

# Reproducing Uneven Development: Global Capital Goods Production and Trade Relations

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## Abstract

Capital formation, the trade and usage of capital goods, are essential processes to comprehend a country's position in the global economic system. Unequal development paths crucially depend on the unequal distribution of and access to the existing capital stock, as well as the means to reproduce it. This paper maps out the production, usage and trade relations of capital goods and the indirect inputs used in capital formation. It makes use of multi-regional input-output (MRIO) analysis by endogenizing the global capital-use matrix of Magacho et al. (2026). To identify the structurally important sectors for a country's capital formation process, a network analysis using a modified concept of the personalized PageRank centrality is conducted. I find that only ten countries produce two-thirds of all capital goods, while the top 30 producers account for approximately 90% of all production. Both production and demand for capital goods are concentrated in high-income and upper-middle-income countries. South-South trade of capital goods is essentially nonexistent. The median domestic production share for capital goods of high-income countries is around 65%, while the median share of all other countries is only 20%. The MRIO analysis shows that peripheral and semi-peripheral countries invest a larger share in the primary sectors, agriculture and mining, and manufacturing than core countries. The network analysis shows that clusters of countries are dependent on different structurally important sectors and countries for their capital formation. Peripheral countries group around specific core and semi-peripheral countries. All countries are structurally dependent on sectors in the US and China for their capital formation. European countries also rely on the major EU economies such as Germany to renew their capital stock, while the African continent strongly relies on South Korea. Based on the PageRank centrality scores, distinct visual patterns emerge, that can be categorized along the core-periphery structure. I argue that the low income elasticity ratio resulting out of the productive structure in peripheral structure, continuously reinforces the existing uneven development and trade patterns due to the recurrent renewal of the capital stock. This keeps it at the lower stages of global value chains (GVCs), leading to a self-reinforcing, vicious cycle of entrapment in primary and low-value goods production with limited agency over reproducing their means of production due to balance-of-payments constraints.

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# 1 Introduction

Capital formation, the trade and usage of capital goods, are essential processes to comprehend a country's position in the global economic system. Unequal development paths crucially depend on the unequal distribution of and access to the existing capital stock, as well as the means to reproduce it. The continuous inability of the periphery to independently (re-)produce its capital stock keeps it at the lower stages of global value chains (GVCs), leading to a self-reinforcing, vicious cycle of entrapment in primary and low-value goods production with limited agency over reproducing their means of production. While there is a well-founded theoretical understanding of the importance of technology and capital goods in shaping trade and power relations, the role of capital formation and trade in capital goods in this process has only been marginally discussed. I fill this gap by providing a comprehensive overview of the direct, indirect, and structural dependencies between countries on the provision of capital goods and their inputs.

In my master's thesis, I answer the following research question: What are the direct and indirect dependencies on intermediary inputs and capital goods for capital formation in different countries? I make use of multi-regional input-output (MRIO) data to explore those dependencies for capital goods production. Further, utilizing network analysis, I identify the structurally important sectors for the production of capital goods.

Capital goods are commodities that are repeatedly used in the production process whose full consumption takes longer than the observed period, which normally is one year. There is no common definition which commodities constitute capital goods. Many sources only define machinery and equipment as capital goods (e.g. Alfaro & Hammel, 2007; Eaton & Kortum, 2001; Mutreja et al., 2014, 2018). This omits the largest category of the construction sectors, as well as the provision of ICT<sup>1</sup> assets, and, depending on the definition of equipment, also of transport equipment. Magacho et al. (2026) and Tausch and Magacho (2025) use a more holistic definition by including those types of assets. My work uses the latter's definition.

Generally, the production of machinery and equipment is spatially concentrated. Mutreja et al. (2018, p. 22) find that in 2011, only ten countries produced 78.3% of all machinery and equipment<sup>2</sup>, while the top 20 producers were responsible for 92.0% of total production. Eaton and Kortum (2001) also describe high concentration in capital goods production and find that in 1985, European countries tended to import capital goods from Germany, while the US and Japan are major suppliers to countries around the Pacific. The recent analysis by Tausch and Magacho (2025) of capital formation in six Latin American countries in 2015 shows that, on average, they need to import 45.8% of all direct and indirect capital goods and inputs for their capital formation.

Throughout my thesis, I make use of the fact that the global economy can be understood

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<sup>1</sup>Information and Communications Technology

<sup>2</sup>They use the term "capital goods"

along a core-periphery concept. This concept is used in Latin American Structuralism and world-systems theory, among other schools of thought (see Porcile et al., 2023; Wallerstein, 1974). The core<sup>3</sup> specializes in technology- and knowledge-intensive production with a general high wage level, while the periphery is mainly producing low-value-added and primary goods in a labor-intensive manner and is subordinate to the economic power of the core (Valdecantos, 2025, p. 2). Semi-peripheries, as conceptualized by Wallerstein (1974, pp. 4–6), are situated between those two types of economies, trading with both of them, whereas it is in an economic superior position towards the center while being subordinate to the core. They have attained a certain level of industrialization, while still being dependent on the extraction of raw materials (Tausch & Althouse, 2025, p. 3).

My analysis builds on the global capital-use matrix by Magacho et al. (2026), which is an extension of the concept by Tausch and Magacho (2025). I find that only ten countries produce two-thirds of all capital goods, while the top 30 producers account for approximately 90% of all production. Both production and demand for capital goods are concentrated in high-income and upper-middle-income countries. The median domestic production share of high-income countries is around 65%, while the median share of all other countries is only 20%. The dependence on imported technology is unidirectional: All countries rely on high-income countries for imported capital goods, and on China to different degrees.

My results show that peripheral and semi-peripheral countries invest a larger share in the primary sectors, agriculture and mining, and manufacturing than core countries. Such an investment structure reflects their subordinate position in the global economic order as suppliers of goods at early stages of production. Countries in the (semi-)periphery thereby reinforce their position by channeling monetary resources into primary and intermediate production stages in GVCs.

Accounting for indirect inputs to produce capital goods uncovers the strong dependence on imports from the core and semi-periphery for peripheral countries. In a general fashion, this is the case for all countries, independent of their position in the global economy, with the major exception of China. However, including intermediate inputs shows that the dependency on higher-income countries for lower-income countries is even higher than in the case of only taking capital goods flows into account. Countries in the core need to import a higher share of indirect than direct inputs but they mainly trade with other countries in the core and with China as a semi-peripheral country.

The network analysis of the capital-augmented MRIO data in terms of investment shows that clusters of countries are dependent on different structurally important sectors and countries. Peripheral countries group around specific core and semi-peripheral countries and country blocks, such as the United States, China, the EU, South Korea but also Brazil or Turkey. Those countries take up a central role in the access to capital goods in relation to their cluster. Any

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<sup>3</sup>Structuralists often also call it the “center” (see e.g. Missio et al., 2015; Porcile et al., 2023; Prebisch, 1950).

disruption in the provisioning of capital goods or inputs for their production would severely affect those countries. Meanwhile, there is a general dependency by all countries on China and the United States; in particular, Chinese manufacturing and US services. This exposes the world's high vulnerability to single countries and sectors to renew and expand its capital stock.

I argue that due to the high import dependency of (semi-)peripheral countries and the existence of balance-of-payments constraints, their position in the global economy and in GVCs is repeatedly reproduced. My network analysis shows clear patterns of structural importance between countries following the core-periphery structure. Those patterns are the result of uneven development and trade patterns, but due to the capacity-creating nature of capital goods, they also reproduce them. Peripheral and semi-peripheral countries need to pursue import-substitution-industrialization (ISI) by increasing their domestic capital goods production and the mutual South-South trade of capital goods. This, however, requires the cooperation by core countries to alleviate balance-of-payments constraints and to transfer technological capabilities.

My thesis makes contributions to two strands of literature. First, it provides an empirical analysis of the production and trade structure of capital goods and their indirect inputs. This fills an important gap in the Structuralist literature by describing the dependencies between different world regions, in particular the strong reliance on capital formation in the core by the periphery. Second, I add to the literature on the usage of network analysis of IO data by employing a modified concept of personalized PageRank centrality to measure structural dependencies of countries for acquiring capital goods, which combines the usage of two different adjacency matrices.

Section 2 provides an overview of the linkage of capital goods production and unequal development paths, and why peripheral countries struggle to produce those goods independently from the core. The section on methodology encompasses an overview of the capital-use matrix and how IO data can be understood as a network (Section 3). In Section 4 I present and in Section 5 I discuss my results. Section 6 concludes.

## 2 Literature Review

The importance of capital formation for the development and growth of an economy has been highlighted by economists for a long time. Among others, Structuralists and post-Keynesians have stressed the crucial role of capital formation for developing countries in the post-war period. Prebisch (1950, p. 5) links the size of a country's capital stock to the prosperity of its population, while Kaldor (1967, p. 30) emphasizes that the ability to produce capital goods domestically leads to higher rates of economic growth. According to Nurkse (1953, p. 1) capital formation is a necessary but not sufficient condition for development.

Capital goods, whether they be machinery, equipment, buildings, transport infrastructure, or software, are central components of any economy. Their deployment is never a means to

itself, nor do they operate on their own. The purpose of machines and other capital goods is to substitute for human labor at lower costs than the labor it replaced (Hornborg, 2023, pp. 21, 36); solely through the application of labor to the machine and in interaction with other inputs, such as land or raw materials, do they unfold their productive potential. As Marx (1867/1990, p. 338) argued, capital goods are only useful in the valorization of labor power and therefore extraction of surplus labor for the capitalist. They do not create new value themselves (Marx, 1867/1990, p. 457).

This antagonistic character of capital goods is not restricted to labor but can be generalized to all its inputs. Capital goods or technology are “embodiments of asymmetric sociometabolic flows” (Hornborg, 2023, p. 56). Such a relation is inherent to any technology. A technology increases the order in the product it created while also increasing the total entropy (Hornborg, 2023, p. 50). Such higher disorder manifests itself through the emission of various forms of waste, the exhaustion of workers at the end of their work day, the depletion of the soil’s nutrients or the remains of former raw material extraction sites such as mines. To restore their former state, additional energy would be needed: as an example, workers need to eat, care for themselves and be cared for to restore their capacity to labor, which requires energy. This concept of asymmetric sociometabolic flows goes in tandem with technologies’ economic requirements: In order for capitalists to apply the usage of machinery to realize profits, the value of the good produced should be higher than the sum of its single inputs (Marx, 1867/1990, p. 233; Georgescu-Roegen, 1981, p. 18). In this sense, “technologies can be understood as socionatural strategies for redistributing human time and natural space” (Hornborg, 2023, p. 87).

The capital stock of an entity, in this case countries, can be regarded as a historic representation of past flows and investment decisions. The maintenance and utilization of a capital stock again requires future flows, both of inputs in the production process, such as materials, energy, land and labor, as well as new capital goods due to depreciation and the expansion of the stock. While requirements for certain inputs may gradually change through a changing composition of the capital stock, it still reproduces the existing class and trade relations. In that sense, “the relation between technology and the structure of world society is recursive” (Hornborg, 2023, p. 96).

Not only are the means for the acquisition and the application of capital goods unequally distributed, but also the means for their reproduction. Capital goods serve a central role in the reproduction of the capitalist economy. Marx (1885/1992, p. 539) and Kalecki (1954, p. 47) both separated the economy into sectors producing capital goods, called *department I*, and those producing consumption goods, *department II* in Marx’ model and *departments II* and *III* in Kalecki’s case<sup>4</sup>. The output of *department I* serves as an input to the other departments as well as input to itself again. It thereby determines the change in the capacity to produce

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<sup>4</sup>Kalecki differed between the provision of consumption goods to capitalists (*department II*) and workers (*department III*).

both consumption and capital goods in the coming periods. Machinery and other capital goods are hence central components to produce consumption goods, intermediate products, and new capital goods. They are the basis for an economy to reproduce itself and to be able to expand its production capacity.

Capital goods are by no means neutral tools. They embody and reproduce the existing class relations (Amin, 1977, p. 172). In a capitalist economy, by definition, only the capitalist class can purchase goods from department I, while workers are restricted to department II. The relations of ownership and the distribution of power are thereby renewed through the acquisition of new capital goods.

This inequality persists beyond classes: The production of capital goods itself is highly capital-intensive, requiring the necessary capital stock in a country to undertake this endeavor. Capital goods are among the most sophisticated products (The Growth Lab at Harvard University, 2024).<sup>5</sup> It comes as no surprise that countries in the core have the most complex export good basket.

Since core countries are in the best position to produce and export capital goods, they also have the best deck of cards to keep that role (Emmanuel, 1972, p. 378; Furtado, 1976, p. 47). Such a power can be exerted in many ways, such as through patents, technological path dependency, as well as geopolitical power over supply chains. Having already established a capital goods-producing industry allows for an easier acquisition or development of new vintages. Producers of capital goods can dictate the conditions of their dissemination (Amin, 1977, p. 172) or decide to fully halt their trade (Furtado, 1976, p. 55). With those products being highly complex, countries being dependent on certain types of capital goods cannot easily substitute them. Certain machines or types of machines are only produced by a few firms around the world. When firms in peripheral countries have to replace parts of such a machine, they continue to rely on the same providers, thereby reproducing the existing trade relations (Althouse et al., 2023, p. 3). Such capital goods cannot easily be replaced as they are the product of many years of research and innovation steps, which require extensive technical knowledge to produce them. The production of semiconductors serves as an illustrative example: There is a monopolization in the production of different components, with the concentration in a few countries in Europe, East Asia and the US (Ren et al., 2023, pp. 1151, 1155). Countries such as the US have also tried to obtain control over upstream segments of semiconductor production by erecting trade barriers and blocking the dissemination on knowledge about producing those technologies to prevent a shift in production to lower-income countries (Ren et al., 2023, pp. 1155, 1157). Ren et al. (2023, p. 1157) also describe that there are path dependencies on Europe and the US by emerging semiconductor producers such as China. Control over the production and dissemination of technology is essential for the core to maintain its power; Prebisch

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<sup>5</sup>According to the product complexity ranking by The Growth Lab at Harvard University (2024), capital goods have some of the highest product complexity indices (PCI): among the 100 highest ranked product categories, 28 products have HS 2012 codes between 84 and 89, which correspond to machinery and equipment.

called it the core’s “structural privilege” (Puntigliano, 2017, p. 107).

To the peripheral countries’ demise, they lack both the facilities to reproduce their own capital stock and the necessary amounts of capital goods to extend their productive capacity. Kaldor (1967, pp. 31–32) describes four stages an industrializing country passes in terms of its acquisition of capital goods. Once it starts to industrialize, the import share of capital goods in comparison to the import share of consumption goods starts rising. One reason is the import substitution of consumption goods that can now be produced domestically. In a second stage, it becomes a net exporter of manufactured goods, while still importing most capital goods. At the third stage, the country undertakes import substitution for capital goods as well. Furtado (1976, p. 212) describes the production of capital goods as the ‘crowning point’ of a country’s industrialization. In the fourth and last stage, the country becomes a net exporter of capital goods.

However, many peripheral countries struggle to move through those stages. According to the Prebisch-Singer thesis, the terms of trade for agricultural and other primary products decline over time in comparison to manufacturing goods (Prebisch, 1950; Singer, 1950/2012). While increases in productivity or gains in technical progress generally lead to rising incomes for manufactured goods, they lead to lower prices for primary products (Singer, 1950/2012, pp. 271–272; Prebisch, 1950, p. 262). They applied on a global scale what has come to be known as Engel’s law, which implies that with rising income, the income share of primary products falls (Ricci, 2021, p. 28). Any benefits from increased labor productivity –due to technical progress –in the production of raw materials and agricultural goods through lower prices would not be reaped domestically but passed on to the buyers in the core (Singer, 1950/2012, pp. 270–271; Prebisch, 1950, p. 14; Prebisch, 1959, p. 262). Second-round effects of investment in capital goods are captured in the center and not the peripheral countries (Singer, 1950/2012, p. 267).

The other central problem to peripheral countries’ development as identified by Prebisch (1950) and Singer (1950/2012) is the disequilibrium in the balance of payments, also known as the balance-of-payments constraints. Kaldor (1967, p. 33) argues that at early stages of industrialization, imports due to the need for capital goods rise faster than exports because there is no significant foreign demand. This collides with the balance-of-payments constraint as outlined by Thirlwall (1979, p. 46). He argues that countries cannot grow faster than the ratio of the growth rate of exports and the income elasticity of imports:

$$y = \frac{x}{\pi} = \frac{\varepsilon}{\pi} y^W, \quad (1)$$

where  $y$  is the balance-of-payments equilibrium growth rate,  $\pi$  is the income elasticity of imports, and  $x$  is the growth rate of exports which can be split into the income elasticity of exports ( $\varepsilon$ ) and the growth rate of the rest of the world ( $y^W$ ) (Thirlwall, 1979, p. 49; Porcile et al.,

2023, p. 267). The elasticity ratio  $\frac{\varepsilon}{\pi}$  is reflective of technological and productive asymmetries: As an economy adopts more sophisticated, high-tech products the income elasticity of exports increases (Porcile et al., 2023, p. 268). Cimoli et al. (2010, p. 389) relate it to the “dynamics of innovation and the international diffusion of technology, which redefines the productive and export structures of the countries.” Hence, the elasticity ratio is reflective of a country’s pattern of specialization (Cimoli et al., 2010, p. 392). A country that starts off with a low capital stock does not have the capabilities to produce export products with high income elasticity of demand. Instead, due to its need to import manufactured goods, it is drawn to exporting primary products with a low income elasticity of demand. This results in a low elasticity ratio. In peripheral countries, this led to a dualistic structure where the primary production is mainly export-oriented (Shaikh, 2007, p. 77; Singer, 1950/2012, p. 266). Based on network analysis and from a Structuralist viewpoint, Gala et al. (2017, p. 17) have shown that the core specializes in more sophisticated and industrialized products, while the periphery only has weak links and exports non-sophisticated primary and intermediate products. Importantly, the export basket of the core is more diversified than that of peripheral countries, which often focus on a few types of primary and intermediate products.

If peripheral countries want to import larger amounts of capital goods, they have to increase their exports (Kalecki, 1976, pp. 27, 51). Since most peripheral countries are net exporters of raw materials and agricultural goods (UNCTAD, 2025), their export structure makes them susceptible to price volatility of raw materials and changes in foreign demand. Hence, increasing the imports of capital goods is at the mercy of export conditions (Ho, 2017, p. 82), where primary goods need to be exported for capital goods to be imported (Prebisch, 1950, p. 2). This can lead to a vicious cycle where larger exports of primary products lead to additional demand for capital goods by the agricultural and mining sectors in peripheral countries, taking away the required resources for an increase in the capital stock in other sectors, particularly the manufacturing sector (Singer, 1950/2012, pp. 268, 274). Porcile et al. (2023, p. 268) describe that patterns of specialization lead to lock-in effects and path dependencies with high inertia. Due to this specialization and with foreign investment flowing primarily in primary sectors led to them being much more capital-intensive than the domestic ones (Singer, 1950/2012, p. 266; Ricci, 2021, p. 28). This complicates the matter for countries to change course.

While discussions about trade structures often revolve around countries as common entities, their economies are constituted of private firms acting under the profit motive, including the task of capital formation. Those investment decisions are primarily undertaken to maximize profits and not necessarily to the benefit of the general population (Robinson, 1976, p. 12). According to Singer (1950/2012, p. 275), peripheral countries fail to industrialize in an upswing because the existing economic regime, by relying on the extraction and export of primary goods, seems to work. Prebisch (1950, p. 40) calls this the “stage of euphoria and prodigality”, where the capital stock is not renewed. In a downswing, those countries, respectively, the firms, do not have the means to acquire the necessary capital goods. Singer (1950/2012, p. 275) attributes

this to a "deplorable lack of foresight". This is one of the reasons for the reinforcement of a vicious cycle, where peripheral countries are not able to build up their own capital stock and their own capital goods production.

Continuing to be dependent on the import of capital goods has immense drawbacks for peripheral countries. They are recurrently forced to export primary products to obtain the necessary reserves to acquire capital goods.

## 3 Methodology

### 3.1 Capital-Use Matrix

The perception of economic activity as an intertwined network of flows between sectors dates at least as far back as to the 17th century. The mercantilist William Petty (1690/1899) was the first to bring such ideas to paper. Many generations of economists, famously the French Physiocrats in the 18th century (Quesnay, 1759/1923) or Léon Walras (1874) in the 19th century, occupied themselves with the representation of the economy as a system of flows between different instances. The contemporary concept of input-output analysis builds to a large extent on the seminal work by Leontief (1936). He later constructed between 1941 and 1943 the first input-output table for the US economy aiding economic planning after World War II (Miller & Blair, 2009, p. 731). Nowadays, input-output analysis is a widely used concept among different economic strands with many national statistical offices publishing updated input-output data on a regular basis. The detailed description of (monetary) flows between sectors in input-output data allows for a wide range of applications: its most fundamental purpose is to describe the interdependencies among industries in an economy used for analysis and economic planning on the subnational, national and international level. Thanks to its simple, expandable structure, new use cases constantly emerge. Some of the most prominent ones include the estimation of demand, supply and price shocks on an economy's output and on other indicators such as employment. Further, it is widely used in environmental analysis to assess a sector's ecological impact or to assign consumption-based emission accounts to countries and sectors.

An input-output (IO) table consists of economic data representing a region, country or multi-regional structure such as the world economy. The IO table represents all the flows between firms aggregated into processing sectors, other economic sectors such as households and the government. In most cases, those flows are recorded as monetary flows. Input-output tables representing more than one region or country are called multi-regional input-output (MRIO) tables. In the MRIO framework, exports and imports are no longer recorded separately but as the flows between specific countries. MRIO tables can be extended to any number of countries or sub-national regions. Sometimes one of the regions is the "Rest of the World" to cover for all countries that have not explicitly been included.

Table 1: Two-Sector, Two-Country Multi-Regional Input-Output (MRIO) Table

| Country       |                    | Final Demand  |               |               |               |            |            | Total Output |
|---------------|--------------------|---------------|---------------|---------------|---------------|------------|------------|--------------|
|               |                    | $r$           |               | $s$           |               | $r$        | $s$        |              |
|               | Processing Sectors | 1             | 2             | 1             | 2             |            |            |              |
| r             | 1                  | $z_{11}^{rr}$ | $z_{12}^{rr}$ | $z_{11}^{rs}$ | $z_{12}^{rs}$ | $f_1^{rr}$ | $f_1^{rs}$ | $x_1^r$      |
|               | 2                  | $z_{21}^{rr}$ | $z_{22}^{rr}$ | $z_{21}^{rs}$ | $z_{22}^{rs}$ | $f_2^{rr}$ | $f_2^{rs}$ | $x_2^r$      |
| s             | 1                  | $z_{11}^{sr}$ | $z_{12}^{sr}$ | $z_{11}^{ss}$ | $z_{12}^{ss}$ | $f_1^{sr}$ | $f_1^{ss}$ | $x_1^s$      |
|               | 2                  | $z_{21}^{sr}$ | $z_{22}^{sr}$ | $z_{21}^{ss}$ | $z_{22}^{ss}$ | $f_2^{sr}$ | $f_2^{ss}$ | $x_2^s$      |
| Payments      | Value Added        | $v_1^r$       | $v_2^r$       | $v_1^s$       | $v_2^s$       | -          | -          | $v$          |
| Total Outlays |                    | $x_1^r$       | $x_2^r$       | $x_1^s$       | $x_2^s$       | $FD^r$     | $FD^s$     | $x$          |

Source: author's illustration inspired by Table 2.2 and 3.1 in Miller and Blair (2009, pp. 14, 77)

Table 1 depicts the essential components of a two-country, two-sector MRIO table. Transactions between the buying sector  $j$  in country  $r$  and the selling sector  $i$  in country  $s$  are recorded as  $z_{ij}^{rs}$ , whereas the sector selling the good (input) is shown row-wise, while the buying sectors (output) are separated into columns. All sectors are listed both as a row/seller and column/buyer. The traded commodity is transferred from sector  $i$  in country  $r$  to sector  $j$  in country  $s$ , while the money (its exchange value) is transferred from  $j$  in  $s$  to  $i$  in  $r$ . Transactions denoted as  $z_{ij}^{rs}$  can be summarized to the quadratic intermediary transaction matrix  $Z$ . The granularity, i.e. the aggregation of firms into sectors, and hence dimensions of such a matrix depends on the available data. In MRIO tables, the  $Z$  matrix represents the domestic relations of, as well as the international trade between sectors:

$$Z = \begin{bmatrix} Z^{rr} & Z^{rs} \\ Z^{sr} & Z^{ss} \end{bmatrix}, \quad (2)$$

where matrices  $Z^{rr}$  and  $Z^{ss}$  depict the intermediary transaction matrix between domestic sectors in the respective country. The matrix  $Z^{rs}$  represents the exports of intermediary goods from sectors in country  $r$  to sectors in  $s$ . In reverse, this is the case for  $Z^{sr}$ .

Final demand consists of sectors buying commodities without providing them as intermediary inputs. This includes household consumption ( $C$ ), government spending ( $G$ ), and investment ( $I$ ). The latter is often divided up into Gross Fixed Capital Formation (GFCF) and the change in inventories. The total final demand vector  $f$  can be compartmentalized similarly to the  $Z$  matrix:

$$f = \begin{bmatrix} f^{rr} & f^{rs} \\ f^{sr} & f^{ss} \end{bmatrix} i = \begin{bmatrix} f^r \\ f^s \end{bmatrix}, \quad (3)$$

where  $f^{rr}$  and  $f^{ss}$  are the final demand matrices for domestically produced goods.  $f^{sr}$  rep-

resents final demand in  $r$  for imports from  $s$ . The reverse is the case for  $f^{rs}$ .  $f^r$  is a vector containing the total final demand for each sector in country  $r$ .  $FD^r$  in Table 1 is the total final demand by country  $r$ .  $i$  is a column vector of ones.

Total output of sector 1 ( $x_1^r$ ) in country  $r$  in Table 1 is:

$$z_{11}^{rr} + z_{12}^{rr} + z_{11}^{rs} + z_{12}^{rs} + f_1^{rr} + f_1^{rs} = x_1^r, \quad (4)$$

where each summand represents the amount of goods supplied by sector 1 in country  $r$ :  $z_{11}^{rr}$  to sector 1 in  $r$ ,  $z_{12}^{rr}$  to sector 2 in  $r$ ,  $z_{11}^{rs}$  exports to sector 1 in  $s$ ,  $z_{12}^{rs}$  exports to sector 2 in  $s$ ,  $f_1^{rr}$  for final demand in  $r$  and  $f_1^{rs}$  as exports for final demand in  $s$ . In total  $x_1^r$  indicates the total amount of goods supplied to the economic sectors and countries covered.

This is the row-wise calculation of total output in the economies covered but economic actors do not only have to pay other processing sectors. They also pay out wages, profits and taxes, and need to account for depreciation (consumption of fixed capital [CFC]) among other transactions. Those can be summarized to a value-added row ( $v$ ). The column-wise total outlays of sector 1 in country  $r$  is:

$$z_{11}^{rr} + z_{21}^{rr} + z_{11}^{sr} + z_{21}^{sr} + v_1^r = x_1^r, \quad (5)$$

where each summand indicates the outlays to a certain instance:  $z_{11}^{rr}$  is the domestic demand for goods of sectors from sector 1 by sector 1,  $z_{12}^{rr}$  is the domestic demand of goods from sector 2 by sector 1,  $z_{11}^{sr}$  are the imported goods from sector 1 in country  $s$ ,  $z_{21}^{sr}$  are the imports from sector 2 in  $s$  and  $v_1^r$  comprises the wages, profits, taxes paid by sector 1, as well as the recorded depreciation of its capital stock. Total expenditure by sector 1 is  $x_1^r$ . Total output needs to be equal to total outlay for each sector.

Total exports from country  $r$  to  $s$  are

$$Z^{rs} + f^{rs} = EX^{rs}, \quad (6)$$

whereas those are simultaneously the imports of  $s$  from  $r$ .

Technical coefficients ( $a_{ij}^{rs}$ ) are the fixed ratio of inputs sector  $j$  in country  $s$  needs from sector  $i$  in country  $r$  ( $z_{ij}^{rs}$ ) to produce a certain level of output  $x_j^s$ :

$$a_{ij}^{rs} = \frac{z_{ij}^{rs}}{x_j^s}. \quad (7)$$

The technical coefficients for all combinations between sectors can be depicted as<sup>6</sup>:

$$A = Z\hat{x}^{-1}, \quad (8)$$

where the hat ( $\hat{\cdot}$ ) indicates the diagonalization of a vector and  $(\hat{x}^{-1})$  is the inverse of  $\hat{x}$ . The production function that results from the set of technical coefficients is one of fixed ratios between inputs: the Leontief production function (Miller & Blair, 2009, p. 18). Inputs in the static IO model are not substitutable.

Total output thereby consists of:

$$x = Ax + f, \quad (9)$$

which can be written as:

$$x = (I - A)^{-1}f, \quad (10)$$

where  $f$  is the vector of total final demand and  $I$  is the identity matrix of the same dimension as  $A$ . This identity can be simplified to:

$$L = (I - A)^{-1}, \quad (11)$$

where  $L$  is the *Leontief inverse* (Miller & Blair, 2009, p. 21). Each element in  $L$  ( $l_{ij}^{rs}$ ) indicates the change in output by sector  $i$  in country  $r$  by a change in final demand of the commodity produced by sector  $j$  in country  $s$ :

$$l_{ij}^{rs} = \frac{\partial x_i^s}{\partial f_j^r}. \quad (12)$$

Crucially, the interpretation of  $L$  assumes a demand-led economy. In the so-called Leontief model, it is assumed that supply can satisfy demand. The  $A$  matrix and hence the  $L$  matrix can be interpreted as the technological structure and the trade relations of the covered economies. The production of a certain commodity demands certain ratios of inputs. The existing technological composition or the current capital stock dictates those ratios.

I use the Gloria MRIO database. Gloria reports MRIO data for 164 countries<sup>7</sup> and 120 sectors in each country representing the whole world (Lenzen et al., 2017)<sup>8</sup>. I work with the data from 2019 since the data by 2020 and 2021 is distorted by the Covid pandemic and the IO tables for the following years have been extrapolated. Further, the capital-use matrix does not exist

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<sup>6</sup>I follow the notation by Miller and Blair (2009).

<sup>7</sup>I exclude the former DR Yemen (Aden) as it no longer exists.

<sup>8</sup>Four regions serve as "Rest of ..." for specific world regions. Importantly, Taiwan as an economically important country is part of "Rest of Asia-Pacific".

beyond 2020. For the sake of my analysis, I group the 120 sectors into 10 larger industries. The income and regional categories I use for countries correspond to the classifications by the World Bank (2026) (see Figure 9 in the appendix).

Most IO tables, including Gloria, lack one particular feature: The provision of capital goods is summed up as a column in the final demand sector (GFCF), while its consumption or depreciation is a row vector in the value added sector (CFC). Crucial information on the interrelation between the suppliers and the corresponding users of capital goods is thereby omitted (Magacho et al., 2026, p. 3; Tausch & Magacho, 2025, p. 504; Ye et al., 2023, p. 2; D. Xu et al., 2023, p. 4; Södersten et al., 2018a, p. 13251). This has already bothered Leontief among others. As part of the Harvard Economic Research Project (HERP) founded in 1948, he commanded researchers –including Robert Solow –to obtain empirical data on capital coefficients (Polenske, 1999, p. 343). In 1953, Leontief (1953, Chapter 3) outlined the concept in detail. The capital coefficient matrix exists alongside the technical coefficient matrix (Magacho et al., 2026, p. 4; Tausch & Magacho, 2025, p. 509; Södersten et al., 2018a, p. 13252; D. Xu et al., 2023, p. 7; Södersten et al., 2020, p. 4). This endogenization should allow for a more dynamic utilization of the IO framework by modelling the changes in the capital stock of subsequent periods. However, due to the concentration of capital goods production in specific sectors, it is doubtful whether the capital coefficient matrix has full rank, i.e., certain rows contain only zeros (Miller & Blair, 2009, p. 641). This made the projections of capital accumulation highly unreliable. Subsequently, further work on the topic was largely abandoned (Steenge & Reyes, 2020, p. 440).

In the past two decades, the endogenization of capital goods usage has gained traction again, thanks to the emergence of data sets such as the KLEMS project recording the existence and distribution of the capital stock (see Timmer et al., 2007; Bontadini et al., 2023; Gu & Hofmann, 2021; Hofman et al., 2016); in particular, capital endogization has been applied to environmentally-extended MRIO (EEMRIO) analysis (Södersten & Lenzen, 2020; Södersten et al., 2018a, 2018b; Södersten et al., 2020). Including capital coefficients provides a more accurate measurement of the magnitude of the multipliers and their distribution (Lenzen & Treloar, 2004, p. 5).<sup>9</sup> Södersten et al. (2018b, pp. 62, 64) found that the higher a country’s GDP per capita is, the less carbon intensive is its investment structure (countries acquire capital goods out of cleaner production). Semi-peripheral countries such as India or South Africa have the most carbon-intensive investment structure (they acquire capital goods whose production has released large amounts of carbon emissions).

For my analysis, I use the capital-use matrices constructed by Magacho et al. (2026), which is based on the concept of Tausch and Magacho (2025) and Södersten et al. (2018b). Based on capital stock data from the KLEMS databases, they construct a capital-stock matrix  $K^{10}$  of the

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<sup>9</sup>Adding a second layer of technical coefficients by definition increases the numerical value of each element in the modified Leontief inverse, or leaves it unchanged.

<sup>10</sup>The values in the  $K$  matrix are stock variables (with the unit [\$]) in contrast to those in the  $Z$  matrix, which are flows [\$/\$yr.]

same dimensions as the intermediate consumption matrix  $Z$  from the Gloria MRIO structure (Magacho et al., 2026, p. 4).  $k_{ij}^{rs}$  describes the stock of capital goods in use by sector  $j$  in country  $s$ , whereas these capital goods have been provided by sector  $i$  in country  $r$ .

$\hat{\delta}K$  denotes the depreciated capital stock, which describes the flows of capital goods between sectors needed to sustain productive capacity.  $\hat{\delta}$  is the diagonalized annualized depreciation rate vector with different rates across countries and sectors.  $\delta_i^r \delta k_{ij}^{rs}$  describes the flow of capital goods from sector  $i$  in country  $r$  to sector  $j$  in country  $s$ .  $\delta_i^r$  is the depreciation rate applied to all capital goods produced by sector  $i$  in country  $r$ .

Based on the concept to obtain the technical coefficient matrix, they obtain the capital-requirement matrix  $B = K\hat{x}^{-1}$ , where  $\hat{x}$  is the total diagonalized output vector.<sup>11</sup> <sup>12</sup>  $\hat{\delta}B$  is the depreciated capital requirements matrix. The capital coefficient:

$$\delta_i^r b_{ij}^{rs} = \frac{\delta_i^r k_{ij}^{rs}}{x_j^s} \quad (13)$$

describes the required amount of capital goods that have depreciated ( $\delta_i^r k_{ij}^{rs}$ ) and need to be bought from sector  $i$  in country  $r$  to produce a certain level of output in sector  $j$  in country  $s$  ( $x_j^s$ ).

The capital-augmented Leontief matrix which indicates the direct and indirect required inputs and capital goods for one unit of output, is thereby extended as follows:

$$L^K = (I - (A + \hat{\delta}B))^{-1}. \quad (14)$$

Note that this capital-augmented Leontief inverse  $L^K$  differs from the original Leontief inverse  $L$ , as it includes the requirements both for direct and indirect inputs as well as for direct and indirect capital goods.

### 3.2 Measuring Structural Dependence

While the analysis of the direct and indirect dependencies of certain sectors indicates which sectors and countries are the most important for acquiring capital goods in terms of their input volume, one can also identify the structurally most important sectors. Those do not necessarily provide the largest input volume, but they are situated at a crucial point in the supply chain for the production of capital goods.

I make use of the fact that input-output matrices are adjacency matrices of a network representing the economy, or more precisely, the relation between its sectors. An economy can

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<sup>11</sup>The notation follows Magacho et al. (2026).

<sup>12</sup> $B$  has the unit  $[yr]$  whereas the  $A$  matrix is unit-free.

be represented as a graph with sectors being the nodes and the monetary flows or technical coefficients between them as weighted, directed edges (Wirkierman et al., 2022, p. 660). This relation has already been described by Solow (1952, p. 42) in the early 1950s.

In input-output data representing a national or global economy, sectors supplying and demanding goods are not evenly distributed. This is due to the aggregation of firms into larger sectors, as well as the differing importance of certain sectors in supply chains. Figure 1 shows the distribution of the weights of the nodes' (sectors) in-degree and edges (monetary flows between sectors) for the technical coefficient matrices  $A$ ,  $\hat{\delta}B$  and  $A + \hat{\delta}B$ . The distribution of the weight of nodes and edges is highly skewed. There are a few sectors in the global economy being responsible for most of its production. Further, there are many weak links between sectors and a few strong ones. Links between sectors (edge weights) and their production output (in-degree node weights) are by no means distributed at random, but the tails of the node weights exhibit the characteristic distribution associated with power laws (see Newman, 2018, Chapter 10.4). This observation is in line with previous network analyses of input-output data (Acemoglu et al., 2012; Carvalho, 2012; Cerina et al., 2015; Giammetti et al., 2020; M. Xu & Liang, 2019).

The network representation allows for many further measures of sectors in terms of their structural centrality<sup>13</sup>. Crucially, Wirkierman et al. (2022, p. 686) shows that centrality measures assign the highest values to other sectors than in the case of output multiplier analysis. A node/sector may not have a high multiplier, but it is structurally central for the network. It may reside at a location in the network's topology that links two otherwise unconnected sets of nodes, while the weights of the edges/technical coefficients pointed at it are relatively small.

Authors have proposed many measures of centrality for input-output networks, such as betweenness or strongest path centrality (Acemoglu et al., 2012; Blöchl et al., 2011; Cerina et al., 2015; Giammetti et al., 2020; M. Xu & Liang, 2019). Among others, Wirkierman et al. (2022) use random walk centrality where one starts off at a random node and undertakes a random walk transitioning to another node based on the weight of the edges. The higher the value of an edge is, the more likely it is to move along that edge. This can be generalized to a transition matrix, where each cell indicates the probability of transitioning or staying at a certain node. This process is called a Markov Chain.<sup>14</sup>

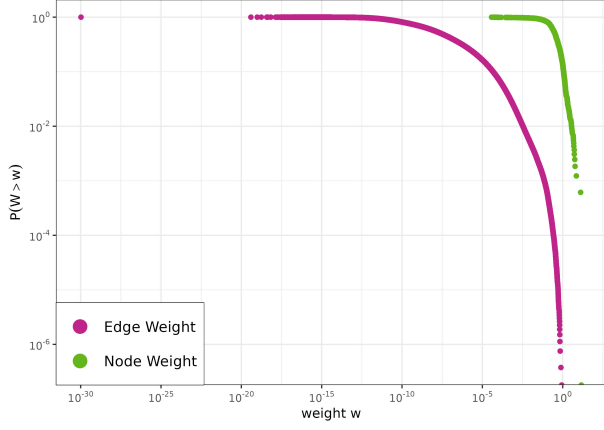
Page et al. (1999) have used a concept called PageRank centrality making use of Markov Chains to find the most important websites on the internet, which resulted in the founding of the search engine Google. Their concept has also been applied to input-output analysis by Carvalho (2012), Cerina et al. (2015), and Zhang et al. (2022).

PageRanks can be calculated very efficiently:

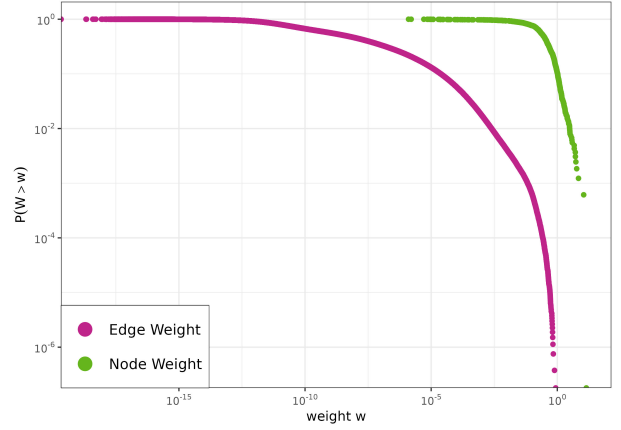
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<sup>13</sup>Measures of centrality indicate which nodes are the most important or central ones in a network (Newman, 2018, p. 159). Depending on the type of centrality, other sectors might be identified as important.

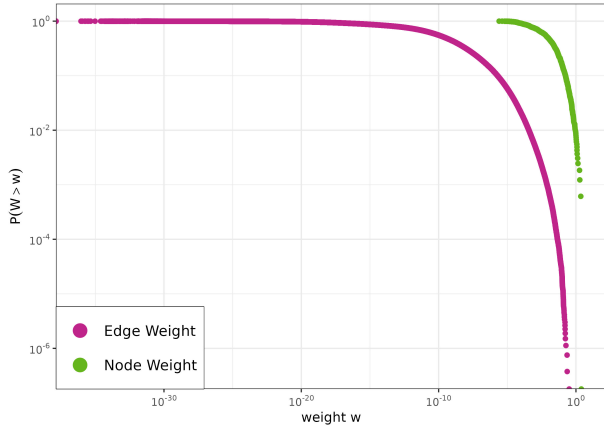
<sup>14</sup>Solow (1952, pp. 42–43) has already pointed out the shared topological properties (and certain differences) of the  $A$  matrix in IO analysis and the transition probability matrix in a Markov Chain.



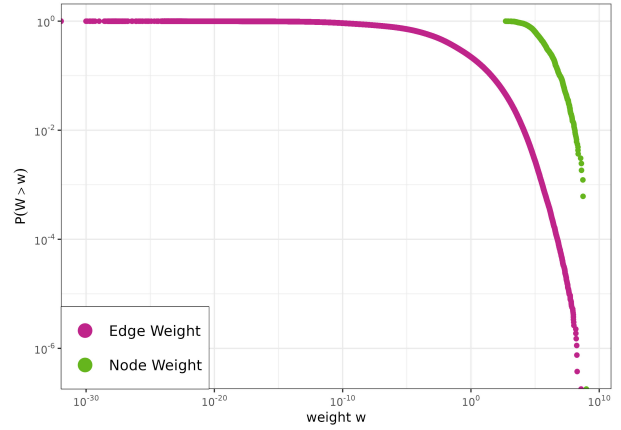
(a)  $A + \hat{\delta}B$



(b)  $A$



(c)  $\hat{\delta}B$



(d)  $\hat{\delta}K$

Figure 1: Complementary Cumulative Density Function (CCDF) of Adjacency Matrices

*Notes:* CCDF indicates the probability of the weight  $P(W > w)$  of an edge or a node being over a certain threshold weight  $w$ . The weight of the nodes is their in-degree weight. The edges are the technical coefficients (monetary flows in thousand USD for the  $\delta K$  matrix) and the nodes are the sectors. All node and edge weight distributions indicate that the distribution of weights in the respective networks follows a heavy-tailed distribution. The weights of technical coefficients/monetary flows are not distributed at random in the IO matrices but are concentrated in the relation between a few sectors. The network analysis is only conducted on the  $A + \hat{\delta}B$  adjacency matrix. The other matrices are included to provide a better understanding of the node and edge weight distributions in the global economy.

$$R_{t+1} = dMR_t + (1 - d)v, \quad (15)$$

where  $R$  is the PageRank vector of length  $N = n_s \cdot n_c$ , with  $n_s$  being the number of sectors,  $n_c$  being the number of countries and  $N$  being the number of nodes.  $M$  is the transition matrix, symbolizing all the probabilities to transition from one node to another. From time to time, the random walk is interrupted by randomly jumping to another node. This prevents being stuck in dead ends and allows for personalization of the ranking. The probability of randomly jumping is indicated by  $(1 - d)$ , where normally  $d = 0.85$ . The vector  $v$  indicates the probabilities of jumping to a particular node. If the probabilities are equally distributed among the nodes, each one has the probability of  $1/N$ . In the case of personalization,  $v$  has different weights for each sector.

The calculation of  $R$  is repeated until  $|R_{t+1} - R_t| < \varepsilon$ , where  $\varepsilon$  is a threshold that indicates the difference between the iterations we allow.  $R_0$  is set to  $R_0 = v$ .

$v$  can be modified to have heterogeneous probabilities. This allows for personalized PageRank (PPR). Since I want to analyze the structural dependency of countries on certain sectors, I set all elements of  $v$  to zero, except those corresponding to the sectors of the respective country. Those sectors are then weighted according to their total demand for capital goods. This allows me to calculate PPRs separately for each country or even sector, where the sectors with the highest PageRank are the structurally most important ones.

The original PageRank is modified to account for the structural importance only in terms of capital formation. Hence, the personalization vector is modified:

$$v^* = M_B v, \quad (16)$$

where  $M_B$  represents the probability of transitioning to a node on how important it is in the provision of capital goods.  $v^*$  redistributes the probabilities of the personalization vector based on how important a sector is for supplying capital goods to the respective non-zero sectors in  $v$ .

The transition matrix is computed as  $M_j = (W_j^{-1} D_j)^T$ , where  $D_j$  is the adjacency matrix, and  $W_j$  is the matrix containing the total weight of out-degrees from a particular node in a diagonalized form:  $W_j = \widehat{(D_j i)}$ .  $i$  is a column vector of ones.  $M_A$  indicates the probabilities of utilizing a sector's capital goods as well as other intermediary inputs. For  $M_A$  the adjacency matrix is  $D_A = (A + \hat{\delta} B)^T$ , whereas for  $M_B$  it is  $D_B = (\hat{\delta} B)^T$ .<sup>15</sup>

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<sup>15</sup>The direction of the edge for an element  $d_{ij}$  is from  $i$  to  $j$ , whereas the first index represents the index of the row and the second the index of the column.

The new equation to calculate the PageRank centrality is:

$$R_{t+1} = dM_A R_t + (1 - d)v^*. \quad (17)$$

Many other measures of centrality have been used to describe input-output networks, but they do not allow for personalization (i.e. the important sectors for a specific region). Therefore, for my analysis, I deem PPR as the best measure to identify central sectors for specific regions.

After having computed the PPR for all countries, they are assigned to clusters. Those clusters are formed based on the similarity between countries in their ranking of the most structurally central sectors for a country. Such a procedure allows for a more granular detection of sectors and countries that are structurally important to a particular set of countries.

There are many different methods to compute the similarity of ranked lists, such as cosine similarity or Spearman’s rank correlation.<sup>16</sup> For this exercise, the order of the top sectors is more relevant than the order of the one at the bottom of the ranking. There are two reasons for this: first, in a scale-free network<sup>17</sup> only a low number of “super-stable” nodes emerge, which are unaffected by disturbances or random changes in the topology of the system<sup>18</sup> (Ghoshal & Barabási, 2011, p. 5). The lower-ranked nodes/sectors are thereby less stable in terms of their assigned rank. Second, for this analysis, I am interested in those sectors that are the most important for a certain country and how similar their ranking is compared to other countries’ rankings. For analyzing broad trade and production relations between countries, the order of the lowest-ranked sectors is not of great interest.

The rank-biased overlap (RBO) fits this requirement by weighting the importance of the ranks, with the ranks on top having the largest weight (Webber et al., 2010). The RBO measure indicates the similarity in structural importance of sectors at the top between two particular countries. Based on this indicator, the countries are hierarchically clustered in a dendrogram.<sup>19</sup> They are clustered based on average-linkage. Average-linkage clustering assigns countries based on their average similarity to all the other countries in the existing cluster.<sup>20</sup>

Hierarchical clustering is useful to identify nodes that are highly similar to one another but does not perform as well at assigning nodes with a lower similarity to those of its cluster to the right cluster (Newman, 2018, p. 537). Each technique to identify community structures has

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<sup>16</sup>Cosine similarity indicates the Euclidean distance between the rank scores of each sector. The Spearman’s rank correlation coefficient indicates how similar two ranked lists are in terms of the similarity of sequences. Both measures treat the upper and lower parts of a ranked sector list equally.

<sup>17</sup>The degree distribution in scale-free networks follows a power law. The tail of the degree distribution of the network I analyse (see Figure 1a) follows a power law, according to its visual pattern.

<sup>18</sup>With the in-degree of nodes kept constant.

<sup>19</sup>The settings for the RBO measure are configured so that the top 10 sectors have a cumulative weight of around 42%, while the cumulative weight of the top 100 sectors is around 96%.

<sup>20</sup>Average-linkage clustering serves as a good compromise between clustering techniques that are either based solely on the most similar or the least similar country in a cluster. See Newman (2018, Chapter 14.5.2) for the (dis-)advantages of different clustering techniques.

different advantages or shortcomings. The aim of this analysis is to identify which particular countries a cluster relies on and what the common characteristics of the countries in a certain cluster are, such as their income group, geographical location and their domestic share of capital goods production. The effect of a single country, which might not have been assigned to the correct cluster, on this analysis should be limited.

To identify the optimal level of clustering, I employ the average silhouette score. The silhouette score measures how well a certain data point fits into the cluster (see Rousseeuw, 1987). The average score provides information on how well all data points have been fitted into a cluster.

## 4 Results

I present my analysis of the world's capital good production in four parts. First, I present some general findings on who demands and supplies capital goods. Second, I look at the dependencies between countries for the supply of capital. Next, I extend this exercise to the indirect dependencies, taking indirect inputs into account. Finally, I will discuss the results of the network analysis by looking at the structural importance of capital formation between different countries.

### 4.1 Concentration of Capital Production

The production of capital goods is highly concentrated (see Table 2). Only ten countries produce two-thirds of all capital goods, while the top 30 producers account for approximately 90% (89.77%). This encompasses all types of capital goods, predominantly machinery and equipment, buildings and structures, and software.

The data on capital goods production reflects what is often cited as a stylized fact. High-income countries are the dominant producers of capital goods: They constitute nine out of the ten largest producers; China complements the list as the only upper-middle-income country. Crucially, the United States alone is responsible for almost 30% (29.97%) of total production, while its runner-up, China, makes up approximately 10% (9.41%) of world production. As a capital-intensive process producing complex products, capital formation is primarily concentrated in high-income countries.

Most importantly, as shown in Figure 2a, around two-thirds of total demand stems as well from high-income countries, around a third from upper-middle income countries, while both the supply and demand of capital goods from lower-income countries make up less than 10% of global production and demand. High-income countries almost exclusively acquire capital goods domestically or from other high-income countries. Upper-middle income countries still receive almost half of all capital goods from their income group or produce them domestically, while the other countries import more than half of their capital goods from high or upper-middle

|                       |                 |                       |              |              |       |                                                   |                 |
|-----------------------|-----------------|-----------------------|--------------|--------------|-------|---------------------------------------------------|-----------------|
| Income Group (Supply) | Total (Imports) | 38.64%                | 47.62%       | 12.66%       | 1.08% | shares of global capital goods flows (sum = 100%) |                 |
|                       | Total (Demand)  | 62.77%                | 30.07%       | 6.65%        | 0.51% |                                                   |                 |
|                       | Domestic        | 48.73%                | 12.77%       | 2.05%        | 0.12% | ←                                                 |                 |
|                       | Low             | 0.02%                 | 0.16%        | 0.08%        | 0.01% |                                                   |                 |
|                       | Lower-Middle    | 0.42%                 | 1.01%        | 0.27%        | 0.07% |                                                   |                 |
|                       | Upper-Middle    | 1.93%                 | 1.44%        | 0.71%        | 0.14% |                                                   |                 |
|                       | High            | 11.67%                | 14.69%       | 3.54%        | 0.18% |                                                   |                 |
|                       |                 | High                  | Upper-Middle | Lower-Middle | Low   | Total (Supply)                                    | Total (Exports) |
|                       |                 | Income Group (Demand) |              |              |       | 78.82%                                            | 82.83%          |

(a) Income Groups

|                 |                                                   |                           |                       |                    |                     |                                                   |            |               |                                                   |                 |
|-----------------|---------------------------------------------------|---------------------------|-----------------------|--------------------|---------------------|---------------------------------------------------|------------|---------------|---------------------------------------------------|-----------------|
| Region (Supply) | Total (Imports)                                   | 4.92%                     | 18.25%                | 3.93%              | 48.57%              | 9.89%                                             | 6.37%      | 8.08%         | shares of global capital goods flows (sum = 100%) |                 |
|                 | Total (Demand)                                    | 4.36%                     | 22.32%                | 1.99%              | 34.62%              | 4.43%                                             | 3.29%      | 28.99%        |                                                   |                 |
|                 | Domestic                                          | 2.56%                     | 15.62%                | 0.54%              | 16.79%              | 0.80%                                             | 0.95%      | 26.02%        | ←                                                 |                 |
|                 | North America                                     | 0.44%                     | 0.79%                 | 0.11%              | 4.42%               | 0.32%                                             | 0.17%      | 0.33%         |                                                   |                 |
|                 | South Asia                                        | 0.02%                     | 0.06%                 | 0.06%              | 0.22%               | 0.03%                                             | 0.01%      | 0.05%         |                                                   |                 |
|                 | Middle East, North Africa, Afghanistan & Pakistan | 0.03%                     | 0.13%                 | 0.07%              | 0.28%               | 0.17%                                             | 0.05%      | 0.03%         |                                                   |                 |
|                 | East Asia & Pacific                               | 0.37%                     | 0.59%                 | 0.43%              | 4.57%               | 0.96%                                             | 1.11%      | 0.99%         |                                                   |                 |
|                 | Sub-Saharan Africa                                | 0.01%                     | 0.04%                 | 0.04%              | 0.35%               | 0.03%                                             | 0.07%      | 0.01%         |                                                   |                 |
|                 | Europe & Central Asia                             | 0.74%                     | 4.97%                 | 0.62%              | 7.43%               | 1.95%                                             | 0.88%      | 1.20%         |                                                   |                 |
|                 | Latin America & Caribbean                         | 0.19%                     | 0.11%                 | 0.10%              | 0.56%               | 0.18%                                             | 0.04%      | 0.35%         |                                                   |                 |
|                 |                                                   | Latin America & Caribbean | Europe & Central Asia | Sub-Saharan Africa | East Asia & Pacific | Middle East, North Africa, Afghanistan & Pakistan | South Asia | North America | Total (Supply)                                    | Total (Exports) |
|                 |                                                   | Region (Demand)           |                       |                    |                     |                                                   |            |               | 32.60%                                            | 17.93%          |
|                 |                                                   |                           |                       |                    |                     |                                                   |            |               | 1.40%                                             | 1.22%           |
|                 |                                                   |                           |                       |                    |                     |                                                   |            |               | 1.56%                                             | 2.07%           |
|                 |                                                   |                           |                       |                    |                     |                                                   |            |               | 25.83%                                            | 24.61%          |
|                 |                                                   |                           |                       |                    |                     |                                                   |            |               | 1.10%                                             | 1.53%           |
|                 |                                                   |                           |                       |                    |                     |                                                   |            |               | 33.41%                                            | 48.46%          |
|                 |                                                   |                           |                       |                    |                     |                                                   |            |               | 4.09%                                             | 4.18%           |

(b) Regional Groups

Figure 2: Shares of Total Global Capital Goods Production by Income and Regional Groups

*Notes:* Each tile depicts the share of total capital goods supplied by a certain income/regional group to another income/regional group demanding it. Flows between or within income/regional groups only represent foreign trade, as domestic production is listed separately. The shares of total supply include the domestically produced capital goods. The shares of total exports and imports omit the domestic flows and represent an income/regional group's share in exports or imports (they both sum up to 100%).

*Reading Example:* The domestic production in North American countries makes up 26.02% of global capital goods production. The imports by the *North America* group from the *South Asia* group makes up 0.05% of global capital goods production. Countries in the *North America* group demand 28.99% and supply 32.60% of all capital goods.

Table 2: Top Ten Capital Producing, Consuming, Net Exporting and Net Importing Economies.

| Producer       |           | Consumer       |           | Net Exporter   | Net Importer         |
|----------------|-----------|----------------|-----------|----------------|----------------------|
| Country        | Share (%) | Country        | Share (%) |                |                      |
| USA            | 29.97     | USA            | 27.15     | USA            | China                |
| China          | 9.41      | China          | 20.37     | United Kingdom | India                |
| Japan          | 5.24      | Japan          | 5.83      | Singapore      | Indonesia            |
| Germany        | 4.55      | Germany        | 3.56      | Netherlands    | Saudi Arabia         |
| United Kingdom | 4.32      | India          | 2.90      | Germany        | Japan                |
| Italy          | 2.76      | France         | 2.75      | Austria        | Iran                 |
| Canada         | 2.63      | United Kingdom | 2.30      | New Zealand    | Rest of Asia-Pacific |
| France         | 2.59      | Italy          | 1.93      | Italy          | Nigeria              |
| Australia      | 2.32      | South Korea    | 1.88      | Canada         | Ukraine              |
| Netherlands    | 2.25      | Canada         | 1.84      | Finland        | Thailand             |
| RoW            | 33.96     | RoW            | 29.49     |                |                      |

*Notes:* Net exporters and importers are ranked based on the absolute size of their trade imbalance in capital goods. The US is the largest net exporter, while China is the largest net importer. “RoW” stands for “Rest of the World”

income countries. All income categories heavily rely on the provisioning of capital goods from high-income countries, while the lower their income is, the less they produce themselves or get from their income group.

Since income and geographical distribution strongly align (see Figure 9), it does not surprise that capital demand and production are concentrated to certain areas of the world (see Figure 2b). North America and Europe almost exclusively rely on their own region for capital goods. East Asia and Latin America, are still able to cover more than half of their demand for capital goods in their own region. Regions such as Sub-Saharan Africa have to import around 75% of capital goods from other regions, primarily from Europe and East Asia. Overall, there is a strong concentration both of production and usage of capital goods in North America, Europe and East Asia.

## 4.2 Sectoral Concentration

The capital-use matrix allows for a more granular view of the share of specific industry’s demand for capital goods. Looking at the agriculture sectors, countries on the African and Asian continent, as well as in Eastern Europe have a much higher share in the total demand for capital goods than the rest of the world (see Figure 3a and 4). While many countries in the named regions have a similar share in demand for capital goods for the mining sector, other high-income countries with a strong mining industry, such as Australia (14.63%) or Poland (12.25%), also devote between 10-15% of their investment to the mining sector (see Figure 3b). Overall, a large majority of the countries on the African, Asian and Latin American

continents channel a larger share of their total capital good demand into primary production than European and North American countries. High-income countries have a higher share of investments in service sectors compared to lower-income countries, while the latter's share tends to be higher in the manufacturing sector (see Figure 3).

Interestingly, the share of capital goods being demanded by capital-producing sectors<sup>21</sup>, that can be summarized to what Marx and Kalecki called *department I*, does not vary between income groups. The overall median share of capital goods demanded by department I is 30.26%.<sup>22</sup> But the share varies strongly across countries<sup>23</sup> with half of the countries having a department I share between 20.79% (Q1) and 30.25% (Q3).

### 4.3 Capital Goods Production

Figure 5 shows that the world can largely be divided into two groups: Those who can produce –a large majority of–their capital goods domestically and the rest who strongly rely on imports. Those who cannot are concentrated in Eastern Europe, on the African continent, in South and East Asia as well as partially in Latin America. The median domestic production share of high-income countries is expectedly high: approximately 65%, with countries like the United States producing 90% of its capital goods domestically. The median domestic production share of all other countries is around 20%.

There are distinct differences in terms of countries' dependencies on the imports of capital goods from specific countries. The European continent relies strongly on EU members, the United Kingdom, the United States and Switzerland, but not on China. Due to their low domestic production share, Eastern European countries are more dependent on the listed countries than states in Western and Central Europe. Among the EU countries, Germany, Austria, Italy and Spain tend to be the main exporters of capital goods to the rest of Europe. The prevalent position of Germany as a supplier of capital goods in Europe is in line with the reported pattern by Eaton and Kortum (2001).

In Latin America, the main trading partner for the import of capital goods is the United States, and to a lesser degree European countries and China. Interestingly, countries such as Haiti or Uruguay have a strong dependency on their respective former colonial rulers. Crucially, Brazil and Chile are almost the sole Latin American suppliers of capital goods to other Latin American countries, but only to a limited set of countries (Brazil: primarily Argentina, Ecuador and Cuba, Chile: Ecuador and Bolivia). Certain countries, such as Brazil, Chile or Colombia, are able to reproduce their own capital stock, but those that have to import capital goods are mainly reliant on countries outside of Latin America.

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<sup>21</sup>*Machinery & Equipment, Transport Equipment, Buildings & Structures, ICT*

<sup>22</sup>Median shares by income group: 29.17% (high), 30.30% (upper-middle), 32.16% (lower-middle), 27.23% (low)

<sup>23</sup>The minimum is as good as zero percent (Benin) stretching all the way to a department I share of 66.22% (Ireland) without accounting for outliers.

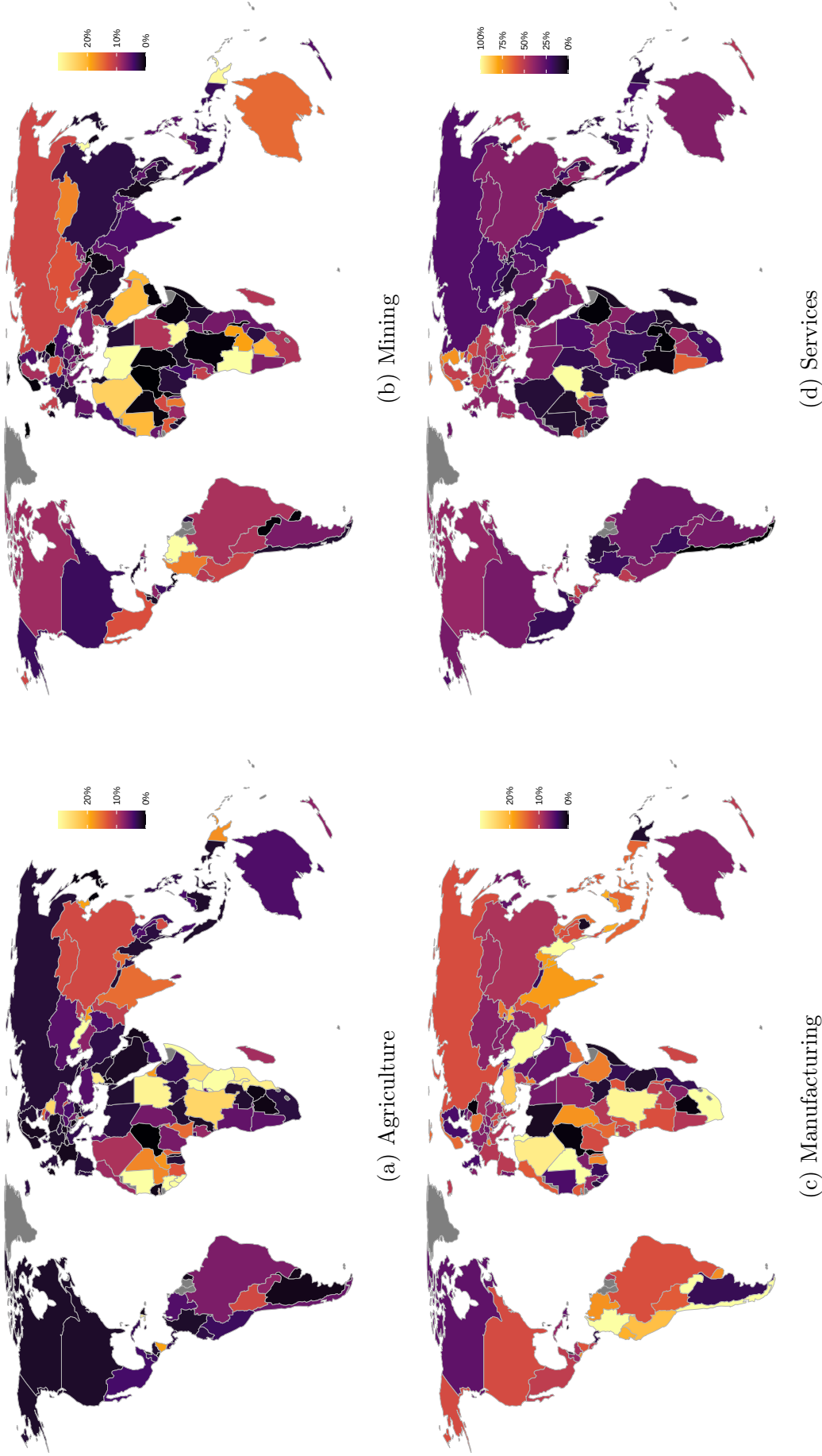


Figure 3: Shares of Total Demand of Sector for Capital Goods

*Notes:* For Subfigures a, b and c, the scale is capped at 30% to allow for a more granular presentation. The scale of Subfigure d differs from the others' by showing values up to 100% as the demand share for services is in general larger in most countries.

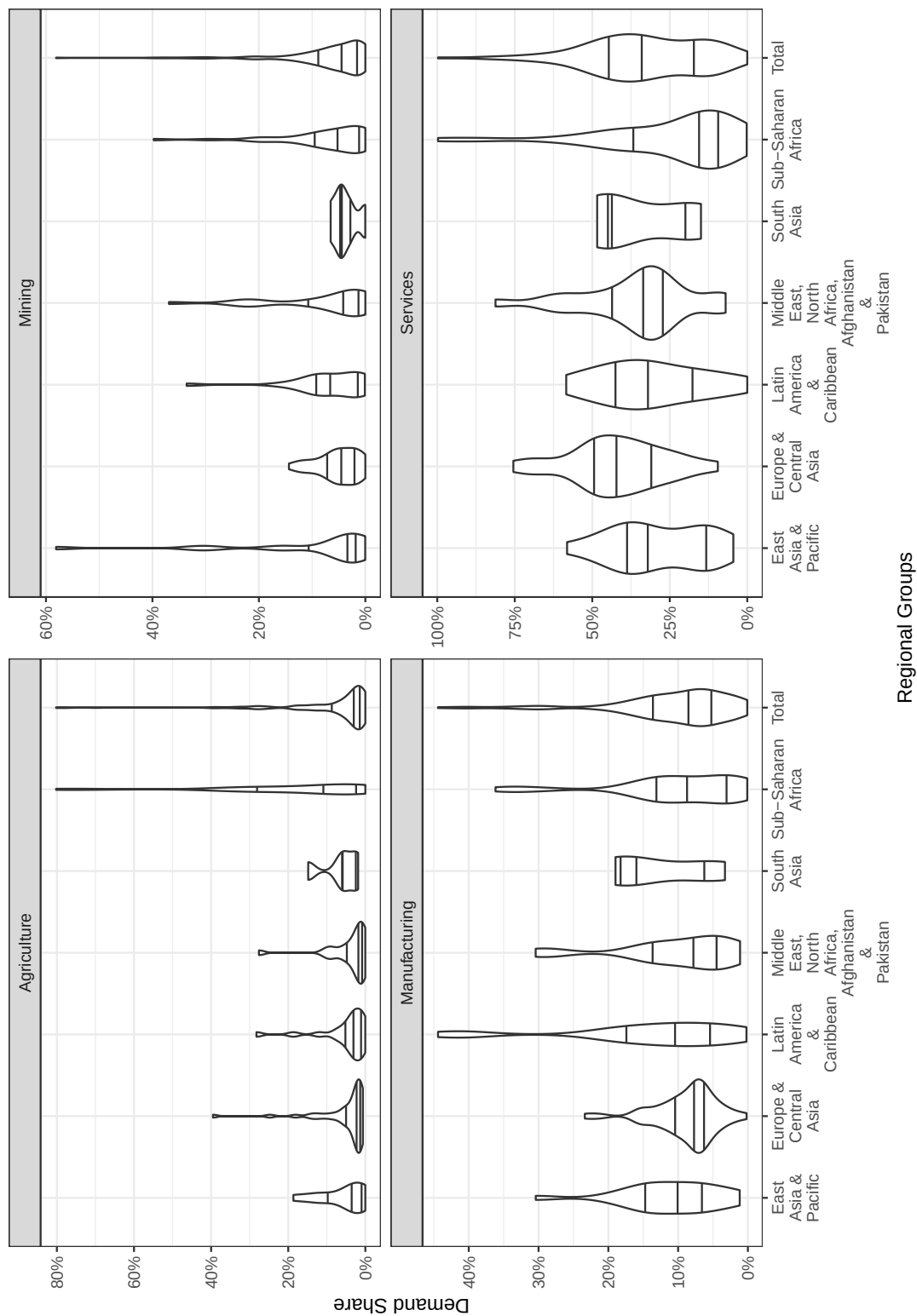


Figure 4: Distribution by Region of Shares of Total Demand of Sector for Capital Goods

*Notes:* The violin plots show the distribution of different sectors' demand for capital goods separated by regional groups. The upper vertical line in each violin plot represents the end of the 3rd quartile, the middle vertical line is the median and the lower vertical line represents the end of the 1st quartile. *Total* shows the common distribution among all countries. The regional group *North America* has been excluded due to only two data points, but the US and Canada are included in the *Total* category.

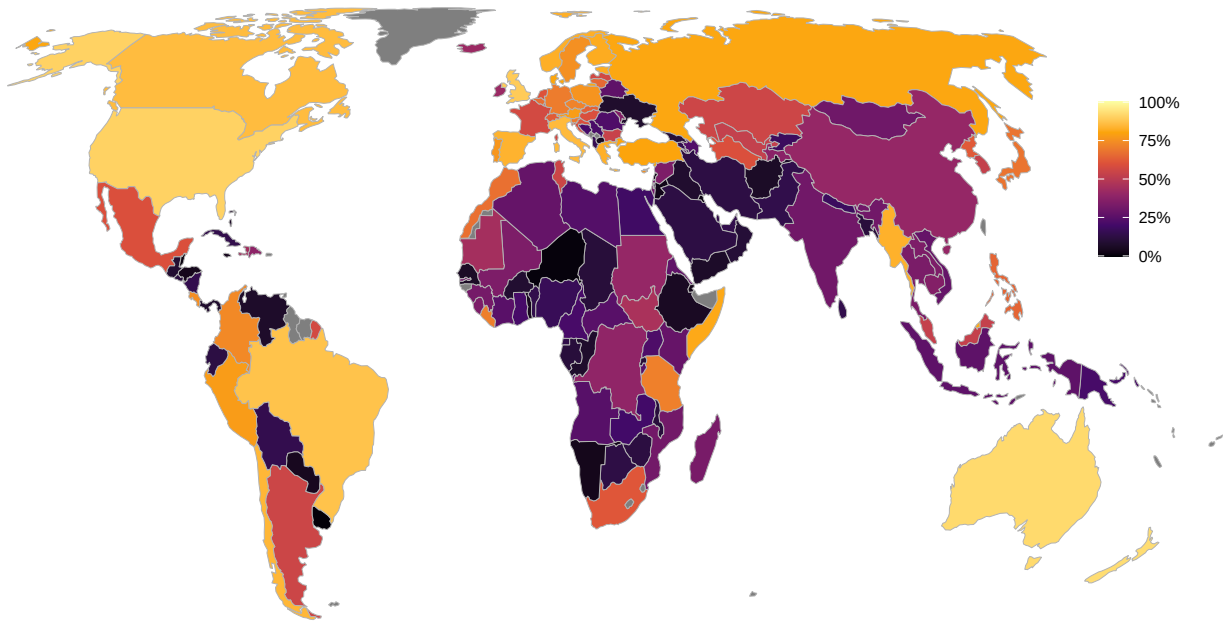


Figure 5: Domestic Production Share of Capital Goods

*Notes:* The world map shows the share of capital goods that are produced and consumed domestically of all consumed capital goods by a country.

Unlike Chile or Brazil, Mexico is not an important exporter to any particular country but has a large domestic production share and buys most of its imported capital goods from the US. Canada also primarily relies on the US for imports but, in contrast to Mexico, is an important supplier of capital goods to Central American and certain African countries such as Senegal. The US itself has no large exposure to any country.

In line with Eaton and Kortum (2001), the US is an important supplier of capital goods in Asia, in particular for countries around the Pacific. However, Japan's role as a capital goods provider is no longer as poignant as in their analysis. Besides the US, many Asian countries are dependent on capital goods imports from China and to a lesser degree from the EU and UK. In general, there is a large variance among countries' dependencies. Importantly, China is dependent on other countries for its capital formation, in contrast to the US as the other major capital goods producer. It mainly relies on imports from the other top five producers of capital goods (US, Germany, Japan, United Kingdom). While India needs to import more of its capital goods than China, its import structure is more diversified: Its main trading partners are Singapore, Australia, the UK, Germany and the US.

The African continent possesses the lowest domestic production shares of capital goods among all the world regions. Many African countries have a highly concentrated exposure to a few economies on other continents. All the previously mentioned countries and country groups such as the US, the UK, China and EU countries make up large shares of exports to African countries. The US's influence is smaller in comparison to its import share in other world regions. There are further important capital goods provider, mainly South Korea, which provides up to a third of all capital goods in many countries. Further, there are several upper-middle income

countries such as Brazil, Turkey and Russia who are important trading partners for a subset of African countries.

The country-level analysis confirms the broader findings: richer regions such as North America and Europe mainly rely on Europe and the US, middle-income regions on Europe, the US and China, while to a lesser degree on other middle-income countries. Lower-income regions are strongly dependent on single countries for their capital goods, with a more pronounced dependence on China and other Asian countries. The importance of rich countries for providing capital goods is positively linked to a country's income, while upper-middle income countries become more important for capital formation the lower a countries income is.

## 4.4 Supply Chain of Capital Goods

Applying a matrix of capital technical coefficients allows not only to analyze the direct flows of capital goods but also the indirect inputs to produce such goods. Those are a composition of capital goods, as well as other types of intermediate inputs, the latter being fully consumed in the production process. By broadening the view to the direct and indirect requirements for capital formation, the perception on trade and production relations between countries shift. Accounting for the provisioning of indirect inputs and capital goods is important, because simply producing capital goods at home is not enough as Kalecki (1976, p. 24) pointed out, since many countries in the (semi-)periphery are even more reliant on intermediate inputs to produce capital goods.

Accounting for the capital coefficients has important implications for the multiplier analysis in general. While endogenizing the provision of capital goods leads to higher multipliers for all sectors, it changes the distribution where those additional expenditures ultimately end up. A sector's multiplier is the sum of the column in the Leontief inverse  $L_K$ . It can be divided into shares of the total multiplier devoted to domestic and foreign sectors.

I find that across all countries, the share of the domestic multiplier decreases with the inclusion of the capital coefficients. The median multiplier share of countries other than high-income countries received by the latter increases by approximately 4.31 percentage points.<sup>24</sup> Upper-middle income countries are still able to grab 1.30 percentage points more from lower-income countries' median multiplier share, while the lower-income countries do not obtain higher multiplier shares from other countries. Due to the skewness of capital goods production, its endogenization increases the share that high-income countries can extract from additional spending in other countries. Overall, the median domestic share of the multiplier decreases the richer an income group is: the median domestic multiplier in low-income countries is 75.78%, while it is only 68.58% in high-income countries. Most of the foreign share of the multiplier remains in the respective income group of a country. However, the median multiplier share going to

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<sup>24</sup>First, I calculated the median of the domestic shares of the ten industries in each country separately. I use the median to avoid the influence of outliers. Second, I calculate the median of all the countries' median shares.

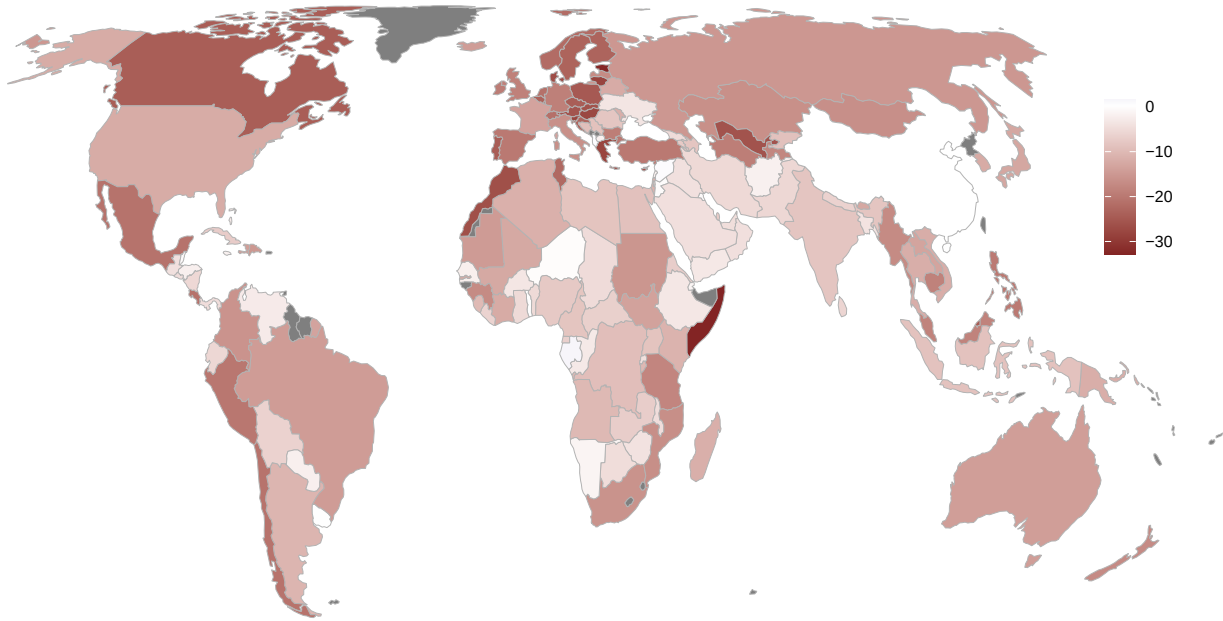


Figure 6: Difference in Domestic production Share of Capital Goods Without and With Indirect Inputs (in Percentage Points)

*Notes:* The world map shows the difference between the domestic production shares of capital goods when indirect inputs are considered and when they are not considered. North Korea has been excluded from the figure because of unrealistically high multiplier values leading to a disproportionate increase in the domestic production share.

high-income countries from other income groups is quite substantial: 15.78%. Endogenizing the capital-use matrix thereby substantially increased the multiplier share of lower-income countries towards high-income countries.

Figure 6 shows that all countries, with the major exception of China, can provide a lower share of goods needed for capital formation domestically, when both direct and indirect inputs and capital goods are accounted for. This is the case across regions and income groups. The median domestic production share for both direct and indirect inputs and capital goods drops to 41.25% for high-income countries while the median share for the other income groups ranges between 12.71% and 18.00%. The drop in the domestic production share is the most pronounced among high-income countries, but the additional requirements for imports of those countries are mainly covered by other high-income countries and to a smaller degree by upper-middle income countries. Most European countries, as the largest group of high-income countries, import a larger share of their direct and indirect inputs and capital goods for capital formation from Germany, the US and China. The Baltic states additionally have a higher dependency on imports from Russia.

The production of capital goods mainly relies on inputs from manufacturing and service sectors. Manufacturing sectors are more frequently situated outside high-income countries, prominently in upper-middle-income countries China. This explains the general higher reliance on upper-middle income countries across all income groups, when indirect inputs and capital

goods are taken into account besides the direct supply of capital goods.

By including the indirect dependencies, there is a concentration in the reliance on imports from a few countries. All countries have to import a larger share of indirect inputs and capital goods than direct capital goods from China. This is particularly pronounced among African and Asian countries. China itself is less exposed to the US, but relies more on imports from Europe and Russia. To a lesser degree, most countries in all regions rely more on the US, Germany and other European countries to either produce or acquire capital goods.

Even though upper-middle-income countries take up a larger share of the benefits from investment expenditures through indirect inputs, all income groups mainly rely on the provision of goods from high-income countries. This has strong implications for lower-income economies: In many of these economies, the majority of the benefits of additional investment spending, such as higher labor demand, would be reaped abroad.

## 4.5 Structural Dependencies

On a global level, there are certain key sectors for the provisioning of capital goods. Their importance is expressed in a high PageRank centrality.<sup>25</sup> Table 3 shows the ten sectors with the highest PageRank. The most central sector to the production of capital goods is *Manufacturing* in China. Although it does not provide capital goods itself, it delivers crucial inputs to produce them. The same is the case for *Services*. *Transport and Equipment* takes up a central role due to the inclusion of *Wholesale and Retail Trade*. It acts as an intermediary between the demanding and supplying sectors. The most central sectors are all situated in the top four capital-producing countries. It does not surprise that non-capital-producing sectors are geographically and structurally closely linked to capital-producing sectors in the same countries. Taking into account the top 50 ranked sectors, 40 are situated in high-income countries, nine in upper-middle income countries: in China, Turkey, Brazil and one in a low-middle-income country (Indian *Manufacturing*). All top 50 sectors are situated in G20 member states.<sup>26</sup>

A high PageRank centrality implies that a sector is linked to one or a few other central sectors, linked to many less central sectors, or to a combination of them, while those sectors do not have many or any other strong links. Sectors with a high centrality are systemically important nodes in the network. This has several implications for the rest of the economy. A sudden negative supply shock may cause ripple effects throughout the network, stalling the formation of the capital stock in certain or all countries. Crucially, those sectors and the countries they are situated in have more control over capital formation, both domestically and, importantly, abroad.

However, not all countries are dependent on the same central sectors and countries. For a

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<sup>25</sup>For the global analysis, the personalization vector  $v$  is unweighted. If the  $v$  were to be weighted, it would primarily show the structurally important sectors as perceived by the main capital goods users.

<sup>26</sup>The Netherlands is represented as an EU member.

Table 3: Top Ten Sectors With the Highest PageRank

| PageRank | Country                  | Sector                |
|----------|--------------------------|-----------------------|
| 0.0355   | China                    | Manufacturing         |
| 0.0289   | United States of America | Services              |
| 0.0216   | China                    | Machinery & Equipment |
| 0.0206   | United States of America | Transport Equipment   |
| 0.0147   | China                    | Transport Equipment   |
| 0.0145   | United States of America | Manufacturing         |
| 0.0120   | Germany                  | Transport Equipment   |
| 0.0113   | Germany                  | Services              |
| 0.0099   | United Kingdom           | Services              |
| 0.0097   | Germany                  | Machinery & Equipment |

more differentiated picture, I apply the calculation of personalized PageRanks to all countries based on their investment structure. Figure 7 shows the countries with the most similar ranking of sectors grouped together in larger clusters. The clusters are named after countries whose sectors are ranked high –and therefore have a high structural importance –in the countries of this cluster. The dendogram once divides the countries into two primary groups (grey shades) and into twenty separate clusters (colored) to provide a more granular set of interlinkages. Countries that are closely linked have similar structural dependencies on certain sectors in terms of those sectors’ PageRank centrality. Noticeably, most countries have the highest similarity in terms of structural dependency with geographically close or historically important countries (e.g., Germany, Hungary, Austria and Switzerland are the most similar). This may also emerge as a property of the estimation choices made by Magacho et al. (2026, A.5.1) for the capital-use matrix. Testing for robustness is beyond the scope of this thesis, but the results of the network analysis should undergo such a check by varying the chosen parameters for estimating the capital-use matrix for countries where no data in a KLEMS database is available.

The average silhouette score for the dendogram in Figure 7 is at its maximum for two clusters (silhouette score: 0.18). This level of clustering divides the covered countries into two clusters corresponding to their primary dependency in terms of the capital goods and intermediary input provisioning. It needs to be emphasized that all countries have a strong structural dependency on sectors in China and the United States. The two large groups differ in countries’ exposure to foreign countries and in which world region those foreign suppliers are situated.

The smaller group, *Europe*, encompassing a third of the displayed countries, includes economies that have a strong dependency on European states for acquiring capital goods. There are two types of countries in the group. The first type comprises Western and Central European countries that possess a high domestic production share of capital goods (of 60% and upwards). The second one consists of (semi-)peripheral countries situated mainly in Eastern Europe and in the Middle East, that have a low domestic production share and rely on imports from the first group for obtaining capital goods.

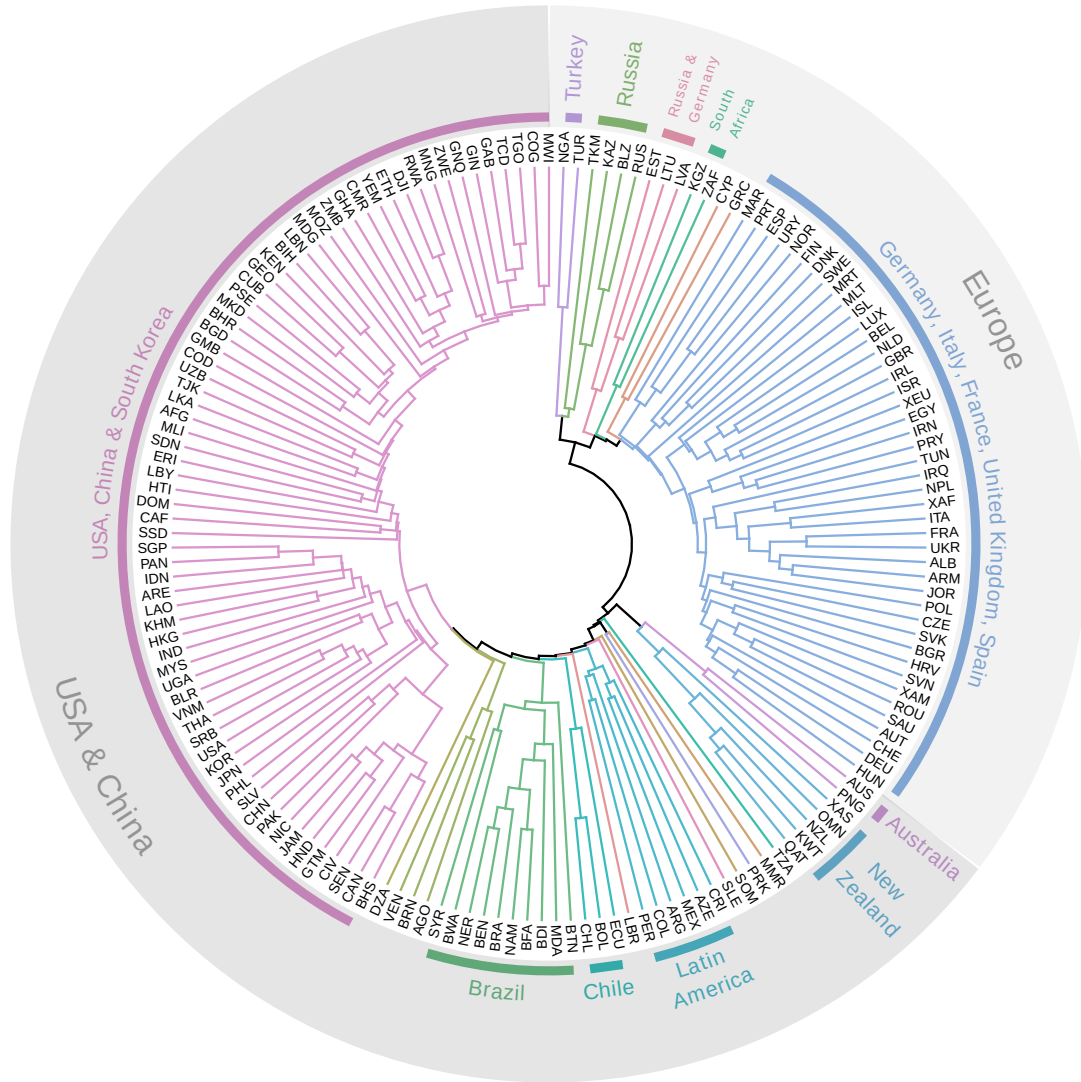


Figure 7: Dendrogram of Hierarchically Clustered Countries Dependent on Their Capital Formation Dependency

*Notes:* This dendrogram connects countries that are the most similar in terms of the order of sectors based on their PageRank centrality scores. The lower the level of connection between countries and clusters, the more similar they are. The dendrogram is divided into twenty clusters, which can be distinguished by their color codes. The label of a cluster indicates a strong structural dependency of it on the listed countries, with the exception of the *Latin America* cluster. Countries in this cluster strongly depend on their domestic sectors, besides the US and China. Those twenty clusters can be grouped into two larger clusters (gray layers), *USA & China* and *Europe*, which indicate the strongest dependencies of the countries in the cluster.

*Reading example:* For Bolivia (BOL), the sectors with the highest PageRank are Chilean. Those who follow are in the US and China. Bolivia can therefore be found in the larger cluster *USA & China* and in the smaller cluster *Chile*.

The larger group, *USA & China*, depends structurally primarily on the US and China, or depends on an additional number of high-income and upper-middle-income countries situated on continents around the Pacific besides these two major economic powers. In this group as well, peripheral, lower-income countries are those being dependent the most. However, in contrast to the group around European countries, their median domestic production share is lower than that in the former. The dependent countries are mainly situated in Africa, Asia, and Latin America.

Separating countries into only two groups obfuscates many specific interdependencies that are displayed, thus, in Figure 7, countries are separated into twenty distinct clusters.<sup>27</sup> This level of distinction allows identifying a more complex set of dependencies, while the number of countries that form single clusters or whose clusters' properties are difficult to describe remains low.

The largest cluster (*US, China & South Korea*) comprises most countries on the African continent, South and East Asian countries, in North America, and Caribbean island states. Besides the already established strong dependency on China & the US, those countries additionally rely on direct and indirect imports from South Korea for their capital formation. Since the total imports and production of the lower-income countries in the cluster are negligible on a global scale, South Korea does not appear among the top exporters of capital goods; however, it bears a high structural importance for countries in this cluster. In this cluster, African countries have a higher exposure to South Korea than the rest of the cluster. Further, on a lower level, one could separate a pocket of eight countries that are additionally structurally reliant on Canada.

The division into a larger number of clusters separated most Latin American countries –and countries being dependent on them –from the *US, China & South Korea* cluster. Three distinct clusters could be identified: Eight countries situated mainly in Africa are dependent on Brazil. The median domestic production share of the cluster of approximately 20% is similar to the *US, China & South Korea* cluster but instead of relying on South Korea, they are dependent on Brazil. A small cluster of Ecuador and Bolivia, which have very low domestic production shares<sup>28</sup>, are dependent on Chile. A third cluster (*Latin America*) consists of Latin American countries with a rather high to high domestic production share (median: 65.92%) that are primarily structurally dependent on their domestic sectors, and the US and China.<sup>29</sup>

Further, two more clusters can be identified. Countries on the Arabian Peninsula and the “the rest of Asia-Pacific” region, which includes Taiwan, cluster around *New Zealand*, while Papua New Guinea has a strong dependency on *Australia*. As can be seen in Figure 7, those two

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<sup>27</sup>In hierarchical clustering, connections between single nodes or smaller clusters are formed at a certain level. Separating into twenty clusters implies that, analytically and graphically, one makes a “cut” at the level where the countries are separated into the chosen number of clusters.

<sup>28</sup>Ecuador: 12.53%, Bolivia 14.68%

<sup>29</sup>Azerbaijan as being outside the Americas, is an outlier in the cluster with a lower domestic production share.

clusters are closely linked.

The larger *Germany, Italy, France, United Kingdom, Spain* cluster is constituted of most EU and EFTA member states, as well as peripheral countries dependent on them with a medium level of domestic production (median: 55.77%). The structurally most important sectors are, besides a global exposure to the US and China, situated in Germany, Italy, France, the United Kingdom, and Spain. The cluster could be further divided into smaller pockets formed around these major European economies.

There are three smaller clusters around semi-peripheral countries (*Turkey, Russia, South Africa*) where peripheral countries with low to very low domestic production shares have a structural exposure to them. Further, the Baltic states have a high domestic production share (median: 65.23%) but structurally depend on Russia and Germany.

Overall, in countries with a high domestic production share of capital goods, their domestic sectors tend to have the highest PageRank centrality scores. Those domestic sectors are the most structurally most important ones in the supply chain of producing capital goods. Further, the higher the domestic production share is, the higher the value of the PageRank centrality scores of their domestic sectors tends to be. As an example, both in Germany (dom. prod. share: 69.84%) and the US (dom. prod. share: 90.20%), the highest-ranked sector is *Services*. The PageRank centrality score of the one in the US is 0.1693, the corresponding one in Germany is only 0.06820. The exposure to the top sector in the US is higher, while Germany is structurally reliant on a larger set of domestic and foreign sectors.

This description of the relations between countries to acquire and produce capital goods shows that there are multiple levels of dependencies: First, the share of domestically produced capital goods determines whether their domestic sectors receive a high PageRank centrality score. Second, sectors in the US and China are structurally important, independent of the country's position in the supply chain of capital goods and its import dependencies. However, countries that rely more on imports are also more dependent on sectors in those two countries. Third, certain economies are structurally dependent on specific core and semi-peripheral countries besides the US and China. The dependency is generally higher among peripheral countries. Importantly, all economies around which other countries group are core or semi-peripheral countries. Specifically, semi-peripheral countries, such as Brazil or Russia, are themselves dependent on core countries for capital formation.

Distinct groups of patterns emerge in terms of countries' structural importance on other countries' capital formation process and on their own. Figure 8 depicts a selection of countries exemplary of a specific group. The dots in the plot for country *a* signify the linkage between the structural importance by country *a* on the capital formation in country *b* and the structural importance by country *b* for capital formation in country *a*. When undertaken for all covered countries, patterns emerge that serve as an indicator of a country's role in the capital goods

supply chain.

Senegal's pattern is representative of a country with peripheral characteristics. All points are arranged along the x-axis. It is not structurally important for any other country, while it is strongly dependent on others for its capital formation. More than half of all covered countries fall into this category.

In contrast, South Africa possesses the typical characteristics of what Wallerstein (1974, pp. 6, 10) describes as a semi-peripheral country: For its capital formation, it relies on countries, first and foremost on high-income countries. Meanwhile, they have a (sometimes substantial) importance for other countries, primarily in the periphery. The sole country in South Africa's (ZAF) cluster in Figure 7, Kyrgyzstan, exhibits the pattern of peripheral countries similar to Senegal –with regards to capital formation (see Figure 10 in the appendix). Crucially, the countries South Africa depends on and the countries it has an impact on are different countries. The visual structural importance pattern of semi-peripheral countries thereby resembles the form of an “L”.

Among core countries, there are different patterns that emerge. The visual structural importance pattern of Spain is typical of mainly larger European economies. It could be described as a secondary core, alluding to the concept by Prebisch (1959, p. 260). While it has an impact on numerous countries' capital formation, it is still non-mutually dependent on major capital goods suppliers such as China, Germany and the US. Additionally, there exists a mutual dependence on other high-income countries with a similar visual pattern. These three parts, one-sided importance, one-sided dependence, and mutual dependence, create a pattern similar to an “h”. Smaller European economies such as Poland, which tend to have a high domestic production share, neither have a large impact on other countries nor are they faced by many one-sided dependencies. This leaves them with a structural importance pattern where most points bundle around the zero origin or along the diagonal with mutual dependencies on other European countries, with a few points related to large capital goods exporters spread along the x-axis. For the sake of this analysis, they can be described as the *tertiary* core.

What distinguishes the US from secondary core countries is its very limited exposure to other countries. Its “I” shape with a high to very high impact in all countries makes it, along the concept of Prebisch (1959, p. 266), the principal core of the world, in terms of capital formation.

China falls between boxes: similar to the US, its sectors, in particular *Manufacturing* and *Machinery & Equipment*, have a strong impact among all countries. What sets it apart from the US is a stronger dependency on high-income countries for its capital formation. In the realm of capital formation, China could best be described as an emerging core country, along the concept by Ho (2017, p. 86).

These are stylized descriptions, as can be seen in Figure 10, there are some nuances, especially

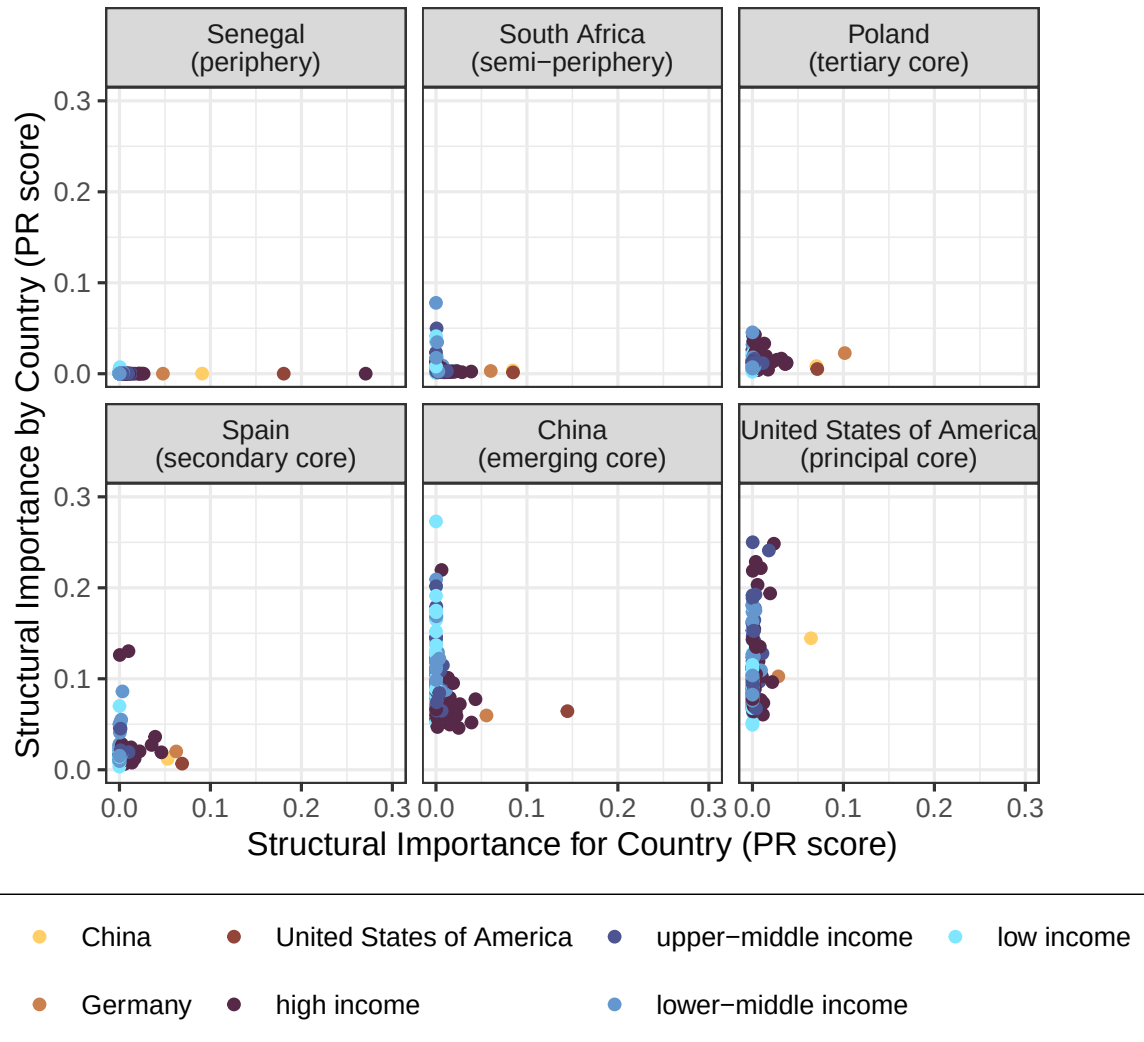


Figure 8: Structural Importance Patterns

*Notes:* The figure depicts the relation structural importance of a country on the capital formation of other countries (y-axis) and the structural importance of those respective countries for a country (x-axis). See Figure 10 for an overview of all countries' structural importance patterns.

*Reading example:* The light yellow dot in the "United States of America" quadrant describes on the x-axis to what extent China is structurally important for capital formation in the US (PR: 0.0644). The y-axis describes the structural importance of the United States for the capital formation in China (PR: 0.1445). It follows that China's structural importance for the US is lower than vice versa.

among countries whose pattern falls between what can be described as semi-periphery, and tertiary or secondary core.

The exercise of conducting a network analysis on the capital-enhanced technical coefficient matrix  $A + \hat{\delta}B$  allows identifying the structurally important sectors and countries. Those align with the previous analysis of the capital-use matrix  $\hat{\delta}K$ . The main capital goods providers are also the most central sectors and countries in the network analysis. But applying this technique allowed for better identification of the role of different countries in the capital goods supply chain and linkage to their respective structurally important countries. It showed that clear core-periphery patterns can be found, with the US as the principal and China as the emerging core having the largest influence.

## 5 Discussion

The undertaken analysis confirms what Structuralist scholars (Furtado, 1976, p. 46) have lamented and what previous studies on the trade and production of capital goods have shown: supply and demand of capital goods are highly concentrated in a few countries, mainly belonging to the high-income category (see Table 2 and Figure 2a). In comparison to the previous work by Mutreja et al. (2018), I find lower concentrations in capital goods production among countries, even if I only account for machinery and equipment. According to their analysis, ten countries produce 80% of all capital goods, while in the case of the capital-use matrix, ten countries produce only two-thirds of all capital goods. These differences may occur due to a diversification of production between 2011 and 2019, or more likely due to differing product definitions<sup>30</sup> and the number of countries covered. The analysis by Mutreja et al. (2018) covers only 102 countries, while mine is based on 163 countries. Analyzing the production and trade relations through a capital-enhanced IO framework provides a more nuanced insight, allowing for a more holistic perception of what encompasses capital goods while differentiating between different types of output.

Capital goods flows are overall the business of high-income countries, and to a lesser degree of upper-middle income countries with a concentration in three world regions: North America, Europe and East Asia (see Figure 2). Most of the countries in those categories are also able to reproduce a majority, some even almost their full capital stock domestically (see Figure 5). The rest of the world is dependent on the first group to varying degrees with often low domestic production shares.

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<sup>30</sup>Mutreja et al. (2018, p. 41) state that they used value-added and gross output data from the formerly called INDSTAT2 database by UNIDO of the covered sectors, implicitly assuming that the whole volume of produced goods by the *machinery and equipment* sector is used as capital goods. INDSTAT Revision 4 covers GFCF data (UNIDO, 2026), but this data seems not to have been used by the authors.

## 5.1 Balance-of-Payments Constraints

Lower-income economies that do not produce capital goods and recurrently have to import them are kept in their position along GVCs through several channels related to capital formation (see Furtado, 1976, p. 110). First, due to their low elasticity ratio, the simple task of renewing the existing productive capacity requires exporting a certain volume of goods –to a large extent of low complexity. Keeping the current capital stock intact is, therefore, at the constant mercy of favorable terms of trade. A decrease in the demand of the rest of the world for the exported goods of a peripheral country, i.e., a drop in the growth rate of exports (see equation (1)), narrows the capacity to import capital goods. This leads to effects that reach beyond a periodical downswing. The productive capacity of such an economy can be reduced over an extensive period due to the long-lasting nature of capital goods. Notably, this is an ever-present threat because the depreciation of the capital stock is an ever-lasting process that demands constant flows of imported capital goods.

Second, the little amount of investment in capital goods by peripheral countries is devoted to a larger extent to primary and intermediate stages of production, namely agriculture, mining and manufacturing, than in the core (see Figure 3 and 4). A certain composition of capital goods/technology dictates the productive possibility of an economy. Directing a larger share of capital goods into primary and intermediary goods production reproduces peripheral countries' low elasticity ratios (Porcile et al., 2023, p. 267).

Third, if a peripheral country intends to change the sectoral composition of its economy and to pursue ISI, it also faces balance-of-payments constraints. If the volume of exports is kept at its current level, the larger share in capital goods for capital-goods-producing industries or industries producing consumption goods with a higher complexity would need to be compensated by a drop in the import of other types of goods or at the cost of capital goods for primary production (Furtado, 1976, p. 120; Kaldor, 1967, p. 31; Kalecki, 1976, p. 27). A drop in imports of consumption or intermediate goods may lead to inflationary pressure if there is not enough domestic capacity to produce those goods, as Prebisch (1950, pp. 52–53) and Kalecki (1976, p. 24) pointed out. Reducing the import of capital goods for agriculture, mining and certain sectors in manufacturing may have detrimental effects on the country's capacity to continue exporting the same volume of those goods, under the assumption that the industrialization process requires time to fully unfold. If, instead, those capital goods are imported additionally, it needs to go in tandem with an increase in the volume of exports (Furtado, 1976, p. 123; Kalecki, 1976, p. 27; Prebisch, 1950, p. 2). Increasing production in export-oriented sectors may again require additional amounts of capital goods by those sectors, either due to a higher depreciation rate as a result of a higher capacity utilization rate or due to the firms' aim to keep the capacity utilization rate fairly constant over time.

Fourth, even if a (semi-)peripheral country such as Mexico has a fairly high domestic production share for capital goods (59.14%), accounting for both direct and indirect inputs and

capital goods, leads to a substantial drop in the share (-20.89 pp) (see Figure 6). Although a country has managed to produce a considerable share of its capital goods domestically, it still has to import input goods recurrently (see Kalecki, 1976, p. 52). Further, a large share of the benefits of additional investments, such as a higher demand for workers, would be reaped abroad.

The current flows of capital goods implicate the structure of the economy in future periods, including its class and trade relations. Relying on imports for capital goods comes at a great cost for peripheral countries. As long as they are under strict balance-of-payments constraints, their position in the global economy is constantly reinforced, even if they only want to renew their existing productive capacities (see Kaldor, 1967, p. 34).

## 5.2 Core-Periphery Patterns in Capital Formation

Countries' positions in the capital goods supply chain, their dependencies and the core-periphery dichotomy can be made visible by conducting a network analysis. Patterns of periphery, semi-periphery and core can be recognized between the different countries (see Figure 8). The resulting patterns and country clusters of the network analysis show that there exists a hierarchy in who supplies and who acquires capital goods.<sup>31</sup> These patterns are presumably a result of the existing trade imbalances and the historically grounded uneven development. However, the fact that those patterns emerge –with regards to capital formation –reinforces the general tendencies in the core-periphery structure, due to the previously outlined mechanisms related to the balance-of-payments constraints. The interplay between renewing the capital stock and the structure of the global economy can be described as recursive (Hornborg, 2023, p. 96), where the concentration of the capital stock and capital goods production acts as a reinforcing mechanism.

In combination with the cluster analysis in Figure 7, a hierarchy of relations emerges, where everyone is dependent on the principal core country, the United States of America, and on the emerging core, China; whereas the latter is itself dependent on the former for its capital formation. Besides these overall dependencies, clusters emerge, that group around secondary core and semi-peripheral countries. The transition in the pattern from semi-peripheral country such as South Africa to a tertiary and secondary core country such as Spain (see Figure 8) is fluid to a certain degree (from the characteristic visual “L” to “h” pattern). Where these types mainly differ are in the tertiary and secondary core's lower one-sided dependency (measured as structural importance) on the principal and emerging core, and more mutual dependencies with other countries, where their level of structural importance for each other is of similar magnitude.

Interestingly, countries that are in a cluster of a country with the semi-peripheral “L” shape

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<sup>31</sup>This does not take all trade relations or different characteristics into account but only countries' positions in the global economy with regard to capital formation.

are almost exclusively peripheral countries and belong to a lower-income group (e.g. the clusters of *Brazil, Chile, Russia, Turkey* and *South Africa*, and the pocket in the *USA, China, South Korea* cluster that has a stronger dependency on South Korea, as well as the pocket around *Canada*). Meanwhile, clusters around secondary core countries consist to a larger degree of countries that mainly have a medium to high domestic production share and have limited dependence on other countries and themselves are not structurally important for other countries (i.e. Poland, Czechia or Belgium), what I have termed as “tertiary core countries”. The countries in the *Latin America* cluster behave similarly as they are only dependent on China and the US, while having a high domestic production share.

There emerges a hierarchy with peripheral countries depending on specific semi-peripheral countries and, separately, some peripheral, very few semi-peripheral and tertiary core countries depending on secondary core countries for the capital formation. Both of these separate strands depend on China and the US. A country’s position in the capital goods supply chain is thereby shaped both on whom it depends as well as to whom it bears structural importance. This creates an interlinked web, where each country’s position is defined relative to the others.

The major exception to this clear hierarchical description poses China. While it has a high structural importance for all countries, it is itself strongly dependent on the US as the principal core, as well as on secondary core countries in Europe. The major reason for that is its comparatively low domestic production share for such an important capital goods supplier (40.53%). Importantly, with exception to the US, this dependency is mutual, or in most cases, China’s importance for the respective secondary core country is even higher. However, China still needs to import more than half of its capital goods and indirect inputs from abroad.

The concentration of capital goods production and the hierarchy in structural importance between countries have two important implications: First, the global economy, and in particular (semi-)peripheral countries, has a large structural dependence on a few countries in the core. A supply shock in capital goods or indirect inputs production in one of these countries would ripple through the global economy. Due to the long-lasting nature of capital goods, path dependencies and lock-in effects, such a shock presumably dissipates through the global production structure over an extensive period. This may lead to hysteresis in peripheral countries where the production capacity in an export-oriented sector gets reduced, thereby reducing its export volume and its ability to import capital goods due to their balance-of-payments constraint. The concentration of structural importance for capital formation in a few sectors and countries not only implies a consolidation of power but also makes the global economy more vulnerable to sudden supply shocks such as natural disasters, conflicts, or the shutdown of trade routes during a pandemic. Increasing climate impacts may exacerbate this vulnerability.

Second, the world, and in particular those countries with a low domestic production share, is dependent on a few sectors concentrated in a few countries for renewing their capital stock. As long as there is no sufficient domestic capacity to produce capital goods, this dependency will

continue and is constantly reproduced. Many scholars emphasize the strong ties of producing and supplying technologies, and the power and control over those goods (Furtado, 1976, p. 47; Amin, 1977, p. 172; Puntigliano, 2017, p. 107). Such a power can be exerted in many ways, such as through patents, technological path dependency, technological complexity as well as geopolitical power over supply chains. This makes it difficult to replace them with vintages from other suppliers or through domestic production; hence handing over control to a few countries to enable the continuation of the production of all types of goods in dependent countries. This power over the capital goods supply chain mainly resides in the US, China, South Korea and European countries, as well as in other countries such as Brazil, Turkey or New Zealand for smaller pockets of countries. Notably, this analysis does not take the ownership of capital goods into account. As an example, a factory owned by a European firm in Bolivia is accounted for in the Bolivian capital stock. In reality, effective control over the means of production and their reproduction might therefore be even more concentrated.

### 5.3 Policy Implications

Such a concentration in the production, usage and trade of capital goods reproduces existing core-periphery patterns, and thereby uneven development. There are several policy implications that can be extracted from the conducted empirical analysis: Peripheral, lower-income countries need to build up their domestic *department 1* and core countries need to effectively enable the technological transfer to the periphery.

The idea of ISI, as outlined by Prebisch (1950) and others, is to domesticate the manufacturing and capital goods producing sector in peripheral countries to subsequently diversify the export structure towards goods with higher complexity (Ho, 2017, p. 71; Prebisch, 1959, p. 253; Tausch & Magacho, 2025, pp. 521–522). This would increase the elasticity ratio, loosening the balance-of-payments constraints in peripheral countries. This implies two important measures: ramping up domestic capital goods production and increasing mutual South-South trade of capital goods and indirect inputs. As shown, the median share of capital goods demanded by *department 1* is around 30% among all income groups; the median share in the low-income group is even slightly lower. However, for peripheral countries to have a chance at catching up, their share needs to be substantially above that of high-income countries. Otherwise the technology gap will persist (Porcile et al., 2023, p. 267).

Importantly, ISI should not be confined to one single country but to a group of economies by incentivizing South-South trade (Ho, 2017, p. 73; Prebisch, 1950, p. 33; Prebisch, 1959, p. 267). Mutual South-South trade of capital goods and indirect inputs does not exist currently. Some scholars (such as Gosens, 2020, p. 940) include the trade with China in this definition, but the previous section has shown that China is on a distinctly different path from (semi-)peripheral countries. Mutual dependency and thereby trade exists among European countries, most of them EU members. The largest European economies still dominate to a certain degree but most of these countries have a high domestic share of capital goods production and mainly rely

on other European countries for their indirect inputs. Such interdependencies with a concurrent domestic capital-producing industry should be a state that peripheral countries could aim for.

However, it is doubtful that such a state can be reached solely on the independent initiative by (semi-)peripheral countries (Furtado, 1964, p. 63). For initiating such a process, they would need more capital goods. Those would obviously need to come again from core countries, while (semi-)peripheral countries still face balance-of-payments constraints. To halt the reproduction of uneven development patterns, it requires the cooperation of core countries. On the one hand, an effective transfer of technology needs to take place, including the training of workers (Porcile et al., 2023, p. 279). This would include allowing for the copying of currently patented technology. Prebisch (1950, pp. 44, 54) points out that the volume of exports does not suffice to finance the necessary imports of financial goods. Hence, core countries also need to ramp up their provision of the required financial means to acquire those capital goods, which, as Prebisch (1950, p. 54) comes with the benefit of additional demand for capital goods provided by the core –at least for a certain period. With regard to the unfolding ecological crises and the environmental pressure of the employment of the existing capital stock, as well as to allow for the catch-up of (semi-)peripheral countries, halting capital accumulation in core countries might be beneficial to the global community.<sup>32</sup>

Under the assumption that trade patterns of capital goods between countries and sectors are fairly stable, at least in the short term, the hierarchical clustering in Figure 7 allows identifying which core countries need to undertake technology transfer to their respective (semi-)peripheral countries in the cluster. The US, China and European countries would need to take up a leading role in this exercise. Further, South Korea obtains a crucial role in technology transfer for the African continent as an important regional capital goods supplier. Semi-peripheral countries such as Brazil, which are capital goods importers from the core and exporters to the periphery, could act as intermediaries passing on technical knowledge and technologies from the core to the periphery. The personalized PageRank would even allow the identification of the structurally most important sectors for each sector in the global economy. While not taken into account in this analysis, it would aid in identifying the most important sector for specific sectors in the periphery to increase and change the composition of their capital stock.

On the other hand, balance-of-payments constraints need to be alleviated by reforming the international financial architecture (IFA). While it has not been the focus of this thesis, the asymmetries in the productive structure and those in the IFA are closely linked (De Paula et al., 2024, p. 113). Countries with a low position in the currency hierarchy also tend to be those with a strong dependence on the import of capital goods and a more-than-average demand share for capital goods for primary and intermediate goods production, which tend to be exporters of those goods (see De Paula et al., 2017; Fritz et al., 2018). They have a high exposure to exchange rate volatility and to sudden capital flight, which forces those countries

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<sup>32</sup>See Hein and Jimenez (2022) for a discussion on the implications of net zero investment in an economy.

to hedge against it by accumulating large –mainly dollar-denominated –foreign reserves (De Paula et al., 2024, p. 98). This enforces the balance-of-payments constraints of peripheral countries, which comes at a great cost for those countries to conduct the necessary investment for structural change (Abeles & Cherkasky, 2020, p. 5). Reforming the IFA and overcoming the existing currency hierarchies, and thereby easing the strong balance-of-payments constraints, would allow (semi-)peripheral countries to shift away from the strategy of exporting primary and intermediate products to attain capital goods; this would allow for more autonomy in building up their domestic capital stock.

## 5.4 Limitations

The capital-use matrix is a useful data source because it contains both the domestic production structure and the trade relations between countries. Trade statistics would omit the domestic part of capital goods production. One major problem that arises when the trade flows of  $\hat{\delta}K$  are compared to the trade statistics of capital goods reported by UN Comtrade (United Nations, 2026)<sup>33</sup> is that different tendencies in terms of trade relations emerge. In the data by the United Nations (2026) for 2019, the US is the largest net importer of capital goods, while China is the largest net exporter, exactly the opposite case as reported in Table 2. Among the largest net exporters reported in the table, the UK, New Zealand and Canada are also listed as net importers in the UN Comtrade data. The other reported net importers in the table are also listed as such in the UN Comtrade data, many still at the top of the list. Meanwhile, Japan, the "Rest of Asia-Pacific", which includes Taiwan,<sup>34</sup> and Thailand are listed as net exporters in the UN Comtrade data. In total, out of the 142 countries that are reported both in the summary table of the capital-use matrix of Magacho et al. (2026) and in the UN Comtrade data for 2019, 61 are registered differently in terms of their net capital goods trade flows. 51 out of those are marked as net exporters in the capital-use matrix, the rest as net importers.

The same problem emerges when trade flows in the capital-use matrix  $\delta K$  are compared to the GFCF column of final demand in the Gloria MRIO data. 59 countries labeled differently in terms of their status as net exporters, 44 are marked as net exporters in the capital-use matrix, the rest as net importers. The largest net importer is also the US followed by India, while the largest net exporter is Germany followed by China. Meanwhile, only 18 countries are classified differently between UN Comtrade data and the Gloria GFCF data.

In general, the definition of capital goods varies. Even among different classification systems where data exists in UN Comtrade, certain variations exist.<sup>35</sup> However, there remains a clear

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<sup>33</sup>The classification used is Broad Economic Categories (BEC) Rev.4. The selected commodity codes are 41 (Capital goods (except transport equipment)) and 521 (Transport equipment and parts and accessories thereof, Other, Industrial), since those are commodities classified as "capital" in the System of Nation Accounts (SNA) (United Nations, 2018, p. 2). BEC Rev.5 would have a specific classification of GFCF, but major countries such as the US and China are not reported for 2019 in UN Comtrade data for those commodity categories (United Nations, 2026).

<sup>34</sup>In the UN Comtrade data, it is reported as "Other Asia, nes"

<sup>35</sup>As an example, while the Harmonized System (HS) codes 84-90 fairly correspond to capital goods, they

disparity between the trade flows in the constructed capital-use matrix  $\hat{\delta}K$ , those reported by United Nations (2026) and the GFCF column in Gloria. This is a clear limitation of my analysis.

While this disparity between different data sources exists, the overall tendency in terms of the biggest exporters and importers of capital goods remains fairly similar between data sources. The order of the countries varies to a certain degree. In UN Comtrade data and Gloria, China and Germany are the largest exporters, while in the capital-use matrix, the US and the UK are listed on top. It remains the case that most of the trade in capital goods is undertaken between higher-income countries in North America, Europe and Asia. I therefore deem my analysis still valid, but readjusting the capital-use matrix for trade flows reported by UN Comtrade and Gloria GFCF data remains an important future task.

In general, the parameters used for creating the capital-use matrix should be tested over a certain array of values to test the robustness of the outcomes, in particular with regard to the network analysis.

## 6 Conclusion

In my thesis I have provided an empirical assessment of capital goods trade and production, and I have linked the process of capital formation to the reproduction of uneven development. I have made use of MRIO data enhanced by a capital-use matrix  $\hat{\delta}K$  created by Magacho et al. (2026). I used a plethora of tools IO analysis has to offer by dissecting the direct flows of capital goods in the  $\hat{\delta}K$  matrix and by taking into account intermediate inputs and capital goods used for capital formation by utilizing the capital-augmented Leontief inverse  $L^K$ . Further, with making use of the web of technical coefficients creating linkages between sectors I conducted a network analysis of the global economy using a modified version of the personalized PageRank centrality score.

My analysis shows that capital formation is dominated by a few high-income countries and China, with regards to every viewpoint, such as production, usage and trade. The top 10 countries produce two-thirds of all capital goods. The rest of the world largely depends on those economies to renew their capital stock, which leads to distinct structural importance patterns resembling the core-periphery structure. Peripheral countries with a higher demand share for capital goods in primary and intermediate production cluster around semi-peripheral and core countries. The latter are high-income and upper-middle-income countries with a high domestic production share of their own capital stock.

I argue that the emerging core-periphery structure in capital formation is both a product only separate by product categories but not by their usage (World Costum Organization, 2022). Some of the included goods can be used by private consumers or might still be fully used up in a year, which falls outside of the capital goods category, while some other product categories might include capital goods.

of historical uneven development and a driver of its future reinforcement. One of the main mechanisms is the heavy balance-of-payments constraint that peripheral countries face. Their strong import dependency on renewing or extending their capital stock makes them reliant on favorable terms of trade. Further analytical research is needed to clearly identify both the channels through which balance-of-payments constraints reinforce the dependence on capital goods imports. Tracing the causalities of how the general core-periphery structure produces core-periphery patterns in capital goods production is an important research avenue. This could be done through analysing the capital-use matrix over a time period longer than a year.

An analysis over time would also allow answering the question on how locked-in those dependencies are. Since capital goods are more complex goods, it may well be the case that countries that go through an industrialization period change their dependencies. From the static analysis, it remains unclear whether certain countries have strong trade ties due to a particular set of technology or whether these trade relations exist due to other reasons, such as common historical or geographical characteristics. It most likely is a composition of both factors. In particular, China's rise as an emerging core country could be better understood by a temporal analysis.

The application of network analysis to MRIO data, and notably the concept of personalized PageRank, is a promising approach to study core-periphery patterns, independently of capital formation. Taking both the general structural importance patterns into account, as well as their change over time, would allow for a more holistic perception where specific countries are situated in GVCs, how they can be classified and whether capital formation is a causal driver for the uneven trade and development structure.

My empirical analysis has shown that there is an asymmetric distribution of capital formation between income and world regions, and that this demands policy interventions. I argue that only a common effort by the international community to alleviate balance-of-payments constraints through a reform of the international financial architecture and a true transfer of technology can break the vicious cycle of reproducing uneven development. Peripheral countries need to pursue ISI and South-South trade, while core countries provide the necessary technical and financial support –to build a common future.

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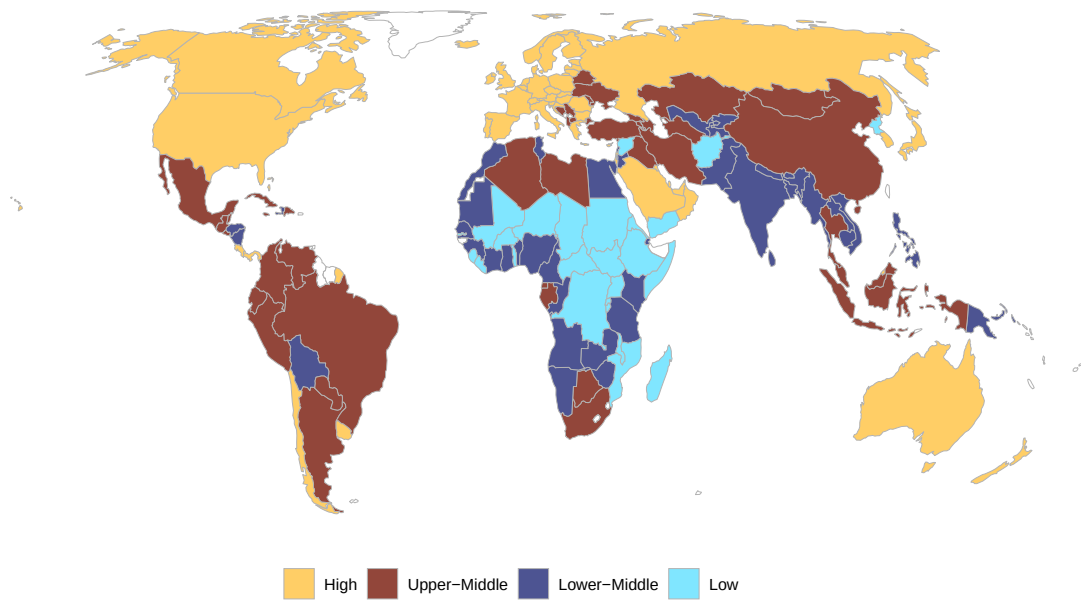
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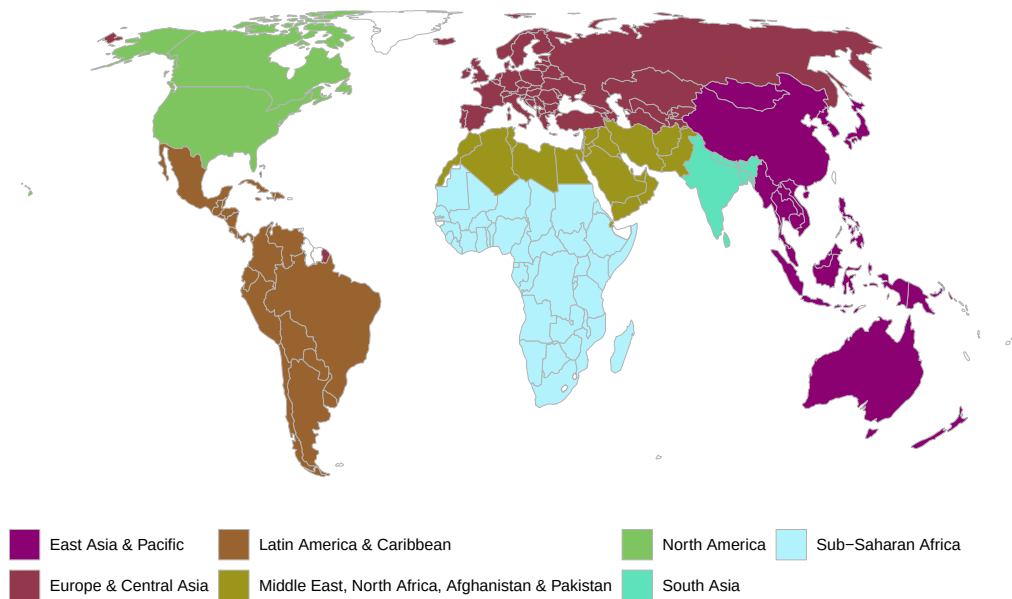
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## A Overview Sector and Country Categories



(a) Income Groups



(b) Regional Groups

Figure 9: Income and Regional Group Categories

*Notes:* Only the countries that are also present in the IO data are colored.

*Source:* World Bank (2026), author's illustration

Table 4: Sector-Industry Correspondance Table

| Sector                                                  | Industry    |
|---------------------------------------------------------|-------------|
| Growing wheat                                           | Agriculture |
| Growing maize                                           | Agriculture |
| Growing cereals n.e.c                                   | Agriculture |
| Growing leguminous crops and oil seeds                  | Agriculture |
| Growing rice                                            | Agriculture |
| Growing vegetables, roots, tubers                       | Agriculture |
| Growing sugar beet and cane                             | Agriculture |
| Growing tobacco                                         | Agriculture |
| Growing fibre crops                                     | Agriculture |
| Growing crops n.e.c.                                    | Agriculture |
| Growing grapes                                          | Agriculture |
| Growing fruits and nuts                                 | Agriculture |
| Growing beverage crops (coffee, tea etc)                | Agriculture |
| Growing spices, aromatic, drug and pharmaceutical crops | Agriculture |
| Seeds and plant propagation                             | Agriculture |
| Raising of cattle                                       | Agriculture |
| Raising of sheep                                        | Agriculture |
| Raising of swine/pigs                                   | Agriculture |
| Raising of poultry                                      | Agriculture |
| Raising of animals n.e.c.; services to agriculture      | Agriculture |
| Forestry and logging                                    | Agriculture |
| Fishing                                                 | Agriculture |
| Crustaceans and molluscs                                | Agriculture |
| Hard coal                                               | Mining      |
| Lignite and peat                                        | Mining      |
| Petroleum extraction                                    | Mining      |
| Gas extraction                                          | Mining      |
| Iron ores                                               | Mining      |
| Uranium ores                                            | Mining      |
| Aluminium ore                                           | Mining      |
| Copper ores                                             | Mining      |
| Gold ores                                               | Mining      |
| Lead/zinc/silver ores                                   | Mining      |
| Nickel ores                                             | Mining      |
| Tin ores                                                | Mining      |
| Other non-ferrous ores                                  | Mining      |
| Quarrying of stone, sand and clay                       | Mining      |
| Chemical and fertilizer minerals                        | Mining      |

|                                                             |               |
|-------------------------------------------------------------|---------------|
| Extraction of salt                                          | Mining        |
| Mining and quarrying n.e.c.; services to mining             | Mining        |
| Beef meat                                                   | Manufacturing |
| Sheep meat                                                  | Manufacturing |
| Pork                                                        | Manufacturing |
| Poultry meat                                                | Manufacturing |
| Other meat products                                         | Manufacturing |
| Fish products                                               | Manufacturing |
| Cereal products                                             | Manufacturing |
| Vegetable products                                          | Manufacturing |
| Fruit products                                              | Manufacturing |
| Food products and feeds n.e.c.                              | Manufacturing |
| Sugar refining; cocoa, chocolate and confectionery          | Manufacturing |
| Animal oils and fats                                        | Manufacturing |
| Vegetable oils and fats                                     | Manufacturing |
| Dairy products                                              | Manufacturing |
| Alcoholic and other beverages                               | Manufacturing |
| Tobacco products                                            | Manufacturing |
| Textiles and clothing                                       | Manufacturing |
| Leather and footwear                                        | Manufacturing |
| Sawmill products                                            | Manufacturing |
| Pulp and paper                                              | Manufacturing |
| Printing                                                    | Manufacturing |
| Coke oven products                                          | Manufacturing |
| Refined petroleum products                                  | Manufacturing |
| Nitrogenous fertilizers                                     | Manufacturing |
| Non-nitrogenous and mixed fertilizers                       | Manufacturing |
| Basic petrochemical products                                | Manufacturing |
| Basic inorganic chemicals                                   | Manufacturing |
| Basic organic chemicals                                     | Manufacturing |
| Pharmaceuticals and medicinal products                      | Manufacturing |
| Dyes, paints, glues, detergents and other chemical products | Manufacturing |
| Rubber products                                             | Manufacturing |
| Plastic products                                            | Manufacturing |
| Clay building materials                                     | Manufacturing |
| Other ceramics n.e.c.                                       | Manufacturing |
| Cement, lime and plaster products                           | Manufacturing |
| Other non-metallic mineral products n.e.c.                  | Manufacturing |
| Basic iron and steel                                        | Manufacturing |
| Basic aluminium                                             | Manufacturing |

|                                                                      |                        |
|----------------------------------------------------------------------|------------------------|
| Basic Copper                                                         | Manufacturing          |
| Basic Gold                                                           | Manufacturing          |
| Basic lead/zinc/silver                                               | Manufacturing          |
| Basic nickel                                                         | Manufacturing          |
| Basic tin                                                            | Manufacturing          |
| Basic non-ferrous metals n.e.c.                                      | Manufacturing          |
| Fabricated metal products                                            | Machinery & Equipment  |
| Machinery and equipment                                              | Machinery & Equipment  |
| Motor vehicles, trailers and semi-trailers                           | Transport Equipment    |
| Other transport equipment                                            | Transport Equipment    |
| Repair and installation of machinery and equipment                   | Machinery & Equipment  |
| Computers; electronic products; optical and precision instruments    | Machinery & Equipment  |
| Electrical equipment                                                 | Machinery & Equipment  |
| Furniture and other manufacturing n.e.c                              | Manufacturing          |
| Electric power generation, transmission and distribution             | Utilities              |
| Distribution of gaseous fuels through mains                          | Utilities              |
| Water collection, treatment and supply; sewerage                     | Utilities              |
| Waste collection, treatment, and disposal                            | Utilities              |
| Materials recovery                                                   | Utilities              |
| Building construction                                                | Buildings & Structures |
| Civil engineering construction                                       | Buildings & Structures |
| Wholesale and retail trade; repair of motor vehicles and motorcycles | Transport Equipment    |
| Road transport                                                       | Transport Equipment    |
| Rail transport                                                       | Transport Equipment    |
| Transport via pipeline                                               | Transport Equipment    |
| Water transport                                                      | Transport Equipment    |
| Air transport                                                        | Transport Equipment    |
| Services to transport                                                | Transport Equipment    |
| Postal and courier services                                          | Transport Equipment    |
| Hospitality                                                          | Services               |
| Publishing                                                           | ICT                    |
| Telecommunications                                                   | ICT                    |
| Information services                                                 | ICT                    |
| Finance and insurance                                                | Services               |
| Property and real estate                                             | Real Estate            |
| Professional, scientific and technical services                      | Services               |
| Administrative services                                              | Services               |
| Government; social security; defence; public order                   | Services               |
| Education                                                            | Services               |

|                                         |          |
|-----------------------------------------|----------|
| Human health and social work activities | Services |
| Arts, entertainment and recreation      | Services |
| Other services                          | Services |

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Table 4: The sectors are the ones covered by the Gloria MRIO data (Lenzen et al., 2017). The industry categories are used in the IO and network analysis.

## B Structural Importance Patterns all Countries

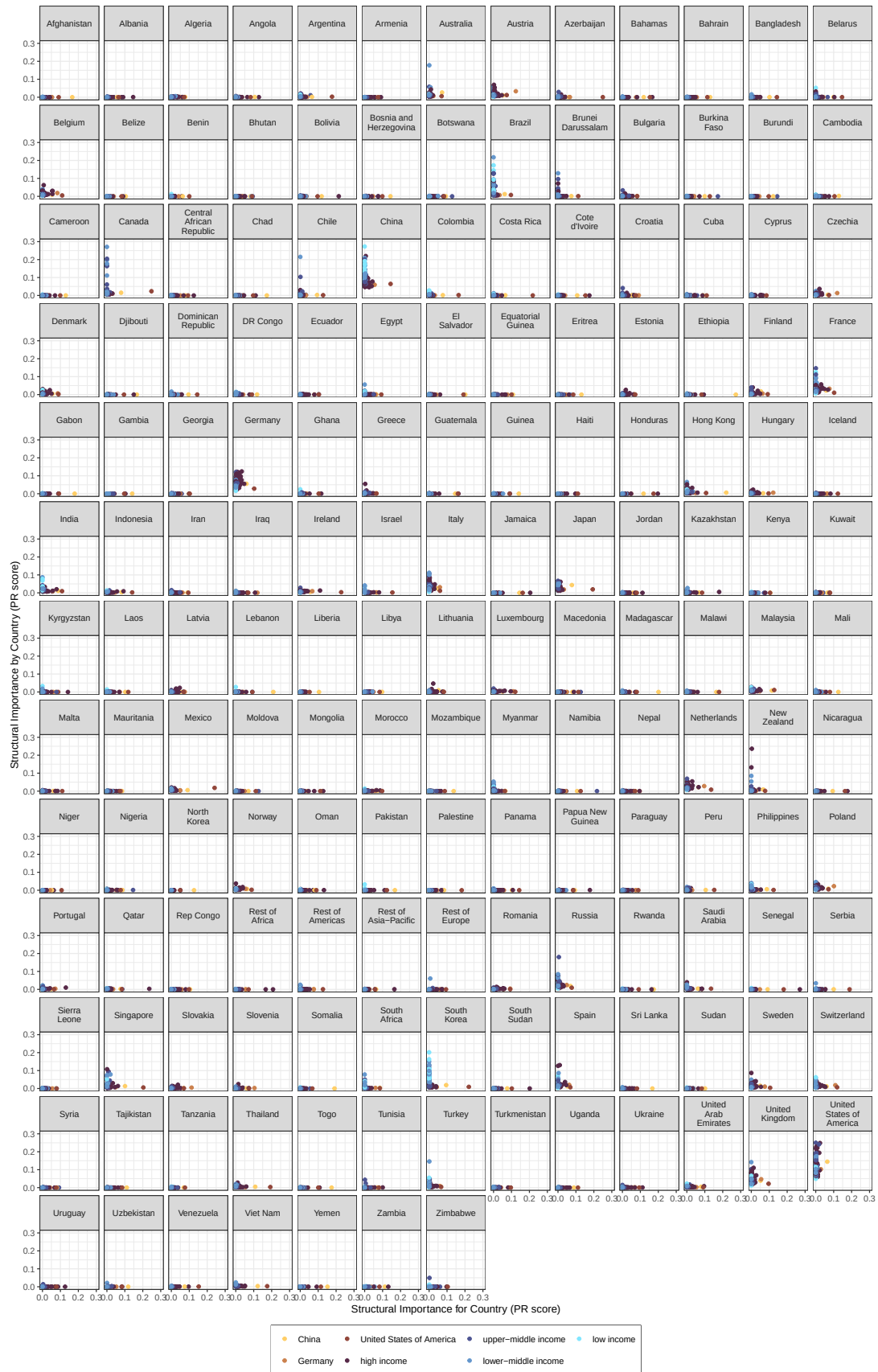


Figure 10: Structural Importance Patterns all Countries