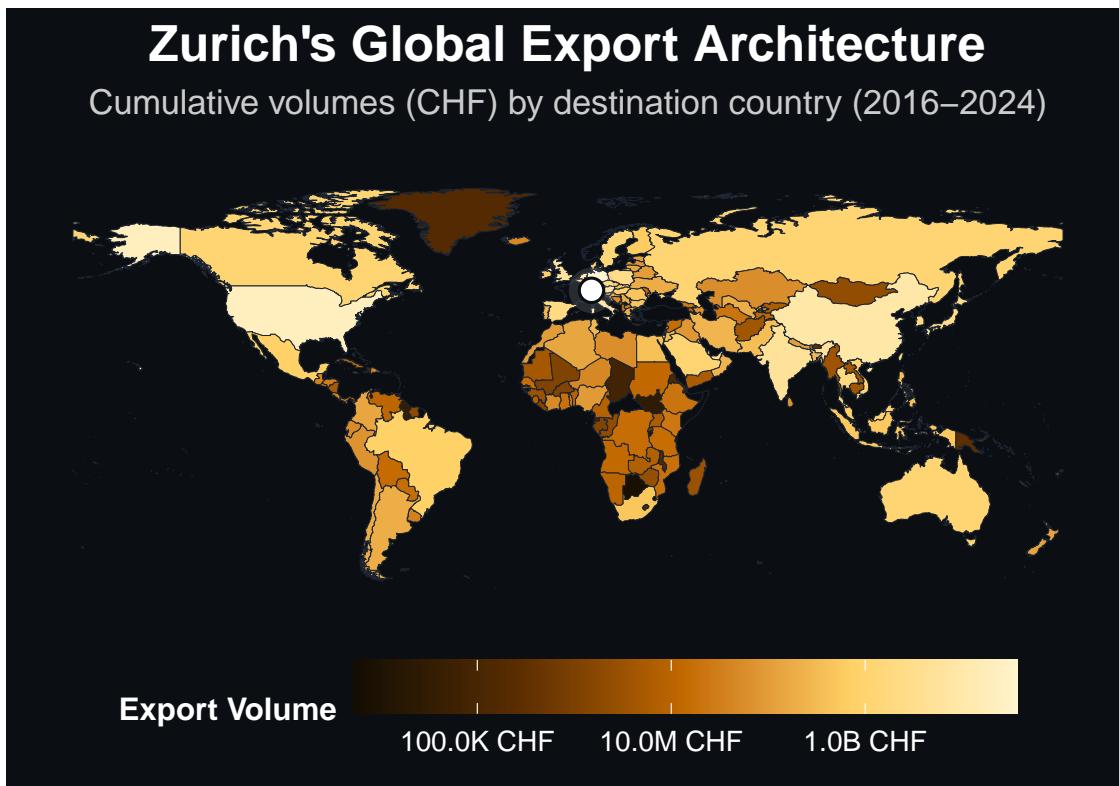
These metrics were selected for their interpretability and robustness within an exploratory framework. They enable meaningful relative comparison across countries without imposing functional assumptions or model-based causality, which lies beyond the scope of this study. Accordingly, all visualisations emphasise structural patterns and comparative positioning rather than predictive precision, reinforcing the descriptive and narrative orientation of the analysis.

2 Plots and Interpretation

2.1 Global Trade Architecture: Spatial Structure of Zurich's Trade Network

The paired world maps provide a structural overview of Zurich's global trade architecture by visualising cumulative exports and imports across the full observation period. Rather than emphasising short-term fluctuations, these maps reveal the geographic logic and asymmetry underlying Zurich's integration into global trade networks.

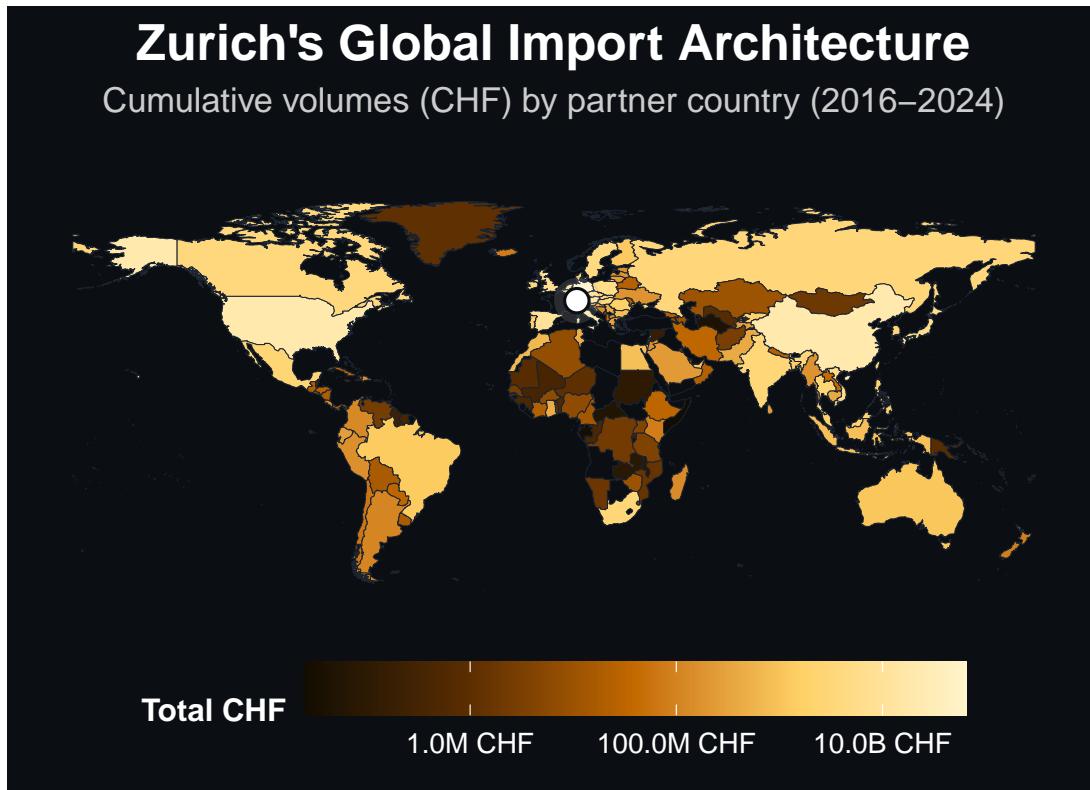
2.1.1 Export Structure: A Regional Core with Selective Global Reach



Zurich's export structure is anchored in a dense European core, with particularly high volumes directed towards neighbouring and economically integrated countries. This concentration reflects Zurich's deep embedding within European value chains, where proximity, regulatory alignment, and long-standing industrial interdependencies facilitate stable and high-volume trade relationships.

Beyond Europe, a limited number of global economic powers, most notably the United States and China, emerge as dominant non-European destinations. Their prominence indicates that Zurich's export engine extends selectively into global markets where demand for high-value, technologically sophisticated goods is structurally entrenched. Overall, the export map reveals a hub-and-spoke configuration: a stable regional backbone complemented by targeted global corridors rather than diffuse worldwide expansion.

2.1.2 Import Structure: Global Dispersion and Supply Chain Diversification



The import map displays a markedly broader spatial footprint. While Europe remains the dominant source of imports, inbound trade volumes are more evenly distributed across Asia, the Americas, and parts of Africa. This dispersion suggests that Zurich's economy draws on a globally diversified supplier base, sourcing raw materials, intermediate goods, and specialised inputs beyond its immediate regional environment.

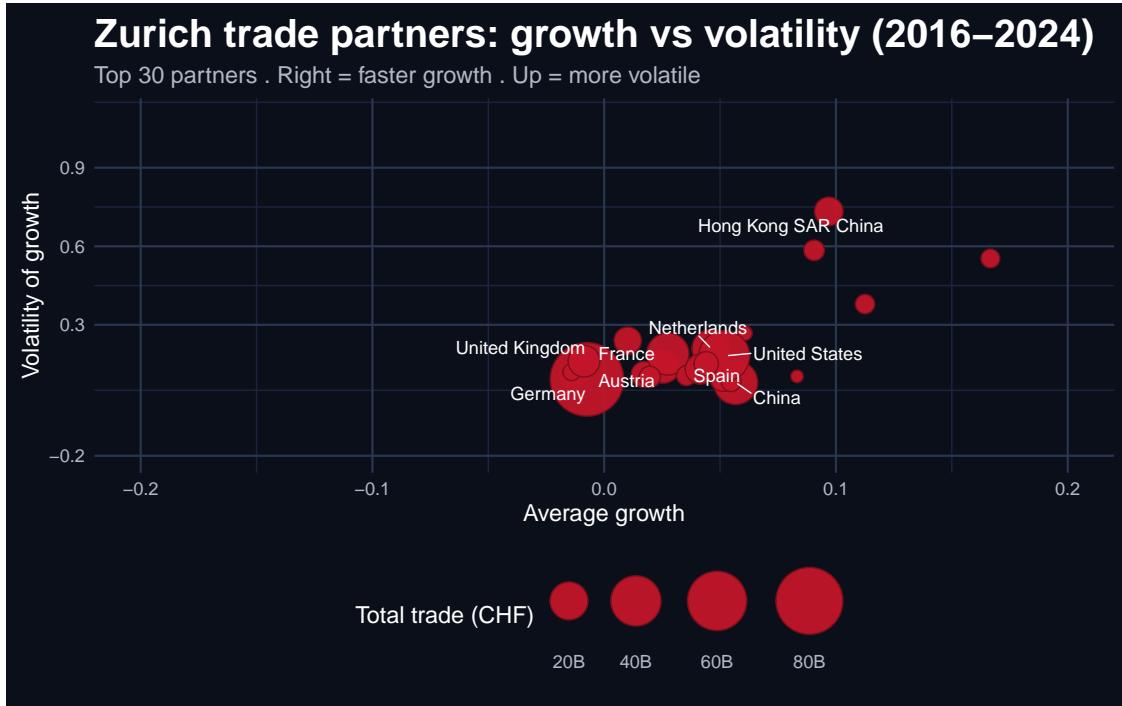
Compared to exports, imports therefore exhibit a higher degree of geographic diversification, pointing to a structural asymmetry: Zurich concentrates its export activity on a limited set of high-capacity markets while maintaining a wide, globally distributed network of suppliers. This pattern indicates a deliberate reliance on international supply chains as a stabilising mechanism.

2.1.3 Structural Synthesis

Taken together, the paired maps reveal a dual architecture. Zurich operates as a regionally embedded exporter within Europe while functioning as a globally integrated importer across continents. This asymmetric configuration suggests a trade model in which value creation is regionally concentrated, while resilience is achieved through broad-based global sourcing. These spatial foundations provide essential context for the subsequent analyses of trade dynamics, rankings, and volatility.

2.2 Growth–Volatility Landscape: Stability versus Dynamism

The growth–volatility scatter plot positions Zurich’s top 30 trade partners within a two-dimensional structural space defined by average growth and growth volatility, with bubble size representing cumulative trade volume. This configuration enables simultaneous assessment of scale, stability, and dynamism within Zurich’s trade portfolio.



A dense cluster of core partners, including Germany, the United States, the Netherlands, France, and Austria, emerges close to the origin of the plot. These countries combine large trade volumes with low volatility and moderate growth, indicating mature and predictable trade relationships. Their position suggests that Zurich’s economic backbone rests on structurally stable partnerships rather than high-growth, high-risk markets.

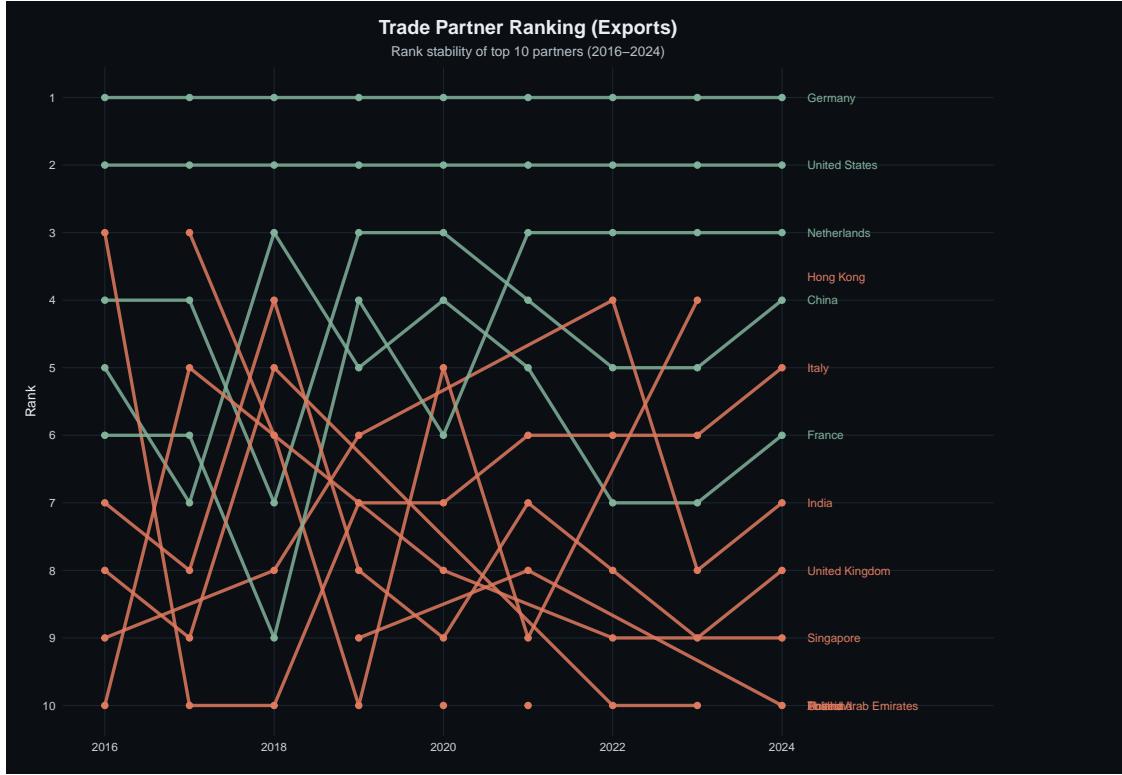
In contrast, several peripheral partners occupy more extreme positions. Countries such as South Africa and Mexico display comparatively strong average growth but elevated volatility, signalling expansion potential coupled with instability. Others, including Hong Kong SAR China and Russia, appear high on the volatility axis despite limited or negative growth, reflecting episodic or shock-sensitive trade dynamics.

The overall distribution reveals a clear core–periphery configuration characterised by a negative association between scale and volatility. Larger trade corridors tend to exhibit greater stability, suggesting that institutional depth and repeated exchange may dampen fluctuations. Smaller or emerging partners, by contrast, contribute dynamism but also introduce variability.

Taken together, the pattern resembles a portfolio architecture: a stable economic core generating predictable baseline flows, complemented by higher-variance peripheral engagements that provide optionality for growth without undermining systemic resilience.

2.3 Hierarchical Stability: Evolution of Top Trade Partners

The bump chart traces the relative ranking of Zurich's top ten export partners between 2016 and 2024, revealing the temporal architecture of the trade hierarchy rather than merely its composition.



2.3.1 The Anchored Apex: Structural Inertia at the Top

Germany and the United States form an immovable apex, consistently occupying the first and second ranks throughout the entire period. Their uninterrupted dominance reflects strong structural inertia: these relationships are deeply embedded within Zurich's export system, and entry into this top tier appears highly constrained. The persistence of rank positions suggests path dependence rather than cyclical fluctuation, indicating institutional and sectoral integration that extends beyond short-term market dynamics.

2.3.2 Upper-Tier Stability with Limited Mobility

Countries such as the Netherlands and China fluctuate modestly within the upper tier, suggesting sustained relevance accompanied by adaptive sectoral realignment. Their limited mobility indicates stability, yet the absence of overtaking behaviour highlights the rigidity of the very top ranks.

2.3.3 The Contestable Middle: Competitive Reordering

Greater rank mobility is observed among mid-tier partners, including Italy and France. Their repeated positional shifts reflect a structurally contestable band in which relative performance is sensitive to sector-specific developments and cyclical demand changes. This middle segment appears competitive rather than entrenched, indicating ongoing reallocation within the export portfolio.

2.3.4 Permeable Margins: Entry and Exit Dynamics

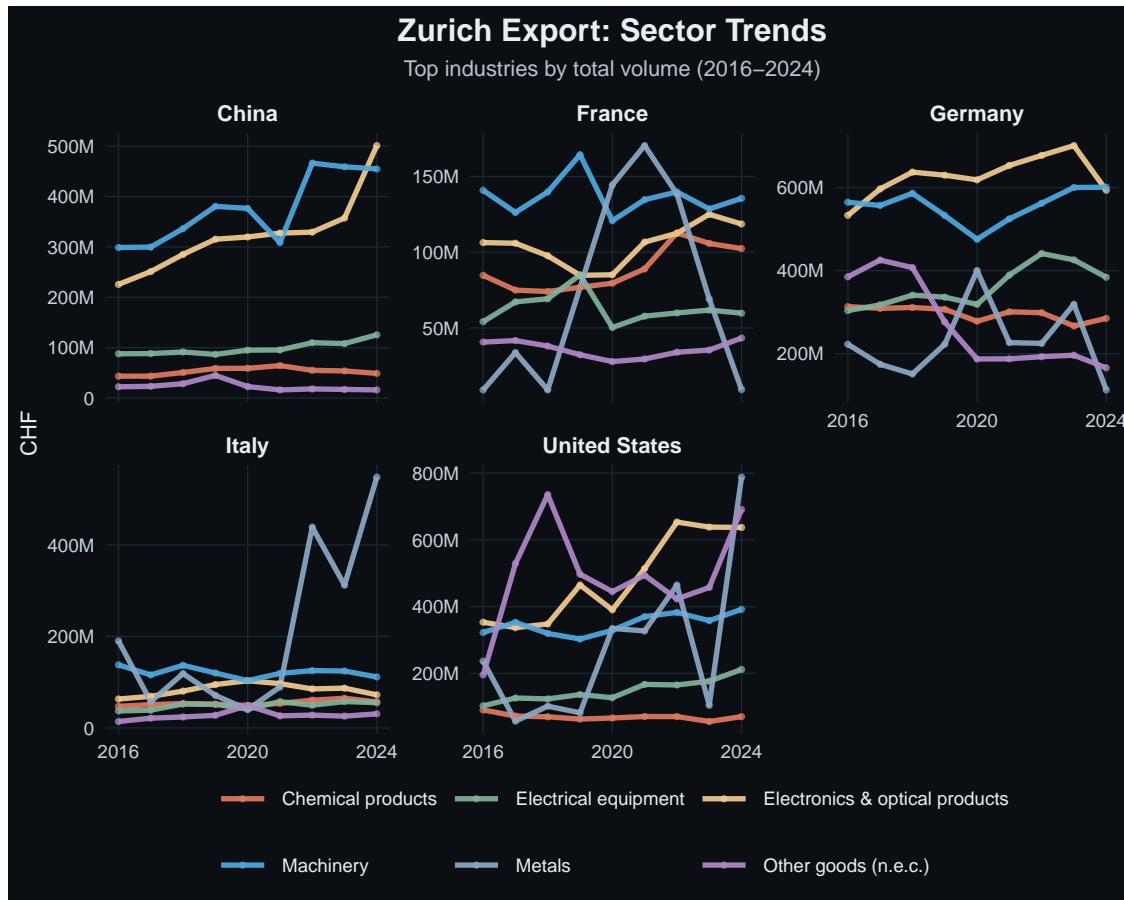
Lower-ranked partners, such as India, the United Kingdom, and Singapore, exhibit the highest degree of rank instability, frequently entering and exiting the top tier. This volatility suggests permeability at the margins of the hierarchy. While upward mobility into the apex remains rare, the lower ranks function as an adaptive frontier where emerging trade relationships can scale temporarily before either consolidating or receding.

2.3.5 Structural Conclusion

Taken together, the bump chart reveals a stratified but dynamic hierarchy: a structurally anchored core, a competitively fluid middle tier, and a volatile outer band. Zurich's export system thus combines path-dependent dominance at the top with adaptive reordering below, reinforcing the interpretation of a stable yet responsive trade architecture.

2.4 Line Chart: Trade Intensity

The multi-facet line plot examines Zurich's export composition across major partner countries, disaggregated by industry and observed over time. By employing country-specific y-scales, the analysis foregrounds within-country structural dynamics rather than absolute cross-country comparisons.



2.4.1 China: Concentrated Technological Dependence

Exports to China are overwhelmingly concentrated in machinery, electronics and optical products. Both sectors exhibit sustained upward trajectories, with electronics accelerating sharply after 2021. Other industries remain marginal, indicating a highly focused export relationship driven by China's demand for advanced industrial technologies.

2.4.2 France: Diversified but Volatile Composition

France displays a comparatively balanced sectoral structure, with machinery and electronics alternating in dominance. Pronounced volatility, particularly in metals, suggests episodic demand rather than steady structural dependence. The export relationship is diversified but less predictable, reflecting sensitivity to short-term industrial cycles.

2.4.3 Germany: Diversified Stability

Germany emerges as Zurich's most structurally stable export market. High and steady volumes across machinery, electronics, and electrical equipment indicate deep industrial integration. Limited volatility across sectors points to a resilient, multi-pillar relationship that cushions sector-specific shocks.

2.4.4 Italy: Sector-Specific Dependency

Exports to Italy are dominated by extreme volatility in metals, particularly after 2021, while other sectors remain comparatively small. This pattern suggests a narrow, event-driven export structure rather than broad-based integration.

2.4.5 United States: Dynamic but Unstable

The United States exhibits the highest overall sectoral volatility. Electronics, other goods, and metals show sharp episodic spikes, while machinery follows a steadier growth path. This combination indicates a high-value but cycle-sensitive export relationship influenced by market conditions and discrete trade events.

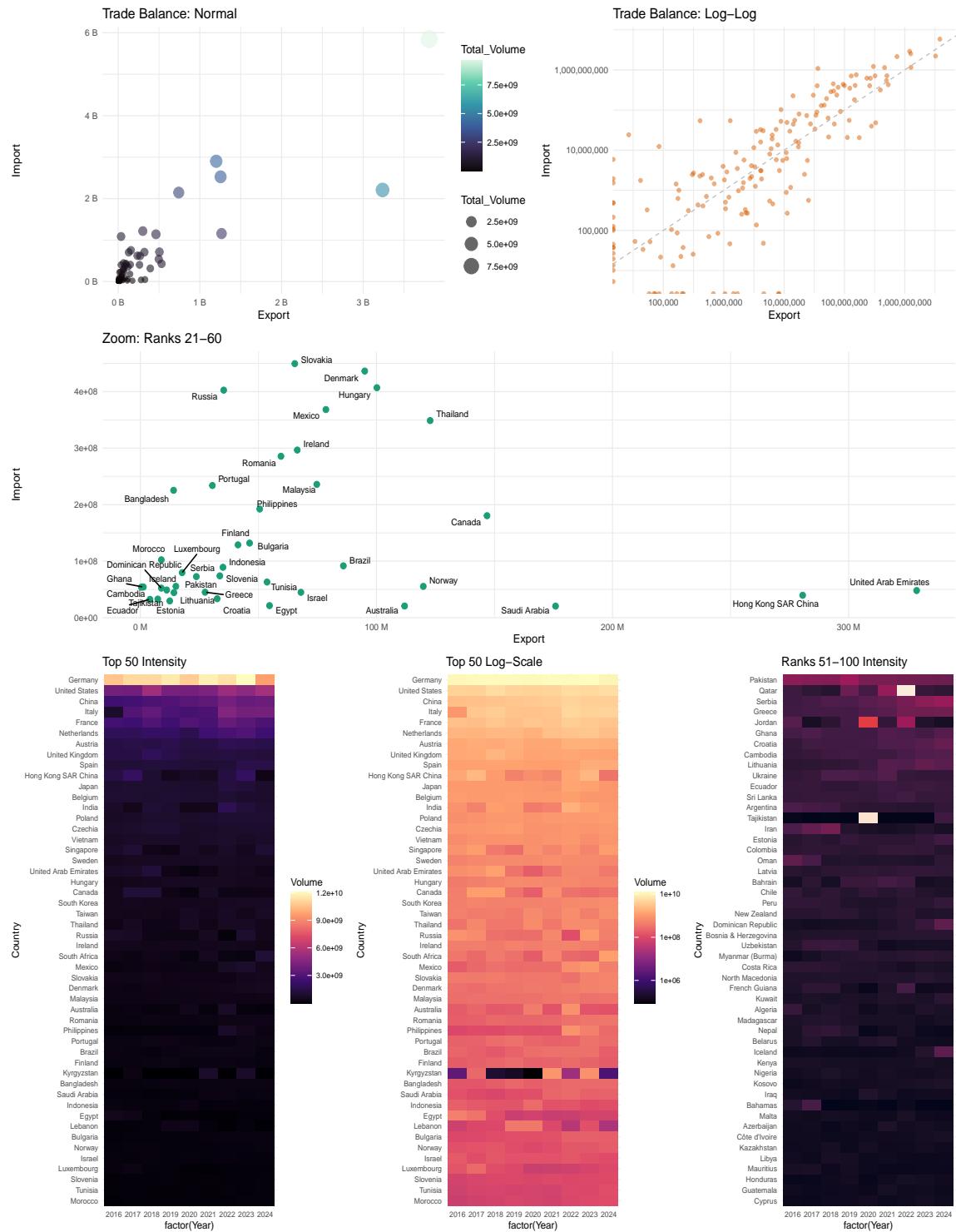
2.4.6 Cross-Country Synthesis

Across all partners, machinery, electronics and optical products form the structural backbone of Zurich's export engine. However, the degree of diversification and volatility varies markedly. Germany represents a model of stable integration, while Italy and the United States illustrate sectorally concentrated and more volatile dependencies. These contrasts underscore the importance of temporal and sectoral disaggregation when interpreting aggregate trade figures.

2.5 Heatmap: Zurich Trade versus GDP

Structural Trade Analysis: Zurich Global Footprint

Integrated view of trade balances and temporal intensity (2016–2024)



To move beyond traditional trade metrics, this section introduces a structural macro-economic study that utilizes trade flows as a proxy for the global economic footprint of the Canton of Zurich. By shifting the analytical focus from absolute volume toward industrial and regional architecture, the study uncovers the specific role the Canton occupies within the prevailing global economic order.

2.5.1 Analytical Framework and Data Architecture

The transformation of raw industrial trade data into a structured macro-economic analysis was guided by a four-stage methodological framework designed to ensure mathematical rigour and interpretive coherence. The first stage involved the implementation of an active-partner filter, removing non-reporting observations and zero-value trade entries. This step reduced distortion in subsequent transformations and ensured stability for logarithmic scaling procedures.

The second stage introduced a multi-scale analytical perspective, conceptualised as a triple-lens framework. Rather than relying on a single metric, trade relationships were examined across three complementary scales. Absolute values (normal scale) were used to identify high-volume partners and dominant trade corridors. Logarithmic scaling was applied to assess proportional symmetry and relative positioning across countries of vastly different economic size. A focused zoom scale further isolated mid-tier partners to reveal structural dynamics that would otherwise be obscured by large-volume outliers.

Subsequently, long-format trade data were reshaped into a partner-level wide structure, establishing a bi-lateral export-import axis for each country. This transformation enabled the evaluation of trade balance symmetry rather than volume alone. The final stage applied temporal heat-mapping to trace trade intensity across the nine-year period from 2016 to 2024, allowing structural persistence and shock sensitivity to be assessed within a unified visual framework.

2.5.2 Structural Revelations and Market Dynamics

The most prominent finding, identified as the trade corridor symmetry, emerged from a log-log scatter plot analysis where nearly all trading partners clustered within a tight, diagonal corridor. This confirms that Zurich does not maintain extractive, one-way relationships; instead, a strong scaling law is at play where a partner's capacity to export back to the Canton grows in direct proportion to its imports from Zurich. Consequently, Zurich is positioned as an integrated economic partner rather than a mere supplier, with any significant deviations representing untapped potential or trade barriers.

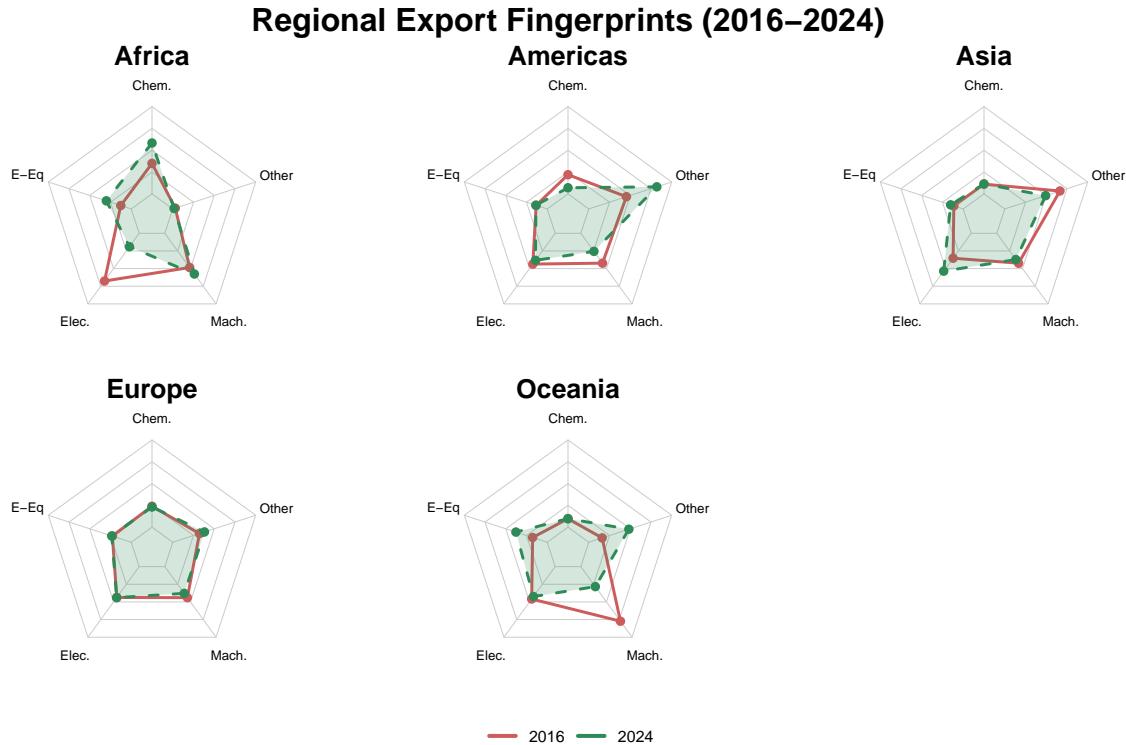
Analysis into baseline resilience through log-transformed heatmaps indicates that Zurich's economy is anchored by broad-based stability, with trade intensity remaining consistent across the top 50 partners even during the global shocks of 2020. While major Giants provide high volume, mid-tier partners provide the structural reliability that cushions the Canton against volatility. Finally, zooming into partners ranked 21–60 identified an Engine Room of countries currently in a High-Intensity Growth Phase. These nations represent the future pillars of Zurich's wealth, occupying a "sweet spot" where established supply chains meet expanding trade presence.

2.5.3 Strategic Synthesis and Conclusion

Zurich operates as a highly specialised economy supported by a global safety net, selling high-complexity high-tile goods like Pharmaceuticals and Tech while maintaining stability through a vast mosaic of imported needs. The structural analysis highlights that as long as the Symmetry Corridor remains tight and the logarithmic intensity of the trade network remains consistent across mid-tier partners, Zurich's economic foundation remains exceptionally sound. The study concludes that the Canton's resilience is fundamentally rooted in its diversified import structure and the deep integration of its export engine into global value chains.

2.6 Spider Plot: Regionwise Trade Shifts

Zurich's global trade is characterized as a living system subject to constant structural transformation. To capture these dynamics, Section 2.6 utilizes Evolutionary Radar Plotting, a method designed to transcend isolated year-over-year comparisons and expose the long-term Structural Drift of the Canton's economic influence.



2.6.1 Methodological Construction of the “Time-Travel” Radar Framework

Standard economic reports often rely on static snapshots that frequently obscure critical signals of structural change. To address this, we leveraged the full 2016–2024 timeline from our primary dataset to identify whether a region is simply increasing its purchase volumes or fundamentally shifting what it buys. This process involved selecting the top six export industries by 2024 volume and calculating their percentage share per continent in both the 2016 baseline and the 2024 current state.

The resulting dual-layer radar charts utilise a specific visual grammar to make these temporal shifts immediately clear to any observer. A red dashed line represents the 2016 economic baseline, serving as the historical starting point, while a green filled area represents the 2024 economic footprint. This overlay allows for an immediate identification of expansion, where the green area stretches beyond the red line, and drift, where the overall shape of the trade web changes to favor new industrial priorities.

2.6.2 Interpretation of Continental Trade DNA

The radar webs illustrate two primary phenomena that define Zurich's global reach: Expansion and Specialization. In mature markets like Europe and the Americas, the webs appear most circular, with the green area expanding almost uniformly across all six industry axes since 2016. This balanced roundness suggests highly resilient relationships where maturity in the market allows for cross-sectoral support; for instance, a

downturn in the pharmaceutical sector can be mitigated by stability in machinery or metal exports, ensuring a steady economic pulse.

In contrast, Asia has undergone a massive and aggressive expansion specifically along the Machinery and Electronics axes. This represents a profound structural pivot where Asia has transitioned from an emerging destination into a dominant, specialized customer for Zurich's most complex technical engineering exports. Similarly, Africa and Oceania exhibit sharp, narrow needle spikes that have elongated significantly since the baseline year. While this growth is impressive, the spike shape indicates a tactical market where Zurich has gained a foothold but remains dangerously concentrated in a few sectors, resulting in higher economic vulnerability if those specific industries face a downturn.

2.6.3 Future-Looking Posture

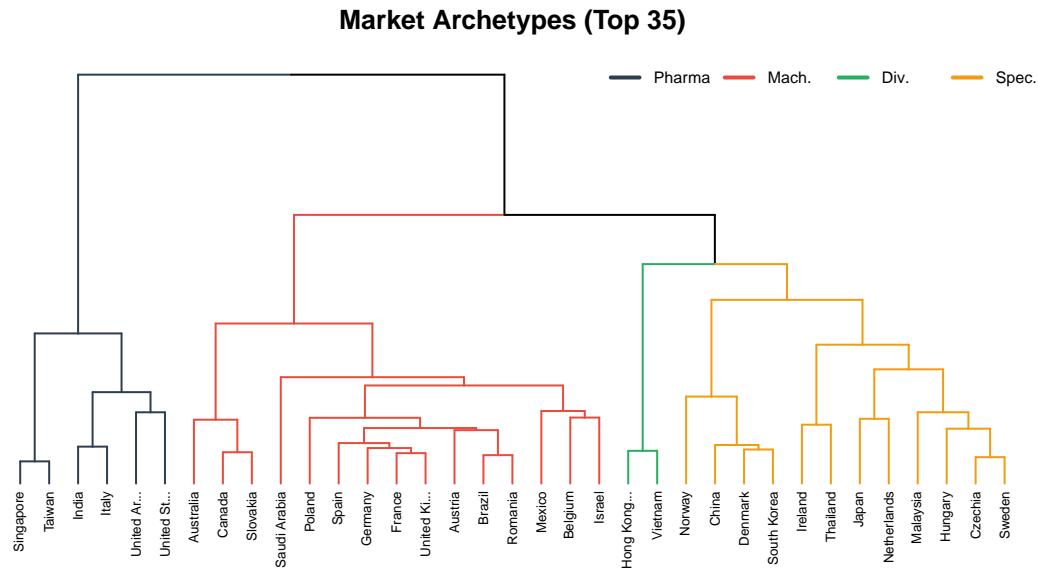
The cumulative evidence suggests that Zurich is successfully transitioning from a generalist supplier into a critical Technological Pillar for the global economy. While Europe remains a stable and diversified core, emerging markets are showing aggressive spikes in high-value sectors, making Zurich indispensable in global supply chains for specialized machinery and chemicals. This shift proves that Zurich's value is increasingly tied to its specialized knowledge and precision manufacturing rather than simple commodity trade.

To maintain this momentum, Zurich can adopt a dual-track approach that balances defense with expansion. In mature markets like Europe and the Americas, the priority is retention and preserving the round web shape to guard against sector-specific recessions. In high-growth tactical markets like Africa or Oceania, Zurich can leverage its current dominance in Machinery to cross-sell into the empty spaces of the radar web, such as Electronics or Pharmaceuticals. By filling in these gaps, Zurich can transform narrow, vulnerable spikes into broad and resilient strategic partnerships.

2.7 Global Mirror: Zurich's Strategic Market Archetypes

This stage of the analysis synthesises Zurich's macroeconomic trade profile by shifting from volume-based comparisons to structural mapping. By combining waffle matrices with multi-scale scatter and heatmap visualisations, the focus moves from aggregate magnitude to underlying sectoral composition and trade symmetry.

Rather than asking which partners trade the most with Zurich, this section examines how trade is structured across industries and whether these structures differ systematically between countries.



2.7.1 Technical Architecture

Traditional economic reporting often emphasises aggregate growth, which can obscure underlying structural concentration and vulnerability. This analysis therefore prioritised sectoral composition and relative proportionality, specifically examining whether high-technology industries such as pharmaceuticals are expanding their share relative to traditional manufacturing sectors within regional trade profiles.

Logarithmic scaling was applied to evaluate proportional trade relationships across partners of widely differing economic size. This enabled meaningful comparison between large and small economies without allowing absolute volume to dominate interpretation. Complementary temporal heat-mapping further facilitated the examination of persistence and shock sensitivity across the global trade network, particularly during periods of external disruption.

The data model incorporated a normalisation procedure to remove non-reporting observations and to consolidate thirty-eight industrial categories into analytically coherent sectoral groupings. To preserve proportional accuracy within waffle matrices, a discrete allocation procedure based on the Largest Remainder Method was applied. This ensured that rounding adjustments did not distort sectoral representation, particularly for smaller industries.

All analyses were conducted within the previously introduced multi-scale framework, examining trade relationships across absolute, logarithmic, and mid-tier focused perspectives in order to capture dominance, proportional balance, and structural nuance within a unified analytical architecture.

2.7.2 Market Revelations

The integrated model reveals a clear structural contrast between Zurich's export and import architectures.

On the export side, several partner countries display high sectoral concentration, particularly in pharmaceuticals and advanced machinery. This reflects strong competitive positioning in knowledge-intensive industries but also indicates increasing exposure to sector-specific fluctuations.

In contrast, import structures are generally more diversified across product categories. This broad-based sourcing pattern reduces dependence on individual sectors and enhances resilience against external supply shocks.

The log-log scatter analysis further identifies a consistent proportional relationship between exports and imports across most partner countries. Rather than maintaining predominantly one-sided trade flows, Zurich appears embedded in reciprocal exchange patterns where higher export volumes tend to be accompanied by correspondingly high import volumes. This proportional symmetry suggests deep economic integration rather than extractive or asymmetrical relationships.

Temporal heatmap analysis supports this interpretation: trade intensity remained comparatively stable across core and mid-tier partners even during the global disruptions of 2020. This indicates that resilience is derived not solely from dominant high-volume partners, but from the durability of the broader trade network.

2.7.3 Strategic Synthesis

The evidence suggests that Zurich functions as a highly specialised exporter embedded within a diversified global sourcing system.

While sectoral concentration strengthens competitive advantage in high-value industries, it simultaneously reduces structural flexibility. As dominant sectors occupy a substantial share of export allocation, the relative space available for emerging industries becomes constrained.

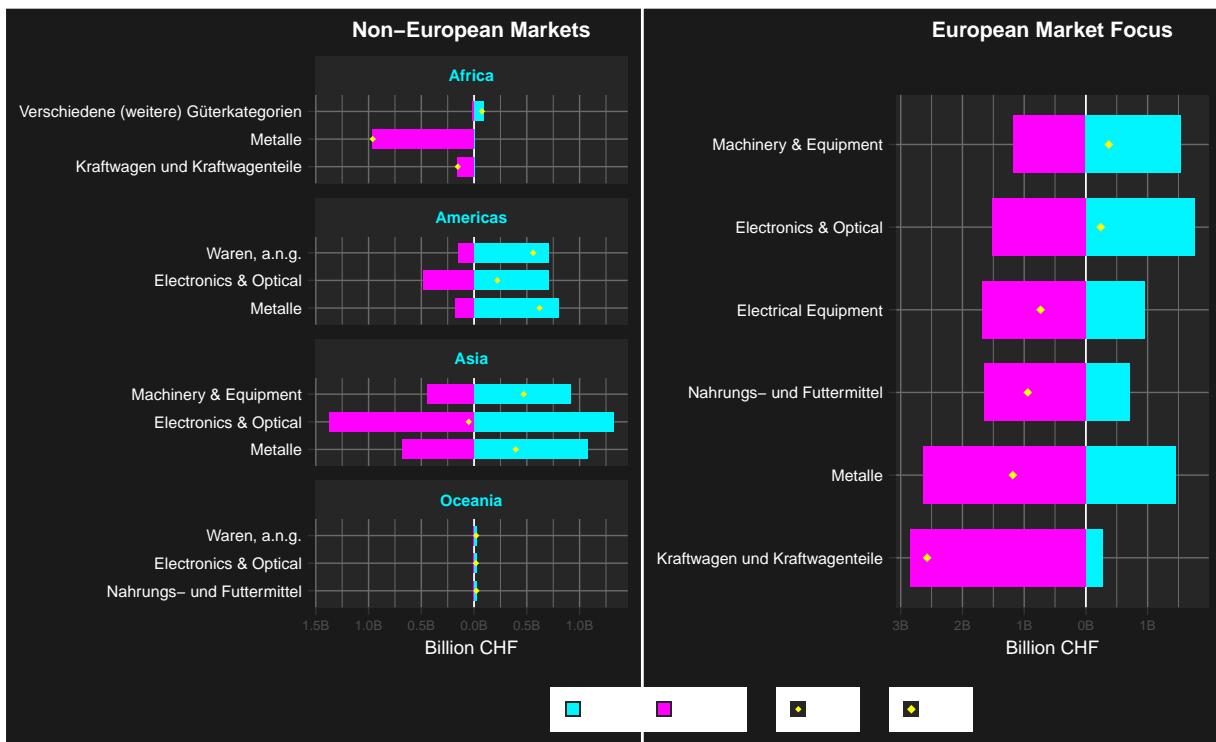
Mid-tier partners (ranks 21–60) emerge as particularly relevant in this context. These countries exhibit growing trade intensity without the saturation observed in top-tier markets, indicating potential for incremental diversification without destabilising existing core relationships.

Overall, Zurich's structural position combines concentrated export expertise with diversified import resilience. Maintaining this balance will be central to sustaining long-term adaptability within an increasingly volatile global trade environment.

2.8 Continental Equilibrium: The Zurich Trade Pulse Analysis

This section examines Zurich's 2024 trade configuration by distinguishing between its deeply integrated European relationships and its more specialised global engagements. Butterfly charts are used to compare exports and imports across regions, highlighting areas of structural balance and asymmetry.

Rather than focusing solely on trade surplus or deficit, the analysis evaluates sectoral leverage and dependency patterns within each continental context.



2.8.1 European Integration and Structural Interdependence

Zurich's relationship with Europe is characterised by high levels of industrial integration across multiple sectors. Export and import flows exhibit relative balance across machinery, electronics, electrical equipment, and intermediate goods, reflecting tightly interwoven value chains.

In several sectors, export volumes exceed imports, indicating competitive strength and sectoral leverage. However, other categories show stronger import dependence, revealing continued reliance on European upstream production networks.

This dual pattern suggests not unilateral dominance but structural interdependence. Zurich's European trade position is anchored in mutual industrial integration rather than asymmetrical dependency.

2.8.2 Global Specialisation Beyond Europe

Outside Europe, Zurich's trade profile becomes more specialised.

In Asian markets, exports are concentrated in machinery and electronics-related products, indicating strong positioning within industrial supply chains. In the Americas, pharmaceuticals and advanced technical goods play a prominent role, reflecting the Canton's expertise in high-value medical and precision sectors.

Trade relationships with Africa and Oceania are comparatively narrower in sectoral scope. While certain industries show strong growth trajectories, the limited diversification within these regions increases sensitivity to sector-specific downturns.

Across non-European regions, Zurich's competitive advantage is rooted in specialised, high-complexity industries rather than broad multi-sector integration.

2.8.3 Core Industrial Pillars

The analysis identifies several industries that consistently shape Zurich's global trade profile.

Pharmaceuticals and life sciences generate substantial trade surpluses and represent a central pillar of export competitiveness. Machinery and electronics contribute to industrial integration across Europe and Asia, though these sectors remain sensitive to partner-country industrial cycles.

Other high-value sectors, including precision instruments and advanced manufacturing goods, reinforce Zurich's position in knowledge-intensive production networks.

At the same time, import-intensive sectors reveal areas of structural dependency, underscoring the importance of maintaining diversified sourcing strategies to mitigate supply risk.

Sustaining Zurich's trade resilience will require balancing specialisation with diversification, preserving competitive advantage in core industries while ensuring flexibility through adaptive sectoral development.

2.9 Chapter of Choice: The Meta-Analysis of Zurich's Industrial DNA (2016–2024)

This final analytical section utilizes Waffle Matrices to move beyond volume-based metrics. It provides a structural deep-dive into the economic attention of Zurich's global trade partners by adopting a zero-sum perspective.



2.9.1 The Rationale

Conventional bar and line charts, while effective for displaying magnitude and trend, often fail to reveal structural risk within an economic system. To address this limitation, this study employs waffle matrices as a complementary visual framework. Unlike continuous charts, the waffle representation imposes a fixed, zero-sum structure: each region is allocated exactly 100 tiles, each representing one percentage point of market share.

Within this configuration, any increase in one industry necessarily implies a reduction elsewhere. This constraint makes sectoral trade-offs immediately visible and allows for the identification of structural displacement processes within a region's trade profile.

In particular, this approach enables the visualisation of sectoral reallocation dynamics, whereby high-technology industries expand their relative footprint while traditional sectors contract. Because waffle ma-

trices depart from conventional Cartesian coordinate systems and instead rely on grid-based area encoding, their implementation required methodological steps beyond those typically covered in standard coursework.

2.9.2 The Largest Remainder Engine

To construct the waffle matrices, a discrete allocation procedure was required. Since each tile represents exactly one percentage point, fractional shares cannot be directly represented. For this reason, the Largest Remainder Method was applied to translate continuous percentage values into integer tile counts while preserving proportional accuracy.

This approach ensures that smaller sectors, such as Creative Services, retain visible representation, preventing aggregation into broad residual categories that might obscure underlying diversity. The rounding procedure guarantees that the total number of allocated tiles equals precisely 100 in every case, maintaining internal consistency across regions and years.

This step extends beyond routine tidyverse transformations, as it involves a formal allocation algorithm designed to preserve structural proportionality under discrete constraints.

2.9.3 Specialization vs. Resilience

The export matrices indicate a pronounced sectoral concentration in pharmaceuticals in Western markets. By 2024, pharmaceutical products account for a dominant share of the grid, substantially compressing smaller manufacturing sectors. While this reflects strong competitive advantage and high-value specialisation, the visual structure also signals increased concentration risk.

A highly concentrated export profile may expose the Canton to elevated vulnerability in the event of sector-specific shocks, as limited diversification reduces buffering capacity.

In contrast, the import matrices display a markedly more fragmented and diversified structure. The distribution of tiles across numerous sectors suggests broad-based sourcing patterns rather than reliance on a small number of inputs. This granular diversification enhances systemic resilience: disruptions in individual sectors are less likely to compromise the overall import architecture.

Viewed in combination, the waffle matrices reveal a structural asymmetry, concentrated export specialisation alongside diversified import sourcing, that underpins both Zurich's strength and its exposure.

2.9.4 Structural Constraints: The Golden Cage Dynamic

The structural configuration suggests a dual dynamic. On the one hand, the dominance of globally demanded sectors such as pharmaceuticals and advanced machinery provides a stable income base and strong international positioning. On the other hand, the high share occupied by these sectors limits structural flexibility.

When dominant industries account for a large proportion of total economic attention, the relative space available for emerging sectors becomes constrained. This may inhibit long-term diversification if not addressed proactively.

To mitigate this constraint, a forward-looking diversification strategy could preserve capacity for niche industries in emerging markets, thereby balancing the benefits of specialisation with the need for adaptive structural renewal.

3 Challenges, Limitations and Reflections

3.1 Data Coverage and Country Matching

A key challenge in this project was the harmonisation of country identifiers, particularly for the global maps. Some countries were not consistently recognised across datasets or spatial reference files, which occasionally led to missing or incorrectly mapped countries (e.g. France disappearing in early versions of the world map). This highlights a common limitation in international trade analysis: country names, codes, and geopolitical definitions do not always align cleanly across data sources and libraries. While these issues were resolved through manual checks and recoding, they underline the importance of careful validation when working with geospatial data.

3.2 Aggregation and Loss of Temporal Detail

Several visualisations rely on aggregation across years (e.g. world maps showing total trade volume across the full period). While this improves readability and highlights long-term patterns, it necessarily masks year-to-year changes, structural breaks, or short-lived shocks. As a result, countries with consistently high volumes dominate the visual narrative, while emerging or declining partners may appear less prominent despite meaningful dynamics in specific years.

3.3 Ranking-based Visualisations

The bump chart of top trade partners illustrates relative positions over time but comes with important limitations. Rankings hide absolute trade volumes, meaning that small rank changes can correspond to large or negligible volume differences. In addition, the choice of a top-10 cut-off introduces sensitivity: countries just outside the threshold may disappear entirely from the plot, even if their trade volume is close to those included. This makes rankings useful for comparative storytelling, but less suitable for precise quantitative interpretation.

3.4 Growth and Volatility Measures

The growth–volatility scatterplot summarises complex time series into two metrics: average growth and volatility. While this enables compact comparison across many partners, it also introduces simplifications. These measures are sensitive to extreme values and short-term fluctuations, and they do not capture structural changes within sub-periods. Furthermore, countries with similar positions in the plot may exhibit very different underlying trajectories, which are only visible when examining the full time series.

3.5 Sector Aggregation and Heterogeneity

Sectoral analyses group products into broad industry categories. While necessary for clarity, this aggregation can mask substantial heterogeneity within sectors, particularly for categories such as electronics & optical products or other goods (n.e.c.). As a result, observed trends may reflect shifts in specific sub-industries rather than the entire sector.

3.6 Visual Design Trade-offs

Producing clear, consistent, and readable visualisations, especially in dark mode, required careful tuning of colour palettes, legends, scales, and facet layouts. Several iterations were needed to ensure that legends, labels and colours were readable across plots. This process highlighted a broader trade-off between aesthetic clarity and information density, particularly when visualising multi-dimensional trade data.

3.7 Reflections and Outlook

Overall, the project demonstrates the strengths of exploratory trade analysis using visual methods, while also illustrating its limits. The findings should be interpreted as descriptive rather than causal, and as complementary views on the same underlying data rather than definitive conclusions. Future extensions of this work could address these limitations by incorporating higher-frequency data, finer sectoral disaggregation, or rolling-window approaches to better capture structural breaks and regime shifts within Zurich's trade system.

3.8 Final Synthesis

The findings in full portray Zurich as a highly specialised yet structurally resilient trading economy: one that derives strength from deep sectoral expertise on the export side while maintaining robustness through broad-based import diversification. This balance between concentration and mosaic resilience defines both the stability and the constraints of Zurich's future trade trajectory.

4 Sources

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