Measuring and visualising global value chains and their sensitivity to disruption

By Martin Bliemel, PhD, Associate Professor and Director of Research at TD School at the University of Technology Sydney (UTS) and Brian Wixted, PhD, Adjunct Professor at Johnson-Shoyama Graduate School of Public Policy University of Saskatchewan.

The world is more connected than we might expect. The famous 1967 study on small-worlds by Stanley Milgram showed that any two people are likely only six degrees of separation from each other. Fast forward a couple decades and that number shrinks, including for inter-business linkages and what's now known as the 'global factory'.

Much has been written about global value chains and trade, but it's notoriously hard to maintain oversight of them at a global scale. In this piece, we explore the use of Sankey and Chord Diagrams to express what global trade looks like and how sensitive they can be to disruption. These diagrams might help explain or visualise a few things to people wondering how inflation and shortages can spread internationally.

We dabbled in Sankey diagram visualisation of global trade data as part of a project lead by Brian Wixted using OECD data that spun out of his PhD and his now freely available book on Cluster Networks and Global Value. We chipped away at this work, with some additional intellectual oomph from the somewhat elusive yet prolific Göran Roos. The fruits of our effort were recently published in this Routledge Companion to Global Value Chains (GVCs). Our chapters started on quantitatively capturing the relationship between innovation and the global structure of export, and landed on a separate chapter and case study about how sensitive global value chains are to disruption.

Most of the diagrams we're showing here never made it into our chapters of case studies in that book and were held back as 'web appendices' when we submitted an earlier version to an academic journal. The Sankey and Chord Diagrams were experimental and didn't make our cut to be included as a web appendix. But, maybe it's time to revisit that. Before we get to the Sankey and Chord diagrams, let's take a spin though the network diagrams of manufacturing industries, followed by some consideration of how sensitive these GVCs can be to changes.

There are many case studies about floods, tsunamis or natural disasters disrupting things like primary industries and how that can spill over to other industries. Another well-known example is the blockage in the Suez. And now, there are obviously questions the impact of sanctions to Russia and also a loss in grain exports form Ukraine, and ripple effects from there.

In our exploration of GVC sensitivities to disruption, we picked on shipbuilding. It's an industry which invokes images of using a lot of domestic or regionally sourced steel and fittings, and generally being low-tech. Well, it turns out even this industry is globally highly interconnected.

First let's have a look at the networks structure of global value architectures. Note, this is based on inter-country input-output (IC-IO) data from around the year 2000 and only includes 48 industries and 24 countries (22 plus 'rest of world' and Mexico, both of which only had data about what they exported). From here, we focussed on 22 manufacturing industries. Critics might say 'Crikey! This is 20-some years behind the times!' and that it omits all the services and the 'global office' we operate in today. Yet still, there is a lot to be learned from this data, which we're (well, mainly Brian) exploring using newer and longitudinal data.

Building Inter-Country Input-Output (IC-IO) models is all a bit complicated but basically you get hold of I-O data, typically one dataset of domestic industry-to-industry trade + one dataset of imports-to-domestic industry (also structured as industry-to-industry trade) for each country. Then you slice up the imports data by bilateral trade flows. It's a pretty complex method and there are some big assumptions, but they are acceptable when working at the macro scale. From this process you end up with massive data tables from which you take it another step and run it through matrix algebra to work out proportions, not just absolute magnitude of trade. This is where most analysis of trade, whether via just the raw data or IC-IO, stops and provides highly aggregated statistics like net exports or super complex network diagrams where it is impossible to understand any details.

We took it a step further to explore the web of trade relations and investigate what the trade networks looked like when pared back to each industry-country combination's most valuable sources.

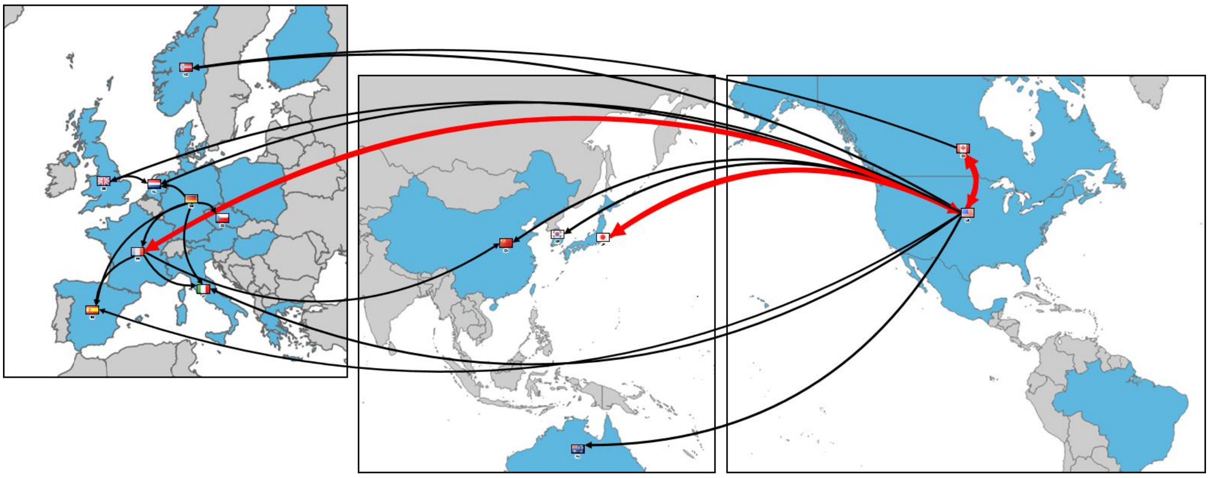
Level	Detail of GVCs analysis
Firm-level	Individual companies trading parts or equipment with one another for a single product
Industry-level	Super complex network flow diagrams such that it is impossible to see any particular flow
Industry-level but seeing just the skeleton (or architecture)	**The primary trade routes between individual countries – comparing different industries**
Macro-level	Macro views of trade between countries or trade blocks – often aggregated to bar charts and graphs

Our analysis effectively looks at the level of the skeleton, by generating industry specific 'x-ray' images. Technically, we called them trade complexes, not sectors or industries, since they capture the intra-industry trade as well as the inter-industry sources to a given industry. Identifying and visualising these trade complexes was probably our methodological innovation that made reviewers' heads explode and made them wonder if we were just making it up at this point. We weren't. By drawing on insights from analysing complex systems and their power-law distributions, we isolated the trade links that accounted for more than 10% of imported value. What remained from that filtering exercise were the skeletons or architectures (pick your favourite metaphor) of global value added for each industry's trade complex. These trade complex could then be quantified and ranked based on how interconnected each industry is, as an indicator of how innovative each industry is. To see how these objective measures stack up against classic but subjective measures of innovativeness across industry, see this chapter.

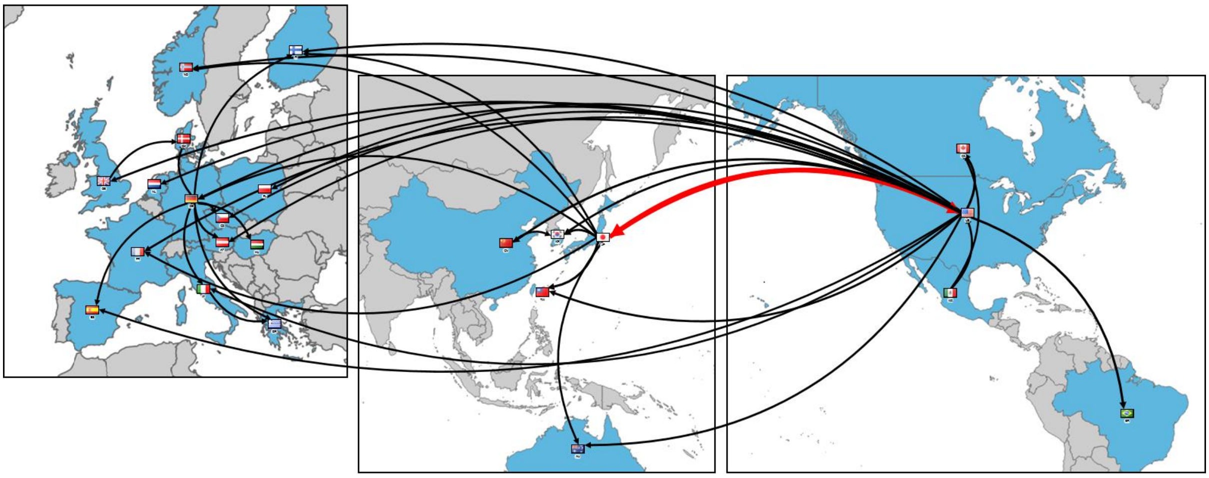
Here's a run-down of the 22 manufacturing industries, according to OECD industry labels from 2000, from the most innovative 'global factories' to the less innovative 'exo-nets'.

Data were available from the blue regions. More recent data sets have more countries, but unfortunately aggregate some industries. "Nec" means not elsewhere specified. Red arrows are bi-directional. The direction of the arrow indicates the direct of the flow of goods.

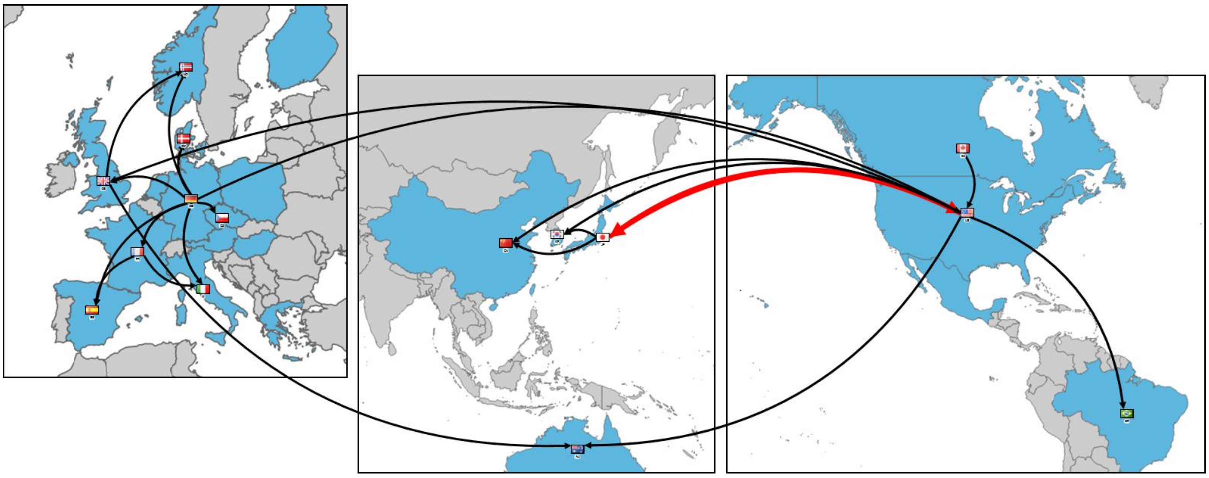
Aircraft and spacecraft (1995 to capture more countries - 2000 countries lacked data)



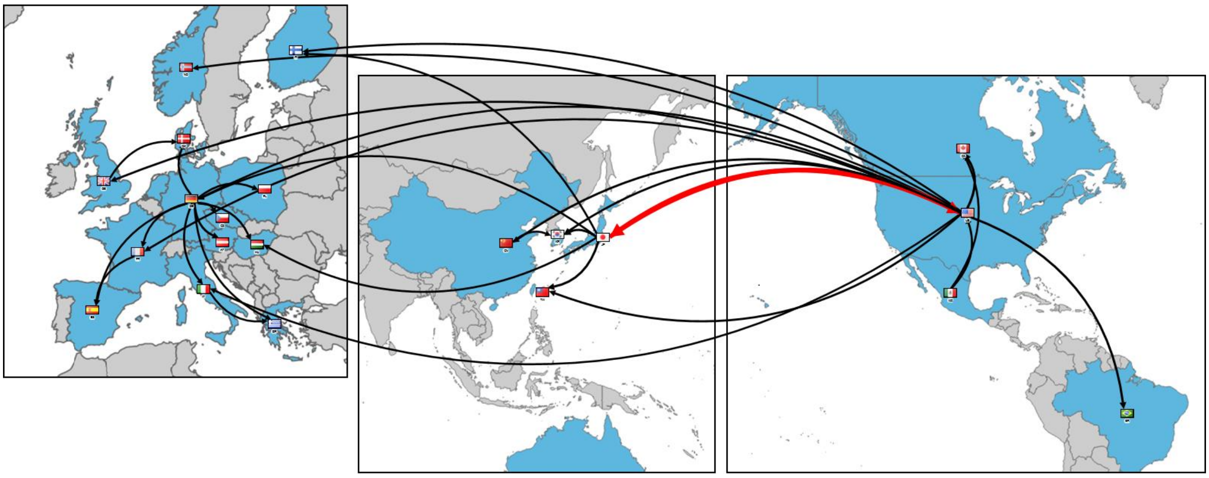
Office, accounting and computing machinery



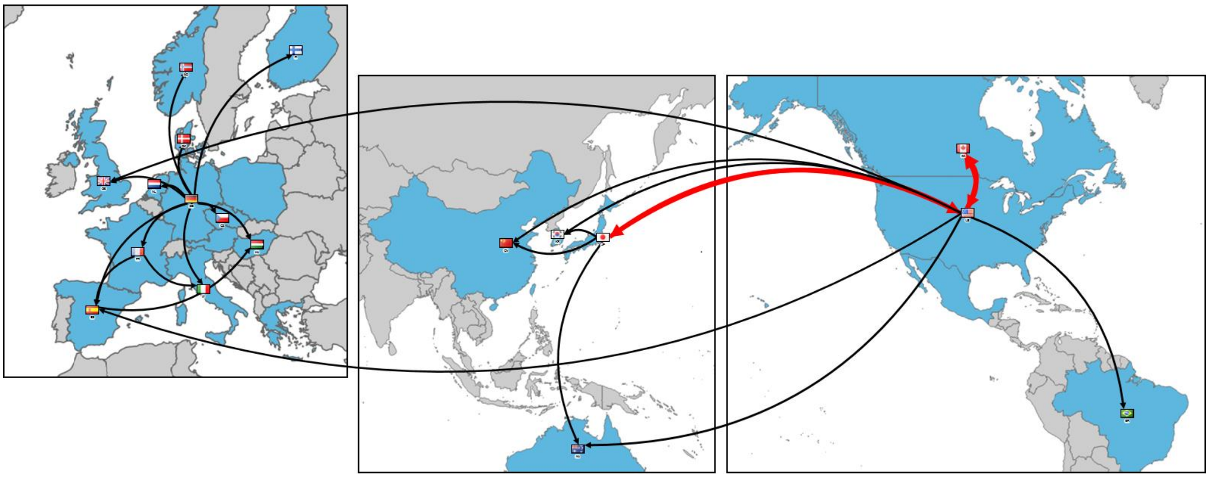
Pharmaceuticals



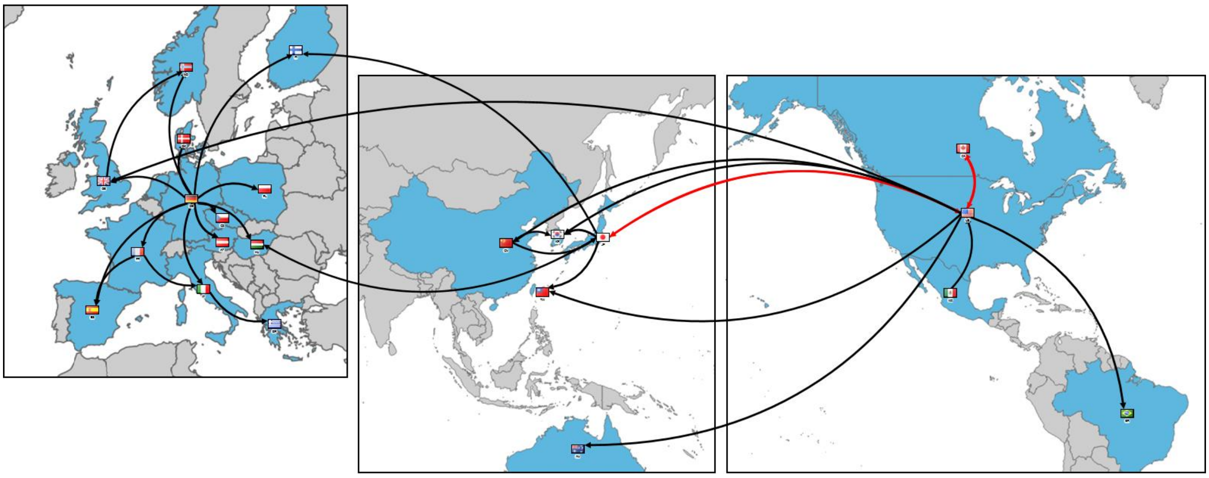
Radio, television and communication equipment



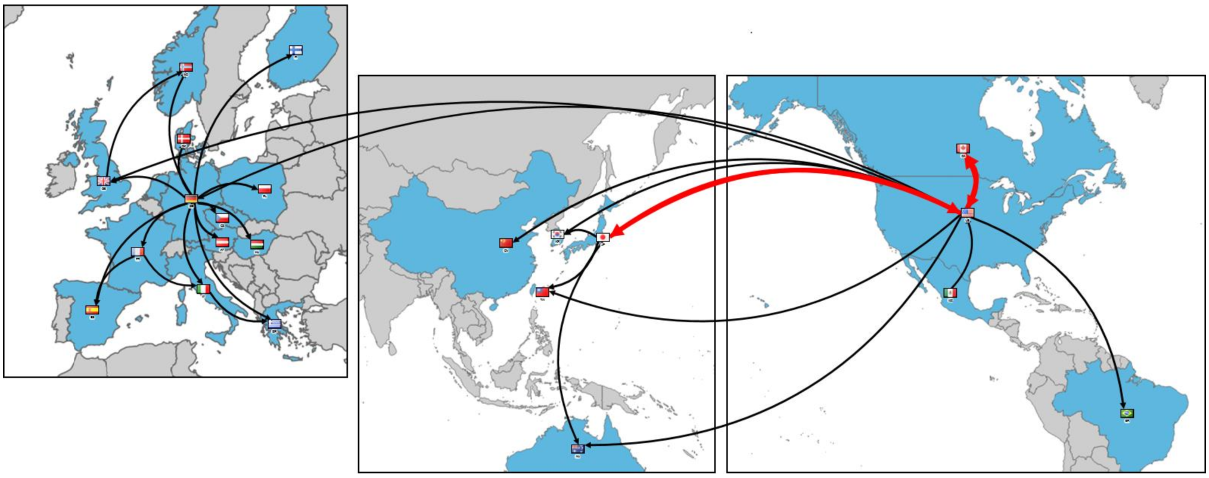
Railroad equipment & transport equipment nec



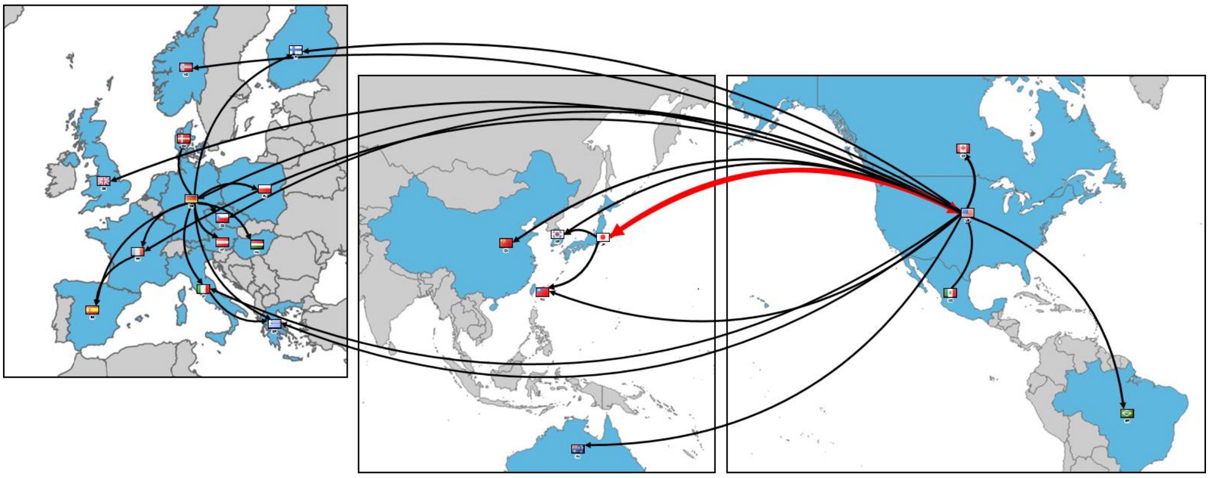
Electrical machinery and apparatus nec



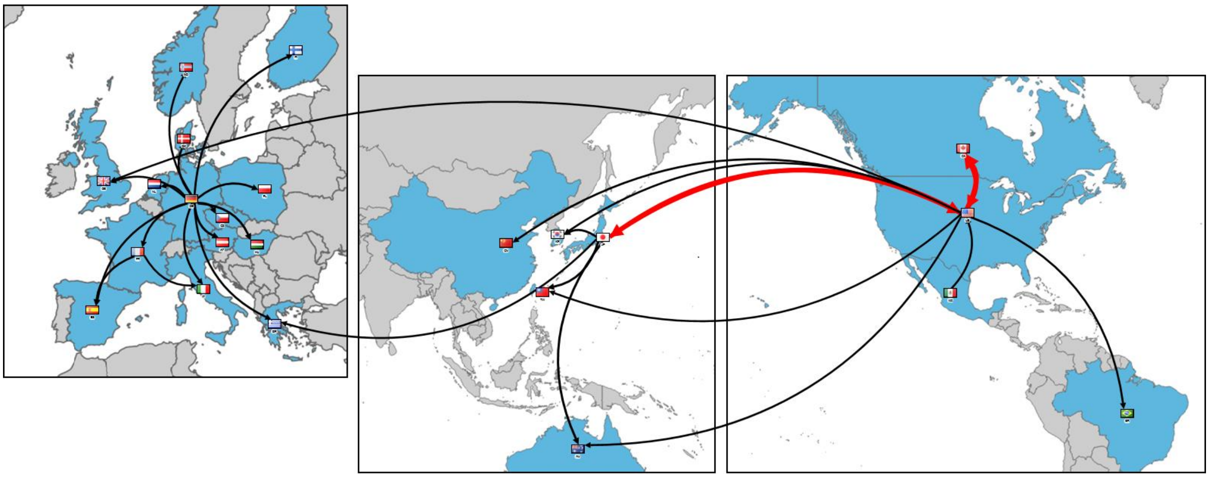
Machinery and equipment nec (aka industrial machinery)



Medical, precision and optical instruments

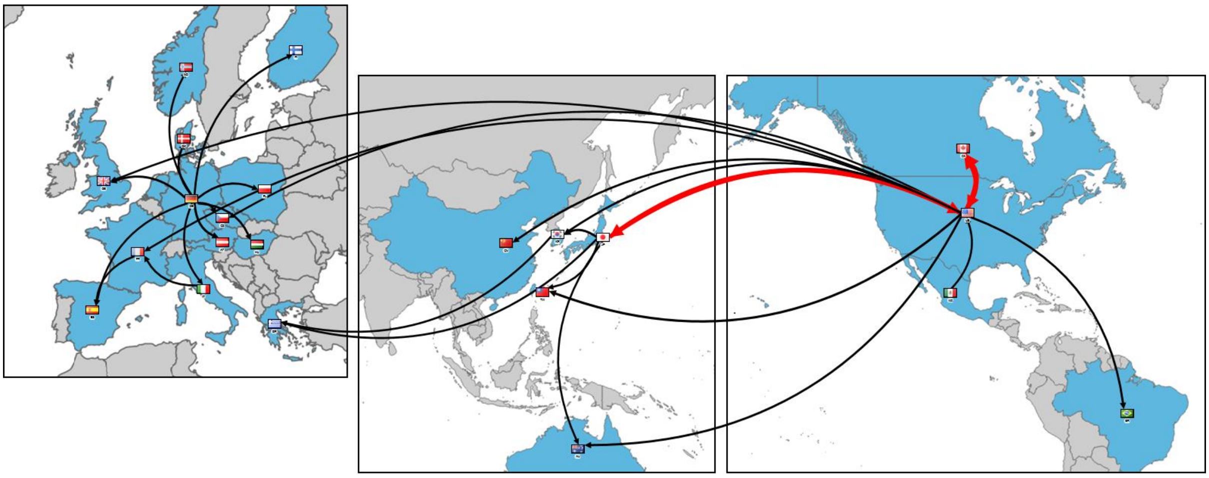


Motor vehicles, trailers and semi-trailers



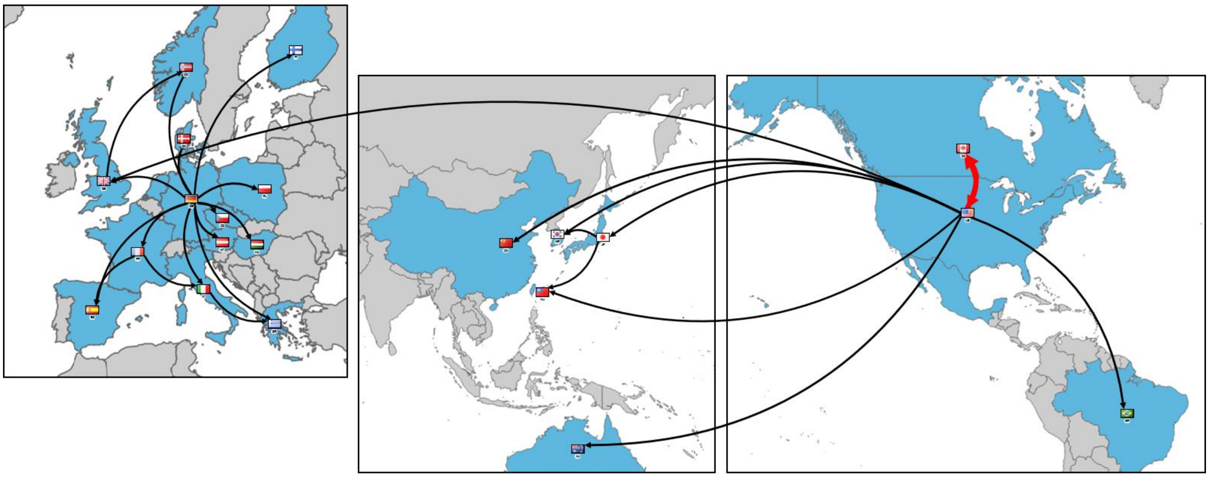
The automotive industry (above) was not quite as global as we initially anticipated, especially in comparison to industries like railroad equipment (further above). This layout also shows how regionalised some industries are, with Europe forming one region and Asia-Pacific plus the Americas forming another. By memory, it was these regionalised industries that nudged us to lay the map out by splitting the Atlantic Ocean, instead of keeping the prime meridian near the middle.

Building & repairing of ships and boats

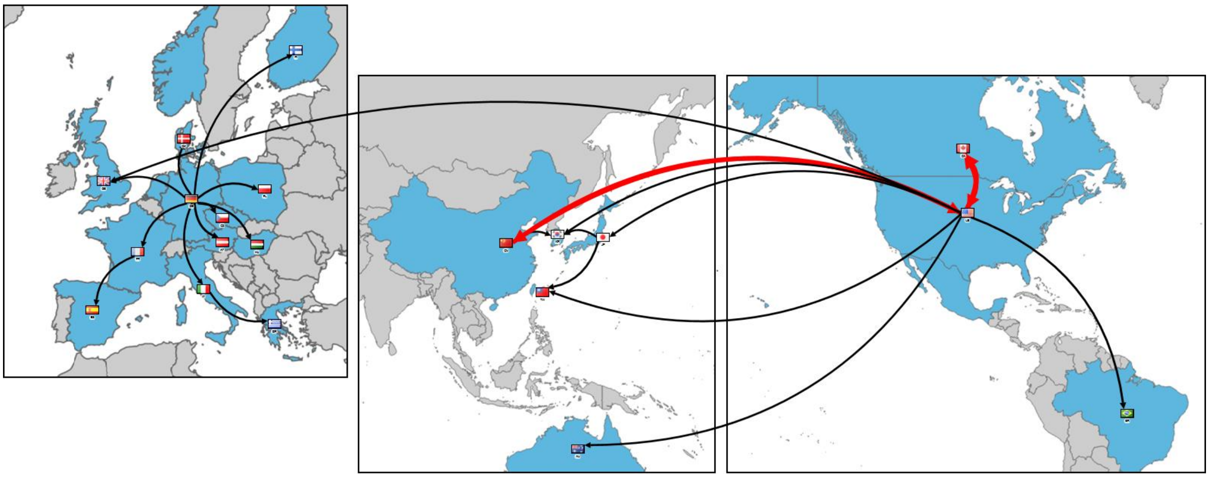


We'll dig deeper on shipbuilding in a moment. Suffice it to say, it was more globally interconnected than we initially expected.

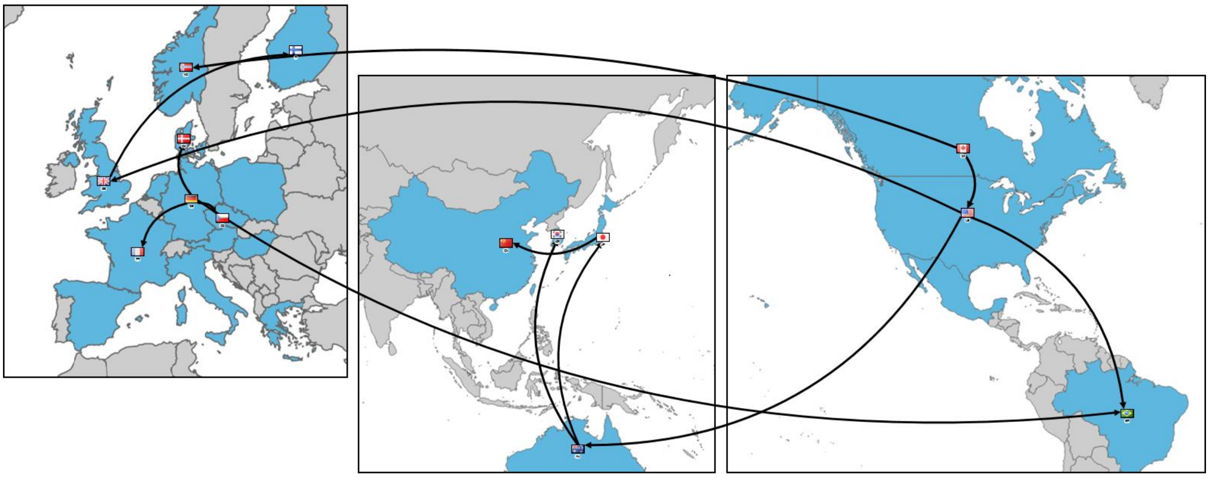
Rubber and plastics products



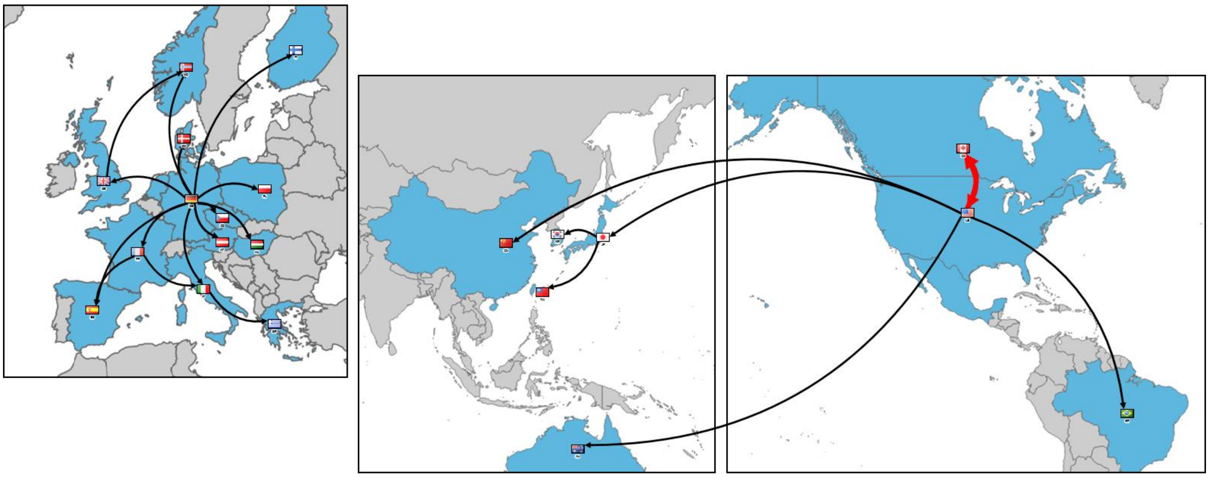
Manufacturing nec; including furniture



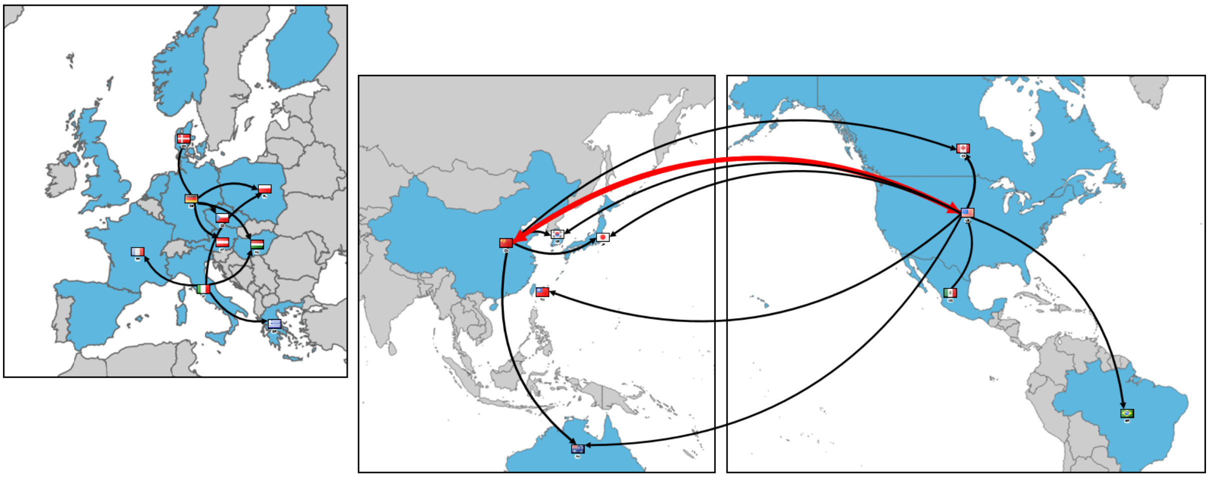
Non-ferrous metals



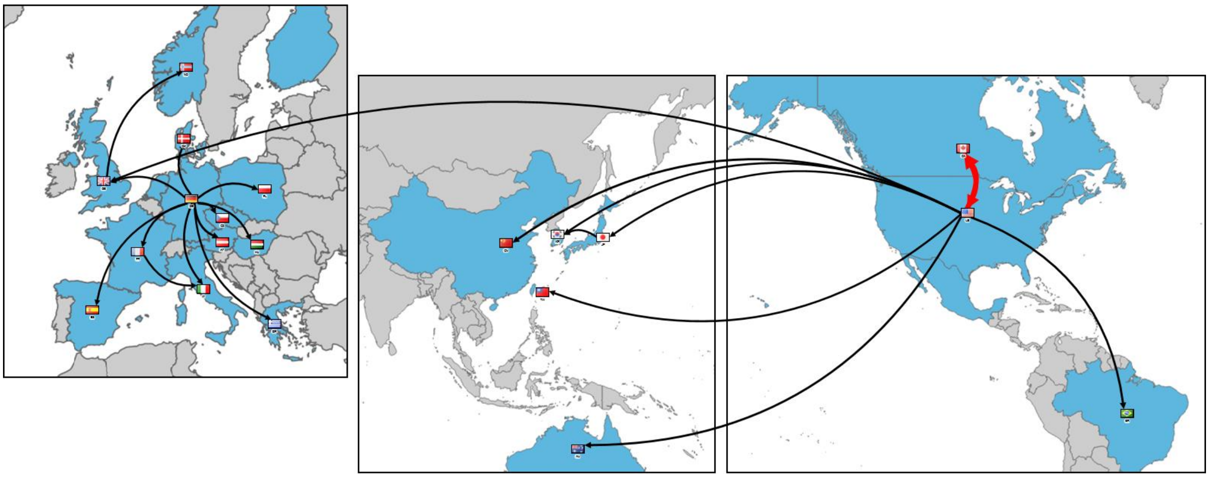
Fabricated metal products, except machinery and equipment



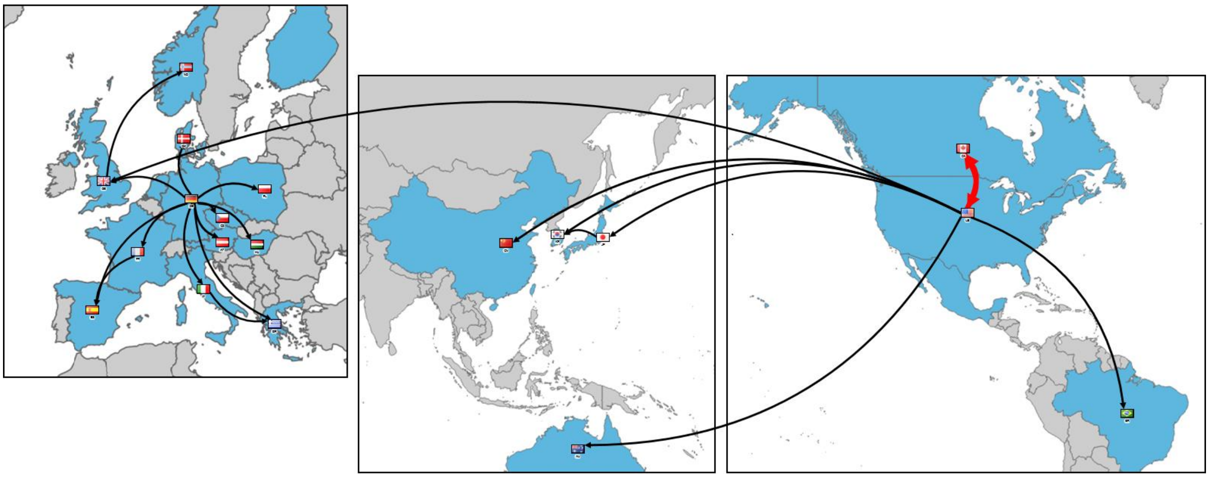
Textiles, textile products, leather and footwear



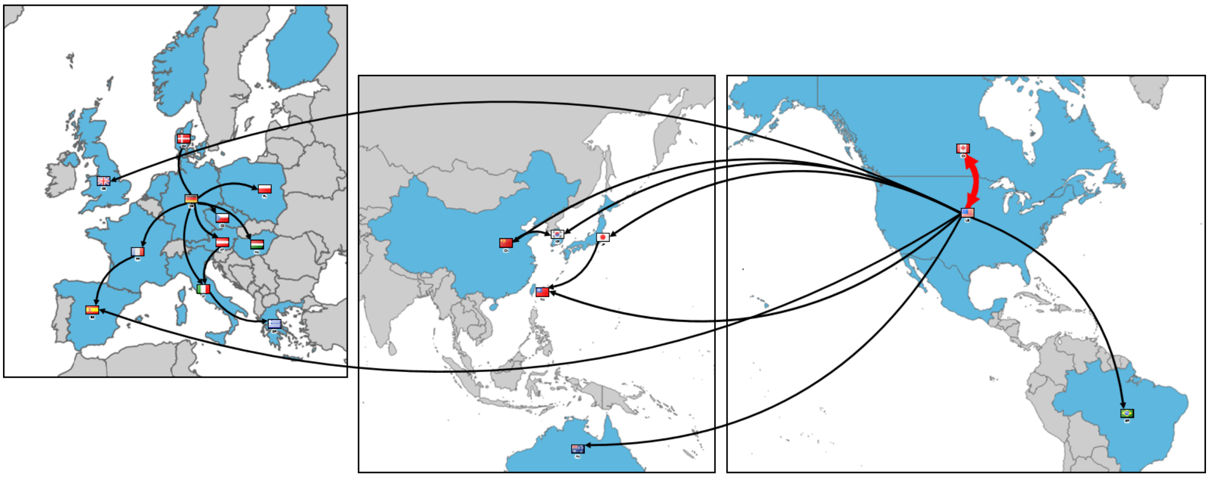
Chemicals excluding pharmaceuticals (industrial & other)



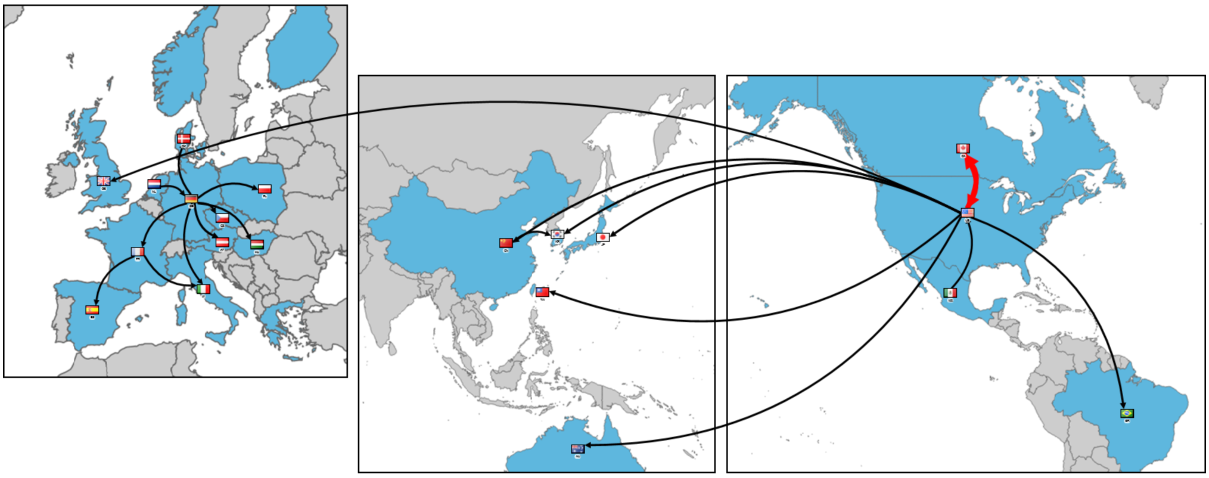
Pulp, paper, paper products, printing and publishing



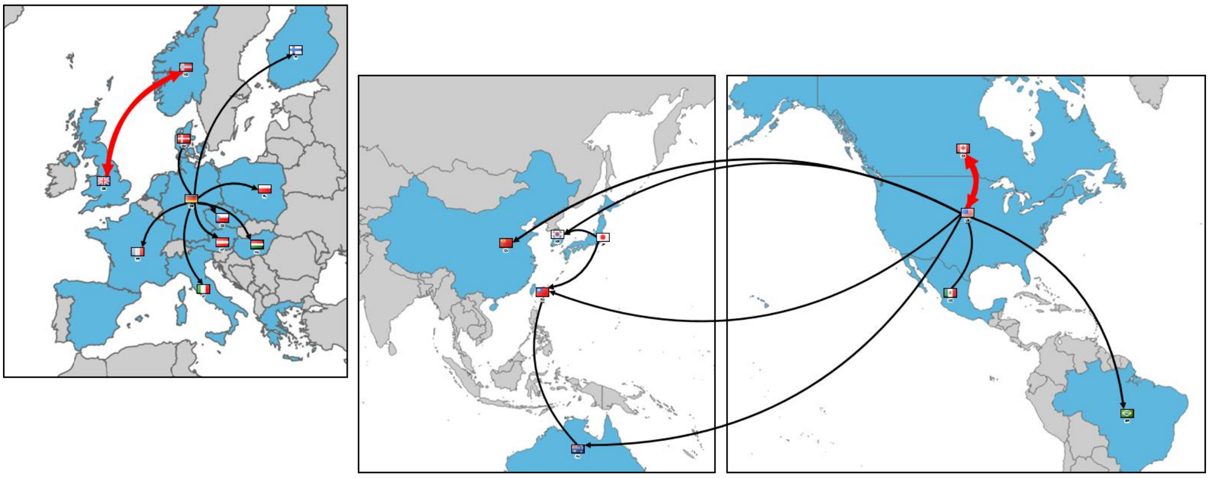
Wood and products of wood and cork



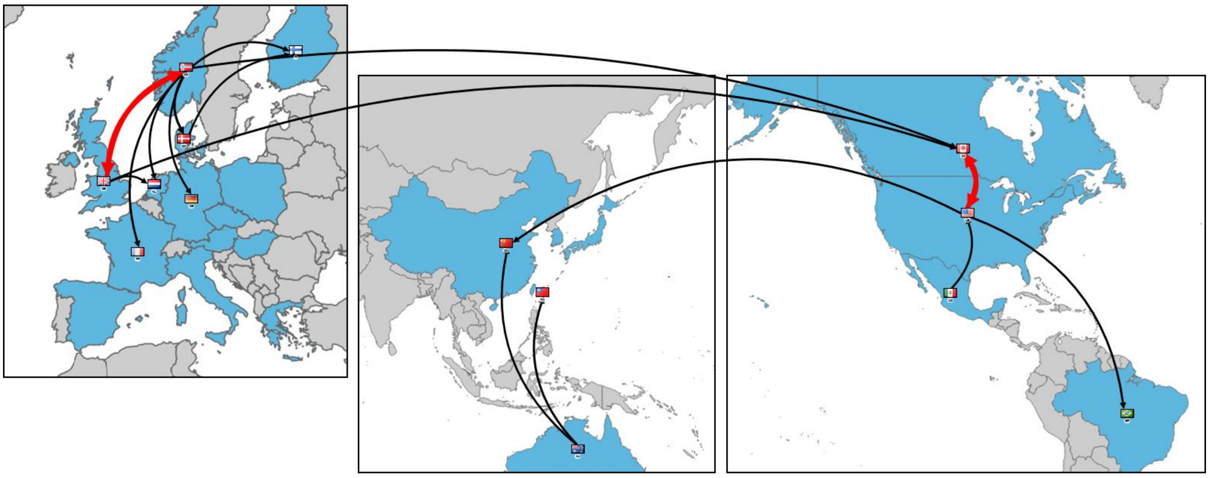
Food products, beverages and tobacco



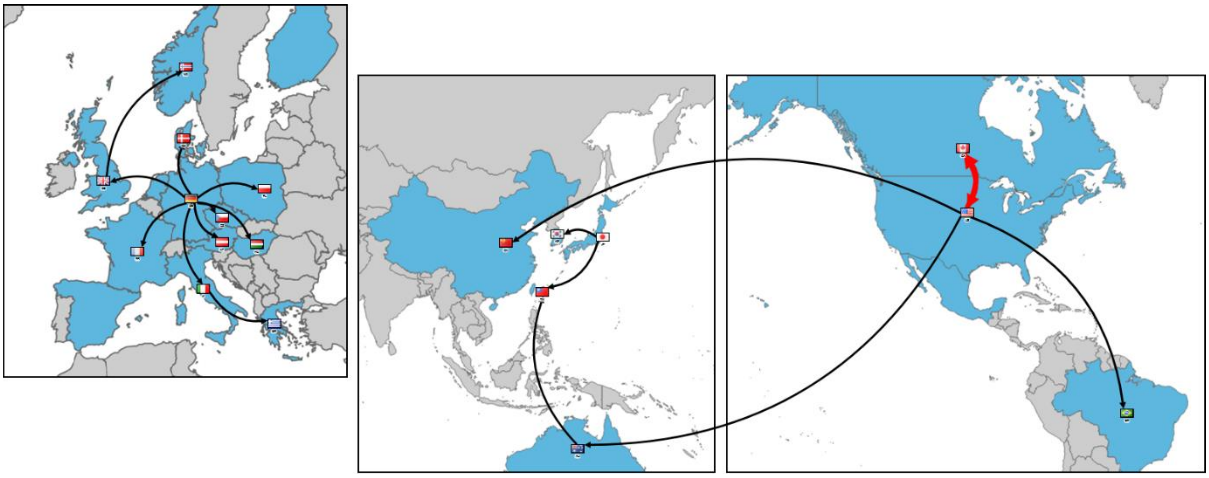
Other non-metallic mineral products



Coke, refined petroleum products and nuclear fuel



Iron and steel



Towards the bottom of the above trade complexes, it become more obvious that the things being traded were largely not ‘goods’, but rather commodities which are more expensive to ship great distances.

Global value chains at the firm or product level are often looked at from raw materials, to end-product, through to disposal. First the ‘boring’ commodities need to be dug up, moved, shipped, processed into a block or ingot of something, shipped again probably, processed again into something useful then shipped / moved again before it goes into something. Some of these economic activities are themselves more complex than they might appear – fertiliser shipments and seed production distribution – but such product specific networks are difficult to illustrate with data.

Here’s the plot twist. While products like minerals and steel may be boring, the *process* of producing them requires a lot of technology, from relatively boring rail lines and ships through to extremely high-tech automation and computerisation (e.g. self-driving mining truck and trains). Thus, a more complex picture starts to unfold, gradually revealing the circular flows in the economy. Due to data limitations, capital investment is not included here, only the commodities and goods and services (including labour) that get *physically incorporated* count. For example, the computers that get built into vehicles are counted, but not the computers required to design them or operate the plant. The use of capital investment is an entirely different dataset – but one which can be treated the same way, although few have. Brian’s current project mentioned above is investigating the data on this.

While the trade complexes provide rich pictures about from where to where resources flow, they also mix inter-industry with intra-industry trade. Let’s separate those a bit more. Bordering on macro-economic analysis, we looked at the proportion of value-add from within the same industry (right column, labelled ‘Self’) and other types of industry. The figure below is the coloured version of the one from our second case study in the in [the Routledge Companion](#) to Global Value Chains (GVCs).

Relative proportion of imported value add by industry

Rank (SPE)	SPE	Industry Complex ↓ \ Source Industries →	Technologies	Chemicals	Commodities	Metals	Semi-Processed	Services	Self
1	1.85	Aircraft and spacecraft	28.2	0.9	0.3	2.1	2.2	5.4	60.9
2	1.77	Office, accounting and computing machinery	62.1	1.8	0.2	0.6	0.8	2.0	32.4
3	1.69	Pharmaceuticals	1.6	39.6	2.5	2.0	5.4	5.5	43.4
4	1.57	Radio, television and communication equipment	37.9	4.4	0.8	2.2	1.4	2.9	50.3
5	1.53	Railroad equipment & transport equip nec	41.2	11.3	1.9	11.9	7.4	7.2	19.1
6	1.45	Electrical machinery and apparatus, nec	13.3	14.6	2.6	18.2	2.9	3.0	45.5
7	1.41	Medical, precision and optical instruments	54.0	6.4	2.7	5.2	4.9	4.0	22.8
8	1.41	Machinery and equip nec (aka industrial machinery)	23.1	7.2	1.2	18.3	7.6	4.5	38.0
9	1.36	Building & repairing of ships and boats	27.4	3.8	1.3	9.3	4.7	3.2	50.4
10	1.36	Motor vehicles, trailers and semi-trailers	17.0	8.4	1.3	8.4	5.3	2.9	56.7
11	1.23	Rubber and plastics products	5.4	65.4	5.0	1.3	6.3	2.9	13.7
12	1.09	Manufacturing nec; including Furniture	7.1	17.4	16.2	16.4	18.5	5.1	19.4
13	1.08	Non-ferrous metals	4.2	4.3	13.4	3.6	3.2	1.1	70.2
14	1.05	Fabricated metal products, except machinery and equip	12.3	8.6	2.7	56.3	1.0	4.5	14.6
15	1.00	Wood and products of wood and cork	5.5	14.0	17.1	1.6	7.1	3.9	50.7
16	1.00	Pulp, paper, paper products, printing and publishing	5.5	14.0	4.4	1.0	2.4	6.3	66.4
17	1.00	Chemicals excluding pharmaceuticals (Industrial & other)	4.1	12.7	5.8	1.1	3.3	5.3	67.6
18	1.00	Textiles, textile products, leather and footwear	3.5	17.6	6.3	0.1	3.8	3.0	65.7
19	0.95	Food products, beverages and tobacco	3.0	14.2	38.8	0.4	2.6	6.5	34.5
20	0.95	Other non-metallic mineral products	12.1	29.6	19.6	5.0	5.3	9.6	18.8
21	0.82	Coke, refined petroleum products and nuclear fuel	0.8	1.5	92.3	0.3	0.1	0.8	4.3
22	0.82	Iron and steel	8.4	6.8	21.6	3.4	2.3	2.9	54.6

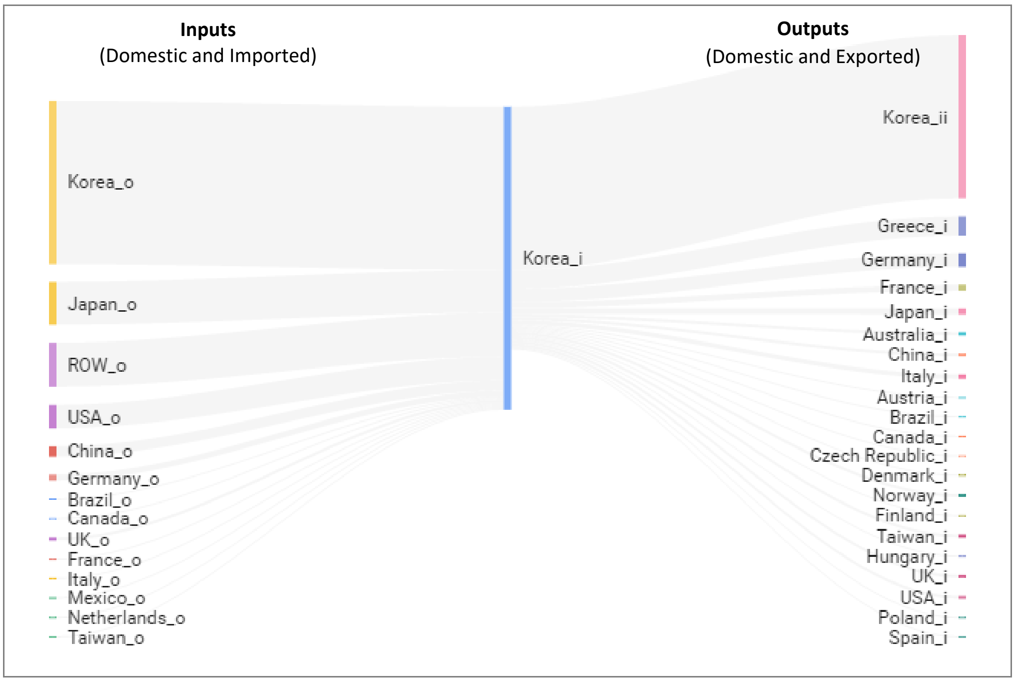
More innovative industries tended to get value-add by drawing on the tech industry, and less innovative industries were drawing on and processing commodities. No rocket science there. But, connections across industries clearly exist, which cause those ripple effects of disruptions across industries. One recent example is that interruptions of neon supplies from Ukraine can exacerbate the current computer chip shortage (Reuters).

Here's where we go a little off script and dig up the Sankey and Chord Diagrams that were buried in a folder for previous versions of this study. The diagrams visually provide a middle ground to the complexity of above network diagrams and the simplicity of the bar chart.

In the aforementioned book and chapters, we dug into Korean shipbuilding as a test case for how sensitive a single industry in a single country could be to its inputs (and outputs).

In the below Sankey Diagram, the middle bar is Korean shipbuilding. The left side lists the source countries, still sticking exclusively to the shipbuilding industry and not including imports from other industries, and also excluding the service industries. The right side lists the destination countries that the Korean shipbuilding is a source for. This doesn't include Rest of World (ROW), either. The width of each stream represents the relative proportion of that flow.

Sankey Diagram of manufactured inputs and outputs of Korean Shipbuilding

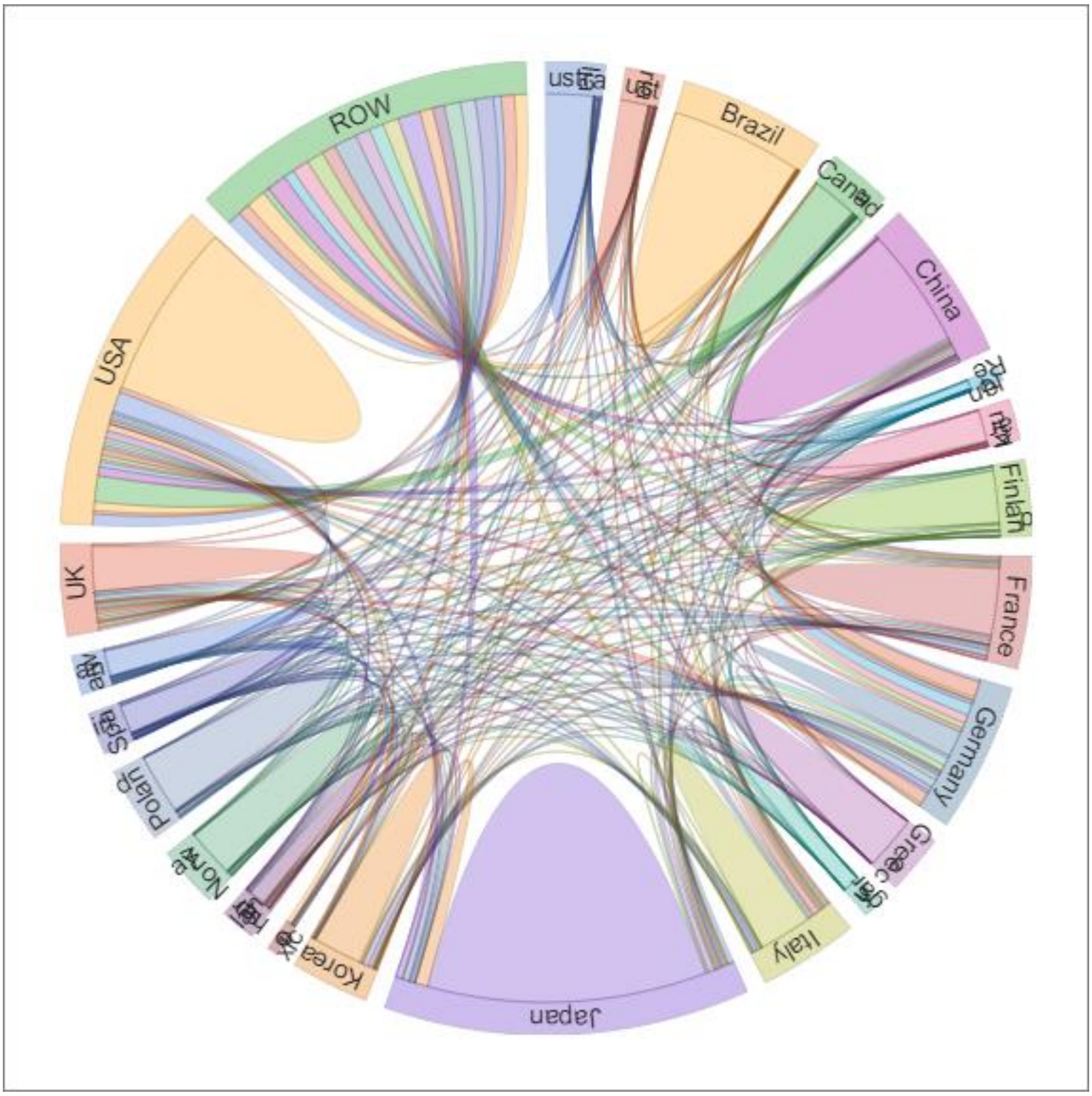


Aren't different visualisation tools great?

Doing all this filtering, mapping, and zooming-in generates visualisations that are easy enough for our brains to understand. But, let's zoom out again, because that's the level at which the world works. It's more complex. Much more complex.

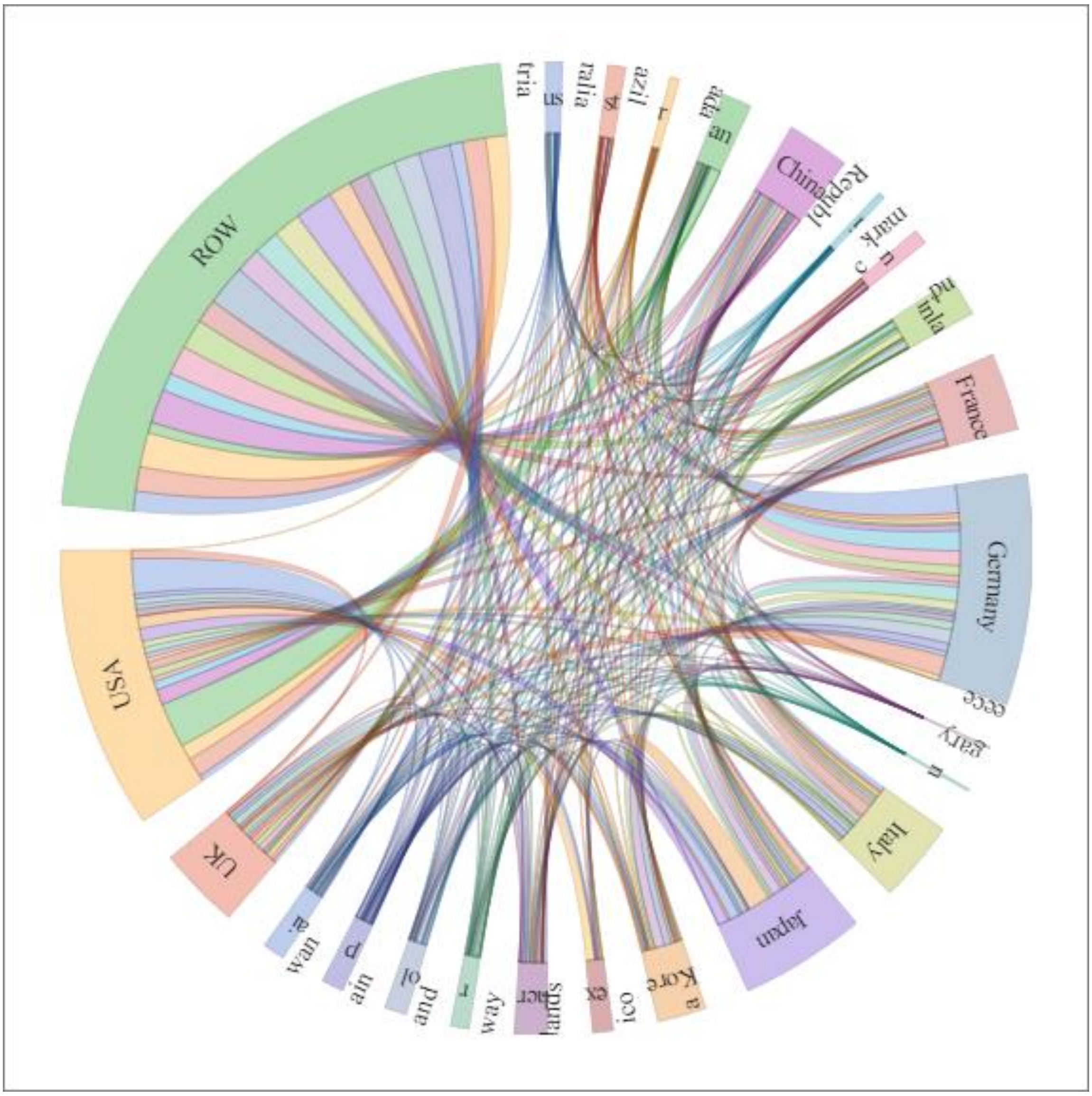
If we expand the above Sankey Diagram of Korean shipbuilding to be a Chord diagram of all countries' shipbuilding industry (i.e. not including trade beyond shipbuilding), it gets messy. It is particularly notable that the ROW contributes a handsome share of shipbuilding inputs to virtually every one of the leading country's shipbuilding industry. The thickness of the link shows the relative value add, with the centre part coloured the same as the country measuring the local transactions and the multi-coloured lines representing the traded value. It is important to note that this presentation remains silent on whether the traded components have strategic importance (e.g. propellers made of specific alloys are likely a small proportion of the total economic value, but of more strategic value than plate steel for the hull).

Chord diagram of international and domestic trade in the shipbuilding industry



Most importantly, most countries' shipbuilding industry is within-country and only some value-add is generated beyond-country. So, even while we're in a giant circular flow of goods and services, there are significant domestic sub-systems within that global system.

Let's hide that domestic intra-industry trade for a moment though.



It’s even more like [rainbow spaghetti](), with some countries at the core of the traded activity and others only modestly connected. And this is just one industry, and not inclusive of industries that supply into shipbuilding or that use shipbuilding as an input.

If you’ve made it this far, I hope you enjoyed the discussion of global value chains while trying to keep the complexity of the whole global economic system at bay. At a very localised level, it’s easy enough to see how missing an ingredient can mess up a recipe, and only sometimes can the absent ingredient be easily sourced elsewhere.

While manufacturing has become more modular, the irony is that the modules have also become more customised to the next destination along the value chain. The general conclusion which I hope is illustrated by the above, is that when there are natural disasters or countries start playing with tariffs or sanctions, there can be all sorts of ripple effects. The sheer number of ripple effects make it hard to predict them, or to identify their relative significance (economically, socially, environmentally, or otherwise).

ABOUT THE AUTHORS

Associate Professor Martin Bliemel is the Director of Research for TD School at the University of Technology Sydney (UTS). TD stands for 'transdisciplinarity' which embraces a multitude of academic disciplines and professional practices to tackle complex societal problems. Martin holds a BSc (Mechanical Engineering) and MBA from Queen's University in Kingston, Canada, and a PhD in Business from Simon Fraser University in Vancouver, Canada. Over his career, Martin has been the director or designer of multiple university-based degree programs, courses, subjects and online programs, for which he has received multiple awards.

Martin's research interests include entrepreneurial networks, accelerators, education, research commercialization, entrepreneurial ecosystems, and the entrepreneurial university. His research has had impact through playing a key role in the design of the Australian federal Incubator Support Programme, the evaluation of the renewable energy fund by the Australian Renewable Energy Agency (ARENA), and advising the state government's Innovation & Productivity Council about precincts and global talent flows. Martin's research has received multiple awards and been published in several prestigious journals including *Nature Nanotechnology*, *Entrepreneurship Theory and Practice*, *Entrepreneurship & Regional Development*, *Technovation, Education+Training*, *International Journal of Entrepreneurial Behavior & Research*, and the *Entrepreneurship Research Journal.*

Brian Wixted (PhD) is an Adjunct Professor with the Johnson-Shoyama Graduate School of Public Policy. His interests are focussed on the network structure of global trade, the adoption of new digital technologies in specific economic settings (especially mining and agriculture) and 21st Century disrupted innovation policy – adapting to the cyber-economy as much as simply promoting firms to create "innovation".