Leveraging Interdependence for Economic Statecraft

The Structure of Power in the Supply Chain for Semiconductors

Tomi Tapani Kristeri
University of Helsinki
Faculty of Social Sciences
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Abstract

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Author: Tomi Kristeri
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Abstract:

Global politics of the 21st century has witnessed two distinct developments: a rise in economic statecraft, or the use of economic means in international influence attempts, and the fragmentation of production into global supply chains. This thesis investigates how these phenomena coexist by analysing how interdependencies in global supply chains can be leveraged in acts of economic statecraft. Specifically, it looks at the structure of interdependencies in the supply chain for semiconductor devices, and how they have been weaponized in the contemporary U.S.–China trade war.

For this, a unique theoretical framework is developed by bringing over insights from Power-Dependence theory, network analysis, and Global Value Chain analysis into International Relations theory on economic statecraft and international interdependence. Arguing that interdependence is a type of power resource, this thesis posits that the interdependent exchange relations between individual firms in a supply chain together constitute a power structure. The topology of this power structure is determined by how interdependence asymmetries are distributed across it. States who are in control of advantageous positions of this topology can leverage interdependencies in acts of economic statecraft against other states. This structure is not fixed and can be shaped by state action, including economic statecraft, that can be motivated either by power balancing or power maximisation. Alternatively, a state may assume a strategy of cost-reduction which is aimed at accepting the state of dependence and power imbalance.

This thesis maps the power structure of the semiconductor supply chain by looking at the chain at the level of the individual firm. The structure is assessed with the help of the Herfindahl-Hirschman index, based on data about where the market on each chain segment of the supply chain is nationally concentrated in. The results of this mapping reveal that the U.S., and to a lesser extent South Korea and Taiwan, are in control of strategically important positions in the supply chain, allowing them to leverage this position against others. China especially is shown to be vulnerable due to its high level of dependence on other countries in the chain. The thesis also shows that the power structure has both motivated China's attempts at achieving 'semiconductor independence' and enabled the U.S.'s use of economic sanctions against China.

Contents

1 Introduction

On the 15th of May 2019, The Trump White House issued an Executive Order ‘Securing the Information and Communications Technology and Services Supply Chain’ (Exec. Order No. 13873, 2021). It declared that threats by ‘foreign adversaries’ to the Information and Communications Technology (ICT) and services supply chain constituted a national security threat and that certain transactions with such actors were now prohibited for U.S. citizens. The specific actors weren’t named, but the obvious target was the Chinese telecommunications company Huawei. It had previously been accused by the U.S. of numerous cases of espionage and IP theft, as well as of conspiracy to subvert U.S.-led sanctions against Iran. On the following day, Huawei was added to the so-called Entity List, prohibiting American firms from doing business with the company, and effectively barring it, and its subsidiary chip designer HiSilicon, from American semiconductor and equipment inputs (Export Administration Regulations, 2019a). A year later, an additional round of sanctions was issued (Export Administration Regulations, 2020a) where the U.S. made use of its Foreign Direct Product Rule (FDPR) to limit the use of American technology by non-U.S. entities dealing with Huawei and affiliated companies.

This episode in the U.S.–China trade war showcases the rising importance of economic statecraft, or the use of economic means for achieving non-economic ends such as national security and power (Baldwin, 1985/2020). It signifies a blurring of the line between economic policy and traditional geopolitics, a liberalist division that largely displaced economic statecraft in the mid-to-late 20th century (Blackwill & Harris, 2016, pp. 166–176). In its place, we are now seeing the rise of an integrated approach that has been called geoeconomics[1]. The resurgence of economic statecraft can not only be seen in the U.S.-China trade war but also in the more general trend of using economic sanctions as a central tool in a nation’s foreign policy toolkit (Yotov et al., 2021).

The world that economic statecraft has been reintroduced into is not the world as it was in previous centuries, however. Specifically, the 21st century is marked by two

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[1] Encompassing a growing literature, the term ‘geoeconomics’ has been used to emphasize the important intersection of geography, politics, and the economy. For an introduction to the contemporary use of the term see the volume edited by Wigell, Scholvin & Aaltola (2019). For the original use of the concept, see Luttwak (1990). Here geoeconomics is used merely as a paradigmatic concept analogous to ‘economic liberalism’. The term ‘economic statecraft’ is used when discussing actual policy.

mutually reinforcing developments: increased global interdependence and the rapid development and proliferation of information and communications technology (ICT).

Networks of interconnection and interdependence in all areas of society connect people, firms, etc., across national borders (Keohane & Nye, 1977/2012). Few types of such networks have had as tremendous of an impact on the world as the global networks of production and trade in commodities. The advancement of ICT has enabled a great 'unbundling' of the productive forces formerly confined to more-or-less unified complexes of factories (R. Baldwin, 2016). From the 1990s onwards, this unbundling, or fragmentation (see Arndt & Kierzkowski, 2001), has birthed global supply chains where individual productive functions are increasingly consigned to separate, nominally independent parties (Gereffi et al., 2005). Political leaders and decision makers now face a challenge in fitting the old 'chessboard' model of 20th-century geopolitics to this new 21st-century world of the 'web' (Slaughter, 2017).

Technological developments have not only enabled the globalization of production and trade but have also lifted cyberspace to the forefront of the contemporary imagination. It has been argued that we are now seeing the rise of 'a digital mentality' where the development of advanced technology as well as the construction and control of networks in the digital realm is becoming more and more relevant to the hard core of national security and international politics (Yan, 2020). For the aspiring China, this signifies an 'innovation imperative' to challenge the dominant United States in a race for technological superiority (Kennedy & Lim, 2018).

The U.S.–China trade war has thus also been called 'the tech war' (Kwan, 2019; Capri, 2020). This points to the fact that at the centre of the conflict lies a contest to dominate the ICT sphere. ICT itself can be seen as forming a 'technology stack' with the platform level of digital ecologies at the top, supported by the system level of digital infrastructure, and with electronic hardware at the base (Holmström & Seppälä, 2020). Competition and conflict can be observed on all three layers of the stack, with bans on foreign social media companies and the regulation concerning 5G infrastructure (Hoffman, et al. 2019; Cartwright, 2020) taking place at the top two layers.

What this thesis is most interested in, however, are the tensions at the base of the stack, within the supply chain for the design, production, and sale of semiconductor devices stretching all across the Pacific. Semiconductor devices are electronic components that can be manipulated to conduct electricity in complex ways, making them crucial for the development of sophisticated electronic devices. The subsection of semiconductor devices at the heart of the ICT revolution is the integrated circuit (IC) chip, colloquially called the ‘microchip’ or just a ‘chip’. Chips are used for everything requiring information computing or storage and are thus the core technology of the information age. Owing to the fact that their design and fabrication are extremely capital intensive, the production of chips displays a high degree of fragmentation, specialization, and thus interdependence between the constituent parts of the supply chain (Varas et al., 2021, p. 4).

It is then no surprise that this highly interdependent supply chain stretching from the U.S. to China has become a crucial flashpoint in the heating relations between the two contesting powers (Holmström & Seppälä, 2020, pp. 6–7). Fearing it might lose its dominant technological position, the U.S. has effectively weaponized its end of the supply chain against China. At the other end, China has made becoming ‘semiconductor independent’ a central target of its industrial policy (Lewis, 2019, p. 15), raising fears that the supply chains could become decoupled, the consequences of which are still up for debate (see e.g., Li, 2019; Lewis, 2019; Farrell & Newman, 2019a; Capri, 2020; Yan, 2020).

1.1 Aims of the Thesis

This thesis aims to answer two questions: *How does economic statecraft within the supply chain for semiconductors work?* and *What is the structure of power in the global supply chain for semiconductors?* These questions concern both the use of power and the distribution of power, respectively. They are also inextricably linked, in that an answer to the second is necessary to answer the first.

Given the strategic importance of the semiconductor industry, highlighted in the U.S.–China trade war, it is surprising that a study paired with an analysis of the chain’s particular characteristics is yet to emerge. One reason for this is the absence of an analytical framework for understanding interstate power in global supply chains on a general level. Studies theorizing economic statecraft are not hard to come by (e.g., D. A. Baldwin, 1985/2020; Drezner, 1999; Blanchard & Ripsman, 2008; Norris, 2016), not even ones exploring the effects of interdependence on the economic means of state power (see Hirschman, 1945/1980; Keohane & Nye, 1977/2012; Drezner et al., 2021). Similarly, there is a rich literature on supply chains in the form of Global Value Chain analysis (see e.g., Fernandez-Stark & Gereffi, 2019). However, as is noted by Horner (2016), the role of state power is neglected in the research agenda for GVC analysis, and as is argued by Farrell and Newman (2021), the traditional models of state-to-state power lose salience in a world defined by global networks, supply chains among them. One aim of this thesis is thus to contribute toward a nascent theoretical foundation for understanding the role of international power within global supply chains on a general level.

The theory building found in section 2 proceeds modularly by finding commonalities, compatibilities, and complementarities in the concept of economic statecraft, Power-Dependence theory, applied network analysis, and Global Value Chains analysis. A common foundation for these approaches is found in the conception of power, found in the works of Robert A. Dahl (e.g., 1957) and most notably also in Lasswell and Kaplan (1950/2017). D. A. Baldwin summarizes this view in four points: “first, that power was a causal concept; second, that power should be viewed as a relational concept rather than a property concept; third, that power was a multidimensional concept; and fourth, that the bases of power were many and varied, with no permanent hierarchy among them.” This approach considers actors, be they states, firms, etc., to be motivated in their actions, including in their use of power, by the cost structure they face when interacting with the world and the other actors in it.

The thesis follows D. A. Baldwin in defining economic statecraft as a specific type of power use: a governmental influence attempt relying primarily on instruments that have a reasonable semblance of monetary value, aimed at influencing the behaviour of another state (D. A. Baldwin, 1985/2020, pp. 28–32). Interdependence on the other hand can be defined as a relationship of mutual reliance and/or support, or dependence, between A and B (see D. A. Baldwin, 1980). It also constitutes a central power resource used in economic statecraft (ibid.). The related concept of ‘independence’ can be used to mean a lack of dependence.

As Özdamar and Shahin (2021) have argued in their recent review of the IR economic sanctions literature, these individual links of interdependence should first and foremost be understood as forming a structure in the form of a network. They argue that this approach could serve as a unifying framework for a fragmented field (ibid.). The way this thesis approaches global networks focuses on the individual economic actors constituting the reality of global and national economies. This thesis thus follows the research agenda set forward by Farrell and Newman (2021, pp. 309–310) in mapping this network topology at the base level to better understand the workings of power on the international level.

The topology of this network structure should not be understood as forming an even plane or a ‘level playing field’, or to be simply constituted of one-sided hierarchical dependencies between some ‘core’ and ‘periphery.’ Instead, interdependencies are more often than not both asymmetrical and unevenly distributed, giving the network a topology of peaks and valleys, gaps, and clusters (Farrell & Newman, 2019b). Because interdependence functions as a power resource, this uneven topology results in an uneven distribution of power, meaning that the network structure is reflective also of a power structure. Thus, the topology of the network enables some states in control of strategic nodes to exert power over others while leaving others more vulnerable (ibid.).

For understanding the particular dynamics of supply chains, as opposed to any other network, an analytical framework specifically designed to theorize and understand their forms and dynamics, Global Value Chains analysis is applied. This framework, widely used in business and development studies, is shown to be both highly complementary to the interdependence approach in International Relations, and also crucial in understanding how interdependence-based power is structured and used in the domain of global supply chains. A similar argument about the usefulness of GVC analysis is brought up by Fuller (2022) in a recent working paper[2]. Fuller, however, argues that GVC analysis should be used instead of the approach argued for by Farrell and Newman. Contra Fuller, this thesis argues for the compatibility of GVC analysis with approaches from IR.

In constructing its theoretical perspective, this thesis wishes to tap into the growing movement advocating for scientific realism[3] in IR, or the view that ‘ontology matters’ and that the social world should be understood as composed of literally real actors and phenomena. This view implies the reality of causation, social structures, and possibly some social entities. This thesis opts for a light conception of scientific realism based on the approach taken by Little (2016). Little advocates for what he calls ‘methodological localism’, or the view that while individual actors are the ontological base of all social phenomena (including causation), this does not exclude the reality and causal relevance of the social structures in which these individuals are embedded (ibid, pp. 70–78). For Little, microfoundations do not constitute reductionism but *explanation*: they are “an account of the mechanisms at the individual actor level (and perhaps at levels intermediate between actors and the current level—e.g., institutions) that work to create the structural and causal properties that we observe at the meso or macro level” (ibid., p. 79). As such,

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[2] Because Fuller’s discussion on the topic covers similar ground, given the shared use of the weaponized interdependence (WI) and GVC analysis, as well as the Huawei-sanctions case, it should be noted that this thesis is not directly inspired by Fuller, was arrived to independently, and started before the publication of the paper in question. Hopefully, however, the discussion in this thesis will prove valuable as a complement to Fuller’s, given the clear merit of both the theoretical combination of WI and GVC analysis, and the case in question.

[3] Realism in social ontology should not be confused with Political Realism discussed within the field of International Relations.

this ontology forms the basis for the network-structural ontology of interdependent and structurally constrained agents advanced in this thesis, as well as the understanding of power as a causal phenomenon that requires mechanistic explanation.

Motivated by the research questions posited earlier, section 2 of this thesis puts forward two main theoretical arguments: that (a1) the leveraging of supply chain interdependence, existing between interlinked individual economic actors, constitutes a mechanism for the mediated delivery of economic influence attempts between states, and that (a2) these instances of power use are to a significant extent co-constituted by the structure of the interdependencies in a supply chain. This means that the distribution of interdependencies structures how states can use power, and that the use of power is capable of further reproducing and reifying the power structure itself.

Following the research agenda set by Farrell and Newman (2021, pp. 309–310), sections 4 and 5 apply this theoretical perspective to the specific case of semiconductor supply chains by mapping its constituent firms and their mutual relations. This thesis argues that (b1) there indeed are significant interdependencies in the semiconductor supply chain that constitute an (uneven) power structure, and that (b2) they can thus function as a power resource for economic statecraft. After this, the second part of section 5 then returns to the case of the U.S.–China trade war by looking at how the actual practice of economic statecraft has been impacted by this power structure.

2 Theory

The scholarly discussion on economic statecraft has largely been concerned with the effectiveness and consequences of economic sanctions[4]. This literature can be roughly divided into three schools of thought (Blanchard & Ripsman, 2008) with ‘liberals’ (e.g., Hufbauer, et al., 1990; Shambaugh, 1999; Abdelal & Kirshner, 1999; Cortright & Lopez, 2002) adopting an approach stressing economic incentives and expecting sanctions to be effective primarily based on their magnitude, and with ‘realists’ (e.g., Pape, 1997; Drury, 1998; Drury & Li, 2006; Peksen & Drury, 2009) emphasizing the overriding importance of states’ political and strategic concerns and thus expecting sanctions to be mostly a fool’s errand.[5] Most of the later scholarship, however, falls in the ‘conditionalist’ camp,

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[4] Following D. A. Baldwin, the terms economic statecraft and economic sanctions will be used synonymously here, but the former concept is preferred because of its analytically clearer character (D. A. Baldwin, 1985/2020, p. 35).

[5] For an additional non-political but sceptical account, see Galtung (1967).

emphasising the various international (Drezner, 1999, 2000; Morgan & Schwebach, 1997; Blanchard & Ripsman, 1999; Mansfield, et al., 2007) and domestic conditions (Kaempfer & Lowenberg, 1988; Haass, 1997; Bolks & Al-Sowayel, 2000) in assessing whether a particular case of sanctions will be effective.

Here, an approach differing from the one focusing on effectiveness will be taken. To paraphrase Jonathan Kirshner (1997, p. 32), we do not only need to know *if* sanctions work but also *how* they work. This direction for inquiry flows directly from the first research question established above: '*How does economic statecraft within the supply chain for semiconductors work?'* This 'how' is explained by referring to one of the central concepts in the whole of political science: *power.* As a contentious concept (see Barnett & Duvall, 2005) power has multiple proposed definitions, but here the classic Dahlian formulation is applied: power is the capacity of A to have B do something B would not otherwise do (Dahl, 1957). This thesis largely follows the application and defense of this definition in IR by D. A. Baldwin (e.g., 2016).

The theory construction in the following subsections follows Meierding & Sigman (2021) in understanding the workings of international power as a combination of (1) power resources, (2) an influence activity, and (3) a causal mechanism. They draw heavily from both Dahl and Baldwin but additionally emphasize the inclusion of the causal mechanism between the influence attempt and its consequences, which provides the causal explanation for why exactly a target would adjust its behaviour in the face of an influence attempt (ibid.).

In this thesis, the relevant power resource is the interdependence nations develop when they enter into trade relations with each other. The types of influence activities these relations enable them to use against each other fall under what are called tools of economic statecraft. Of the types of mechanisms Meierding & Sigman list, *leverage* is here the most central. Leverage involves affecting the costs and benefits the target faces when taking an action and can involve either the use of rewards or punishments (ibid.).

The subsection immediately below begins with an overview of D. A. Baldwin's concept of economic statecraft along with related power concepts as well as the advantages and limitations they have for the task at hand. Subsection 2.2 then discusses interdependence and its potential as a power concept both from an abstract angle following Emerson's Power-Dependence theory and from the particular point of view of international trade as understood by Hirschman. Subsection 2.3 extends the discussion from the bilateral level to the level of global economic networks with the application of insights from Network Analysis and, more specific to supply chains, Global Value Chain analysis. Finally, subsection 2.4. concludes the Theory section with a summary.

2.1 Economic Statecraft

Discussion on sanctions and international power is most useful to start from the discussion on influence activities, or the actual activities and instruments used by A to produce a (desired) change in B's behaviour (D. A. Baldwin, 2016, pp. 12–32). Statecraft is a specific type of influence activity practiced by one state and directed at another (D. A. Baldwin, 1985/2020, pp. 6–7), and of which economic statecraft (ES) is a subtype.

As was noted in the introduction, David A. Baldwin (1985/2020, pp. 28–32) defines ES as a governmental influence attempt relying on instruments that have a reasonable semblance of monetary value, aimed at influencing the behaviour of another state[6]. The concept puts focus on the *means* of power, rather than the ends that the use of power results in: as bombing a library is not cultural statecraft, so bombing a factory should not be considered economic statecraft. By definition ES describes *economic* means: they have a reasonable semblance of monetary value. From this also follows that ES doesn't specify what the *ends* of power use are or what they should be. Crucially, Baldwin also stresses that ES is to be understood as a *property* of an actor (a property concept) as opposed to a relation between two or more actors (a relational concept). Property concepts are concepts where no comparison to others is needed for measuring or understanding them. This means that the tools of ES should be seen as *ways of attempting influence* and thus distinct from power resources (such as interdependence which is focused on later), upon which the success of ES is contingent on. (ibid., p. 21, 39)

Table 1 provides a list of different policy instruments that Baldwin classifies as ES. They are categorized based on whether they directly target trade or capital and whether they are positive (reward) or negative (punishment) by nature. While the table doesn't include all possible types of ES, notably excluding monetary statecraft,[7] the areas most relevant to the subject at hand, trade and capital, are covered. The mechanism by which the listed instruments work is by leveraging the ability to impose various costs and benefits on the target state: e.g. issuing tariffs and quotas, declining licenses, or blacklisting companies restrict the ability of the target to do trade with the issuer, possibly leaving

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[6] Baldwin specifically talks about 'international actors' but from the greater context, it is reasonable to infer that he is in fact talking about other states.

[7] For more on the importance of monetary statecraft, see Kirshner (1995) and Cohen (2016, 2018).

them worse off. That such an influence attempt is successful supposes that the issuer controls power resources that it can then leverage. In the case of trade, a central power resource is the interdependence between the countries. What power resources are exactly, is returned to later.

Table 1

Examples of economic statecraft

Trade	Capital
Positive	
Decrease in tariffs and quotas Most-favoured-nation treatment Purchase of goods Export/import subsidies Granting licenses	International aid Investment guarantees Encouraging investment (incoming and outgoing) Favourable taxation
Negative	
Embargo/boycott Increase in tariffs and quotas Withdrawing most-favoured-nation treatment Blacklisting License denial Dumping Preclusive buying	Freezing assets Capital controls Suspending international aid Expropriation Unfavourable taxation Withholding dues to international organization

A concise version of the list provided in D. A. Baldwin (1985/2020, pp. 39–40).
Also includes the threats and promises of the above.

Some modifications need to be made to the ES concept before applying it further. Firstly, Baldwin’s definition represents a distinctly statist conception of international politics, in the sense that it black-boxes the state to encompass all of the national economy. In this view, there are only states interacting with other states without any non-state actors equipped with independent powers of their own. It also disregards the transnational character of both trade and capital. This view is both simplistic and unnecessary, even for a study focusing primarily on state interactions. It is simplistic because it cannot provide a clear picture of actual mechanisms, and unnecessary because the concept of ES doesn’t inherently necessitate it. Instead, the state should be understood to be a distinct actor *within* the economy who can exert control over economic actors falling under its jurisdiction. In fact, with all of the instruments listed above, the state is still reliant on actors external to itself to go through with the attempted use of ES.

This is a point also stressed by Norris: everyday economic processes are not conducted by the state directly or by the nation as a harmonious whole, but instead by independent contesting and coordinating economic actors (Norris, 2016, pp. 11-25). If a state wishes to influence other states by utilizing its economic power, it needs to exert some type of control upon these third actors through either economic incentives, rule setting, or political control (ibid). Similarly, as noted by Kirshner (1997), this logic applies to the other end of the influence attempt as well, with the groups and actors within the targeted state being affected, which then places pressure on the state itself. Because of this, ES shouldn't be understood to function by 'direct contact' between states, but instead through a chain of causation constituted by the actions of individually linked economic actors within both the national and the global economies. This means that when talking about ES being targeted at other states, it should be clarified to mean this type of mediated causality.

A second note, it could be argued, is that the ES concept provides a very limited view of international politics: it shows statecraft as only directed at influencing the behaviour of others and not at all (as is often the case in the common usage of the term[8]) at advancing or protecting one's position within the international system. This is an argument made by Weiss & Thurbon (2021). They see that in addition to a discussion on domestic economic policy[9], the concept of 'the developmental state' has been overburdened by using it in cases where the aim of state action is to advance foreign policy and security goals. Examples they use relate to the advancement of technological capabilities to the ends of national superiority and/or independence. For them, these are cases of ES, not of industrial policy, and the use of the concept only muddles the waters of useful analysis.[10]

What Weiss & Thurbon are in effect saying is that state actions aimed at bettering state capacity to effectively use ES, as well as to protect oneself from foreign uses of ES, should in themselves be considered ES. To the extent that one is still describing governmental influence attempts aimed at influencing *others*, this doesn't conflict with the ES concept as used by Baldwin. The problem arises with the inclusion of actions aimed domestically, such as in cases of domestic economic policy, which would risk the reverse of the intended effect and dilute the ES concept instead, by making it difficult to

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[8] For Baldwin common usage among laymen, academics and policymakers is central to conceptual analysis and is provided as a central criterion for assessing its appropriateness both in D. A. Baldwin (1985/2020, p. 11) and in D. A. Baldwin (1980).

[9] By this they mean traditional industrial policy: job creation, bailouts, protectionism, tax incentives etc.

[10] A similar argument is made by Aggarwal and Reddie (2020) with their concept of 'new economic statecraft'.

differentiate ES from ‘non-strategic’ domestic economic policy. One reason for this is that policy actions often have unintended and multiple goals (D. A. Baldwin, 1985/2020, pp. 14–17) which can be either ‘strategic’, ‘non-strategic’ or both. Another reason is that economic capacities are often both storable and somewhat fungible. It would thus be possible to utilize existing instruments and capacities, originally created for innocuous purposes, to achieve offensive ends (D. A. Baldwin, 1971). In that case, there wouldn’t be an end to the list of economic policy actions that could be classified as ES.

Weiss & Thurbon are still correct, however, in drawing attention not only to state actions but also to the aggregate ‘economic power’ or ‘economic capacity’ of a state. As opposed to a property concept such as ES, power and capacity described by terms such as ‘superiority’ and ‘independence’ are relational concepts (D. A. Baldwin, 1985/2020, pp. 18): their weight is measured in relation to the power and capacity of other actors. Specifically, the terms can be seen as describing *power resources* (D. A. Baldwin, 1979; 1985/2020, 21–23), which are the source from which the ability to effectively use power is derived. Examples of power resources are the size of one’s army, one’s economic wealth, or the status of one’s culture or ideology.

This differentiation between activities and resources also reflects what Keohane & Nye (1977/2012, pp. 17–18) call the difference between *process,* or allocative/bargaining behaviour between actors, and *the structure,* or the distribution of capabilities among the actors. What this means is that, aside from enabling effective ES, the distribution of power resources also constitutes *structural power,* which is here defined as the potential power deriving from the distribution of resources, i.e., from an actor’s position within a power structure (Molm, 1997, pp. 29–39). As noted by D. A. Baldwin (2016, pp. 80–84), such an approach to structural power is very much compatible with the Dahlian concept of power.

Within the domain of international trade and production, economic interdependence can have major security implications or ‘security externalities’ (Norris, 2016, pp. 12–13; Gowa & Mansfield, 1993) and is thus an important power resource for states engaging with each other in that domain (see D. A. Baldwin, 1980). Economic statecraft utilizing economic interdependencies will involve both building up favourable asymmetrical interdependence with other states and leveraging those interdependencies by using various ES instruments, including those depicted in Table 1.

Those actions that cannot be called ES but build up interdependence-based power resources through domestic economic policy, can be labelled as ‘*strategic economic* *policy*' to differentiate them from ES. These instruments can generally be categorized along the lines of regulative and facilitative state actions (e.g., a favourable regulative and tax environment) as well as industrial policy actions such as direct state production or purchasing (through e.g., state-owned enterprises and public sector organizations) (see e.g., Horner, 2016).

To summarize, this subsection has argued for D. A. Baldwin's conceptualisation of economic statecraft defined as a governmental influence attempt relying on instruments that have a reasonable semblance of monetary value, aimed at influencing the behaviour of another state. The concept was adopted with the clarification that it should not be understood to speak about 'direct contact' between states but rather about a mediated causal chain which is constituted by lower-level economic actors throughout the national and global economies. The interdependence between these interlinked actors in global supply chains can be used as a power resource for economic statecraft because it can be leveraged to inflict costs on others. It was also noted that another term must be used to describe state actions aimed domestically at influencing the power resources and thus the structural power position of the state. This was labelled 'strategic economic policy'. The next subsection will now turn to discuss both interdependence-based economic statecraft and various state actions aimed at increasing interdependence as a power resource.

2.2 Interdependence

Much of the discussion on economic interdependence within IR has concerned its relationship with military conflict. 'Liberals' see interdependence as peace conducing (e.g., Angell, 1910/2012; Rosecrance, 1987; Keohane, 1990; Mansfield; 1995; Oneal & Russet, 1997), while 'realists' view it as a possible spark for conflict (Waltz, 1970/1983; Gilpin, 1981, Grieco, 1988, 1993; Mearsheimer, 1994/1995; Barbieri, 1996, 2002). Others yet hold its effects as contingent on some other factor such as dyadic capitalism (Gartzke, et al., 2001; McDonald, 2004, 2007, 2009; Gartzke, 2007), dyadic democracy (Gelpi & Grieco, 2003), economic development (Mousseau, 2000; Mousseau, et al., 2003; Hegre, 2000), trade agreements (Mansfield & Pevehouse, 2000) or expectations about the international environment (Copeland, 1996, 2014).

This thesis makes a different point, however: that interdependence can itself be used as a power resource and then leveraged to wield economic statecraft. Thus, while trade can be used to supersede war, as liberals contend, it can also function as the power political alternative to it. The general framework for this can be found in the leading conceptualization of international interdependence, the Theory of Complex Interdependence, which was first laid out by Keohane and Nye in their seminal article titled ‘Power and Interdependence’ (Keohane & Nye, 1973) and that was further developed in their book of the same name (Keohane & Nye, 1977/2012).

Writing in the middle of the Cold War détente, Keohane and Nye focused on what they saw as a new development in the structure of the international realm, resulting from an increased multiplicity and complexity of international linkages, which made countries more *sensitive* to the effects of each other’s actions. Adapting to these effects by policy action is costly, making states more or less *vulnerable*[11] depending on how dependent on one another they are (ibid). For example, every state in a system using oil for an energy source is sensitive to a drop in oil prices, but a state with a more robust domestic energy production capacity, through e.g., natural gas or renewables, will be less vulnerable than a state dependent on imported oil.

According to Keohane and Nye, a diversity of, and a disappearing hierarchy between, issues and tools of statecraft makes military action less relevant under the conditions of complex interdependence (Keohane & Nye, 1977/2012, pp. 22–24). Instead of traditional warfare, they note the ability of states to use economic statecraft by leveraging the relative vulnerability, or independence, of other states to their advantage:

> We must also be careful not to define interdependence entirely in terms of situations of evenly balanced mutual dependence. It is asymmetries in dependence that are most likely to provide sources of influence for actors in their dealings with one another. Less dependent actors can often use the interdependent relationship as a source of power in bargaining over an issue and perhaps to affect other issues. (ibid. p. 9)

While Keohane and Nye were instrumental in conceptualizing the developments within the international security environment during the time of nascent globalization, theirs was not the first to draw attention to how interdependence could be used for power politics. An even earlier conceptualization can be found in Albert Hirschman’s book *National Power and the Structure of Foreign Trade* (1945/1980). Before further applying the concept of interdependence to international relations and international trade, however,

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[11] While Keohane and Nye divide interdependence into sensitivity and vulnerability interdependence, it is the latter only that can truly be called interdependence in the full sense of the word (D. A. Baldwin, 1980, pp. 491–492).

it is useful to define it in the abstract. A branch of social theory called Social Exchange Theory will prove very suitable for this task[12].

2.2.1 Interdependence as Power

Social Exchange Theory studies the interaction of, and specifically the exchange between, value-driven actors[13]. For this thesis, the crucial edge that Social Exchange Theory has over the theory of exchange in microeconomics is that it doesn't assume transactions to just be independent one-time occurrences but instead explicitly focuses on the long-term exchange *relations* formed between actors (Molm, 1997, p. 12). An influential strand of Social Exchange Theory, useful for understanding interdependence relations specifically, is Power-Dependence theory which was first formulated by Emerson (1962). The most interesting part of the theory, in terms of the objectives of this thesis, is its preoccupation with both structure and power.

Emerson understood the social world as being constituted by actors who are at all times engaged in different types of exchange relations. He diverged from the view that these relations were merely technical, arguing instead that exchange was imbued with power and structured by a mutual dependency between actors. According to his Power-Dependence theory, it is the same interdependence which allows actors to gain through exchange that also provides them with the ability for wielding influence over one another. (Emerson, 1962)

The central composite parts of Power-Dependency theory are the actors' different needs, as well as the corresponding resources[14] that can fulfil those needs. Resources can be either material (food, money, oil etc.) or immaterial (affection, status etc.), and are distributed in such a way that actors have to engage in exchange to fulfil their needs. Self-sufficiency thus always comes with a price, whereas social exchange and trade are mutually beneficial. (Molm, 1997, pp. 13–20)

This shared gain from exchange forms a bond of mutual dependency (D) between actors, which is directly proportional to the gain received from the current option (CO) taken, and negatively proportional to the availability of the best forgone outside option

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[12] It has even been argued that Complex Interdependence is just a specifically adapted form of Social Exchange Theory for International Relations (Molm, 1997, p. 2).

[13] More specifically, Social Exchange Theory assumes actors to be generally utilitarian and 'behave in ways that increase outcomes they positively value and decrease outcomes they negatively value' (Molm, 1997, pp. 13–15).

[14] Resources here are not to be conflated with 'power resources' as described above. Instead, the interdependence born out of actors' need for resources is to be understood as a power resource.

(FO) (Emerson, 1962, pp. 32–33). This is identical to the concept of opportunity costs, or the costs of forgoing the benefit from another option not chosen.[15] For example, between some A and B, where A possesses resources that B needs/wants, B's dependence on A (D_{ba}) is measured by how much it gains from the relationship (CO_b), as opposed to the potential gains from the best outside option available (FO_b). The degree of dependence of B on A can then be formulated as: $D_{ab} = CO_b – FO_b$.

Dependence thus instils in both actors a shared *interest* in controlling or influencing the actions of the other, as well as the *ability* to do so by leveraging their capacity to exit the exchange relationship. This means that the relation of dependence is also a relation of power, where A's power over B (P_{ab})[16] is equal to B's dependence on A: $P_{ab} = D_{ba}$ (ibid.). This power is defined by Emerson as the potential of A to influence B or the amount of resistance by B that can be overcome by A (ibid.).

Because exchange relations bring about *mutual* (or *inter*-) dependence A and B both have power over each other. When this potential power is balanced ($P_{ab} = P_{ba}$), both actors refrain from power use out of fear that the advantages they enjoy by taking part in the exchange would be disturbed (Emerson, 1962, pp. 33–34). Relations whose average power is higher, measured by the average of the absolute power in the relationship, tend to have higher cohesion, meaning that the relationship is more likely to form and last, even in cases of conflict (ibid, p. 34; Molm, 1997, pp. 30–31).

However, when the power/dependence relationship is imbalanced ($P_{ab} > P_{ba}$ or $P_{ab} < P_{ba}$), the more powerful/less dependent party can leverage the relationship for their advantage and thus opens up the possibility of power use. In a dependence relationship, the use of power functions by limiting the rewards provided to the other party: A, who possesses a power advantage over B ($P_{ab} > P_{ba}$), can either limit or stop providing B with the resources it needs/wants. In exchange for not doing so, A may demand B pay some rewards such as additional resources, either on that domain or some external one[17]. (Emerson, 1962, p. 33, 34; Molm, 1997, pp. 32–33)

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[15] This has been noted by D. A. Baldwin (1980, pp. 499–500). B's high dependence on A is just another way of saying that B's opportunity costs of exiting the relationship with A are high (ibid, p. 490). This is also the fashion in which the definitions have been formulated here. They thus differ slightly from Emerson's original formulations but serve the same purpose.

[16] This only measures the power derived from dependence. The totality of A's power over B might be higher or lower depending on other factors.

[17] For example, material goods can be used to obtain nonmaterial benefits or vice versa. Note the similarity of this to the ability of states to use economic tools for non-economic ends, as has been described above as one central feature of economic statecraft.

At this point, the compatibility of this view with the view of power introduced thus far in this thesis should be noted. Both Emerson and Baldwin understand power relationally as the ability of A to influence the behaviour of B. Emerson's 'power' also corresponds with the more general term 'power resource' in that they both are defined as a *potential*, which is then actualized in use (influence action). Additionally, Emerson provides a theory about the causal mechanism involved in interdependence-based power: A can *leverage* the exchange relationship by exiting it and thus manipulate the costs and benefits B faces.

Aside from providing a theory of how influence activities function in exchange relations, Emerson also discusses how actions aimed at increasing dependence-based power resources work. When faced with the risk of dependence-based power, B must logically pursue one of two strategies: cost-reduction or power balancing. The first refers to a situation where B, the dependent party, will accept the power imbalance, and the dependence inherent in it, by reducing the costs it might face in that position. This can involve the rationalization or acceptance of A's power use, or otherwise a change of values and goals to be more in line with A so that power use is less likely. Importantly, this strategy does not alter the imbalance of power; for that end, B must choose a strategy of power balancing. (Emerson, 1962, pp. 34–35)

Considering that the factors governing a relation where B is asymmetrically dependent on A can be formulated as: $CO_b - FO_b = CO_a - FO_a$, it is clear that B has four power balancing actions available to it, one for each factor (Emerson, 1962, p. 35). The first two of these actions[18] concern the manipulation of the value gained from exchange, i.e., the level demand for a resource. First, (1) B can reduce the value it gains from the exchange with A ($\downarrow CO_b$). In economic terms, this would require that B has to lower the demand it has for resources provided by A. Because Power-Dependency Theory does not consider the relations internal to actors as outside options, this strategy also includes the possibility of B lowering its demand for a resource by providing it to itself (becoming more self-sufficient). Alternatively, (2) B can increase the value that A gains from the exchange ($\uparrow CO_a$). This would require B to either make A value more the resources B provides or develop the capacity to provide A with resources it does value.

The other two possible actions involve the introduction of outside options, i.e., the alternative supply of a resource. To discuss these strategies, Emerson introduces the

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[18] The actions listed here are adapted from Emerson (1962, pp. 35–40), where they are called 'operations.'

concept of a power network[19] (ibid, p. 36), a structure constituted of all the dyadic dependence relations within a system. The simplest possible network is only constituted by two relations: that between A and B and that between A and C. In this case, A can gain the resources it needs from both B and C, whereas B and C are only able to gain the resources they need from A. Looking only at the available options for each of the actors, A is the most powerful with B and C being asymmetrically dependent on A.

With the third possible action (3), given the context of the above power network, B can attempt to increase the availability of a needed resource from other sources ($\uparrow FO_b$). This means that B could extend the network to include a relation between B and C, or some other actor D. Alternatively (4), B can also attempt to decrease the availability of the resources that it provides for A from alternate sources ($\downarrow FO_a$). This would involve B attempting to influence the other actor C, for example, by coercion or by forming a coalition against A.

All four power balancing actions involve some level of cost. Aside from opportunity costs, two other types of cost are also involved: the investment costs that must be taken to acquire a new resource[20] and the actual costs of losing a traded resource (Molm, 1997, p. 16). Of these, investment costs are more important because the capacity to acquire a new resource is central to all of the described actions.

The above-described interest of the less powerful party to balance against the more powerful, for Emerson constitutes a drive toward a balanced system of exchange relations. Whether this is the case is very suspect, however. Given that the operations involved in power balancing depict strategies of power maximisation, there is no real reason as to why the more powerful party would not use similar actions to counter-act such balancing; more so given that it is in the more powerful and thus capable position. In the same vein, even balanced relations are not safe from these drives toward power maximisation. (Molm, 1997, pp. 37–38)

Questions that follow from this line of thinking, such as how much actors value an improved power position over the existing gains from an exchange (whether they work by the zero-sum logic of geopolitics or the positive-sum logic of economics) and in what situations are they willing to initiate powerplays, are of course central questions for the field of International Relations. Thus, applying Power-Dependence theory to questions in

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[19] The network concept will be discussed in more detail in subsection 2.3

[20] In the case of international trade, and especially foreign direct investment, forming new exchange relations can also impose significant investment costs.

IR seems like an intuitive avenue of inquiry (see D. A. Baldwin, 1998). The next part of this subsection will attempt to bridge this divide by looking at the how Power-Dependence theory can be applied to international trade by discussing the path-breaking work of Albert Hirschman.

2.2.2 Interdependence and Economic Statecraft in International Trade

As D. A. Baldwin (2016, p. 159) has argued, Albert O. Hirschman, in his book *National Power and the Structure of Foreign Trade* (1945/1980), provides one of the strongest conceptualizations of international interdependence and economic statecraft available. This influence can be found in everything from Keohane and Nye's *Power and Interdependence* (see Keohane & Nye, 1987) to the *dependencia* theory rising from Latin America in the 1960s and 1970s (Hirschman, 1945/1980, pp. vi–xii).

In his book, Hirschman (1945/1980, p. 13) discusses the economic determinants of national power[21], especially the role played by foreign trade and the relations of dependence arising from it. To this end, he develops a thesis on how the structure of international trade, and the power position of a country within that structure, enable power use. Thus, he provides a theory of dependence as a power resource within the domain of trade relations that is very similar to the one posited by Emerson in his Power-Dependence theory decades later.

Hirschman posits that foreign trade has two effects on the power resources of a country: the supply effect and the influence effect. The supply effect concerns the enhancement of a country's military power through the positive effects of trade, such as the plentiful supply of goods (especially strategic resources) and the efficient allocation of resources. While the supply effect thus always requires the threat of war to be meaningful, the influence effect functions itself as an alternative means of coercion, or what can also be called economic statecraft. (ibid., pp. 14–15)

The influence effect and the mechanism by which it works are enabled by three simple facts. First, trade produces mutual dependence by leaving both parties better off compared to autarky (self-sufficiency), meaning that exiting a trade relationship is to some extent costly for both parties (ibid., pp. 9–10). Second, this dependence can be asymmetrical when one party gains more from the relationship than the other (ibid., pp.

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[21] Hirschman understands national power as the 'power of coercion which one nation may bring to bear upon other nations, the method of coercion being military or 'peaceful'' (Hirschman, 1945/1980, p. 13), a definition which is well in line with the understanding of economic statecraft in this thesis.

10–12). And third, every sovereign nation can either cut off or restrict its trade (ibid., pp. 15–17). Just as Power-Dependence theory posits, the ability to impose costs on others, granted by the capacity to leverage dependence, puts the less dependent A in a position of power over B that is equal to B's dependence on A.

Trade dependence can come about in two ways. First, and more intuitively, dependence can arise from a need for resources in a colloquial sense: a need for industrial or consumer goods. When B is dependent on A in this sense, it must either have a comparative disadvantage in producing the goods domestically or few options in choosing an alternative supplier. The second and less intuitive type of dependence is a dependence on external markets and the revenue they bring. If B is dependent on A's market to export its goods, it either has too little domestic demand able to absorb the production and/or too few alternative markets that are willing to buy those goods.

Just like Baldwin and Emerson, Hirschman understands power and dependence to be about the costs and benefits actors face. He theorizes two types of costs: opportunity costs and the costs of adjustment.[22] Opportunity costs describe the relative costs/gains from one equilibrium state over another, whereas costs of adjustment are the costs involved in the adjustment itself (Hirschman, 1945/1980, pp. 17–19). These other equilibria represent either an alternative relation with another trade partner, or a state of autarky. The costs of adjustment vary based on how effectively factors of production (labour and capital) can be redeployed to new uses (ibid., p. 28), how concentrated the production for export is in certain products or regionally (ease of absorbing production by domestic demand, exposure regional to shocks) (ibid.), how strong the vested interests in trade are (ibid.), and how differentiated (specific) the exported/imported[23] goods are (ibid., p. 32).

Hirschman details several policies through which country A, who is pursuing a power policy, should be able to instil dependence in its trade partner B and thus achieve a power position over them.[24] Within the context of the prior discussion in this thesis, these should be understood to be actions aimed at increasing the interdependence-based

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[22] The concept of 'opportunity costs' is the same for Hirschman as for Power-Dependence theory.

[23] Hirschman only includes imported goods in this because when they are highly differentiated, they foster fixed consumption habits and production techniques in the importing country. However, there is no reason why the producing country wouldn't face the same adjustment costs when trying to redirect differentiated production to some other market.

[24] Hirschman's theory building is done to discuss the power politics employed by Nazi Germany in Eastern and South-Eastern Europe and is thus prone to taking on the point of view of the more powerful, less dependent party, but in principle many if not all of the described policies should work as well for the party in the dependent position.

power resources available to the actor. These policies can be divided into two categories: those designed to make it more difficult for the trading partner to dispense entirely with trade, and those designed to make it more difficult for the trading partner to shift trade to third countries (ibid., pp. 34–35). When compared with Emerson, Hirschman's first category overlaps with the former's 'action 1' (increasing the partner's gains from trade), and the second category with 'action 3' (reducing the partner's outside options).

To make it *difficult for B to dispense entirely with trade regarding some good*, A can increase its partner's gain from trade by developing trade in goods that B has no possibility of producing on their own (ibid., pp. 24–25), or by directing trade toward poorer countries for whom the gains from trade are already high (ibid., p. 25). A can also try to increase B's adjustment difficulties in case of a stoppage in trade by trading with countries that have low mobility in their factors of production, and by inducing B to have a high concentration of production regionally or in a single good (ibid., pp. 26–29). Additionally, A can try to create alliances with groups within B that have a shared interest in trade (ibid., p. 29).

To make it *difficult for B to shift their trade away from A*, A can, again, direct trade toward countries whose total trade is small, and where the share of A–B -trade relative to all trade is larger than in A (ibid., pp. 30–31). If A is the importer, it may encourage B to produce goods for which there is little demand in other countries than in A (ibid., p. 31), drive prices of the good above world prices by encouraging high-cost production or by monetary manipulation (ibid., pp. 31–32), or grant B some other export advantages such as a guarantee of stable prices (ibid.). On the other hand, if A is the exporter it can trade in highly differentiated goods and create consumption and production habits in B (ibid.). In a case where A wishes to extend B's dependence on the export side to imports as well, it can also develop bilateral trade with B (ibid., p. 33). Optimally, A may try to influence transit trade to pass through its territory which can then be leveraged with very little cost to A (ibid., pp. 33–34).

The above policy instruments can be read to be directed at increasing a nation's interdependence-based power resources through both ES and strategic economic policy.[25] By comparing the above to the list of ES instruments that were presented in Table 1, it can be seen that many of the policies rely on positive instruments to establish a trade

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[25] The various non-economic instruments presented by Hirschman are not discussed here, but it is clear that they also play a major role in a state's overall toolbox.

relationship with a new trading partner; examples of such instruments would be a decrease in tariffs/quotas, direct purchases, and import/export subsidies. Negative ES instruments can also be used for this purpose (e.g., dumping). Some of the policies, such as the development of production in specific strategic goods, also depend on domestically directed strategic economic policy.

Hirschman also notes that it is an ‘elementary defensive principle of the smaller trading countries not to have too large a share of their trade with any single great trading country’ (Hirschman, 1945/1980, p. 31), alluding to the fact noted by Emerson that increasing one’s outside options also decreases dependence (action 4). Increasing a state’s diversity of suppliers/markets could be achieved through the instruments of ES (creating new trade relationships, influencing production abroad), by strategic economic policy (e.g., upgrading production within the same sector, developing new production in a different sector) as well as by other tools of statecraft (e.g., diplomacy). He also discusses the significant literature on the merits of using protection and import substitution (switching to the domestic production of a needed good) to further national security goals (pp. 3–12), corresponding to Emerson’s ‘action 2’ (manipulating one’s gains from an exchange), while still curiously leaving it outside of his taxonomy on national power conducing trading methods. Decoupling from international trade by import substitution could be achieved both by ES (e.g., tariffs/quotas, blacklisting, licence denial, capital expropriation) and by strategic economic policy instruments (e.g., subsidies, public investment, public-private partnerships).

To condense all these possible policy actions for increasing interdependence-based power resources in a more general framework, it can be said that a country pursuing such a policy should (1) minimize its dependence on trade by diversifying its suppliers/markets, both by import substitution (while still reaping the gains from the supply effect) and by limiting one’s adjustment costs, and (2) maximize its monopoly and monopsony power[26] by ensuring that others face a limited diversity of suppliers/markets for the goods it produces and that others’ adjustment costs are high.

As a summary, this subsection has described what exactly is meant by interdependence being a power resource and a point of leverage for economic statecraft. The central starting point was found in the fact that the parties engaged in a relation of

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[26] In this context, monopsony power is also often called ‘market power’. Within the framework developed here, monopoly and monopsony power should just be seen as subtypes of what here have been called interdependence-based power resources.

interdependence are left both sensitive and possibly vulnerable to the actions of each other. Following insights from Power-Dependence theory, these kinds of exchange relationships were exposed as possible points of leverage where the party with fewer options and more to gain from the relationship is left in a lower position of power relative to the party with more options and less to gain. The actors engaged in exchange can increase their relative power (resources) by either increasing the other party's dependence on the relationship or by decreasing their own. This dynamic proved to be very similar in the case of international trade, where dependence relationships are formed based on the demand for either external supply or markets, and where the gained interdependence-based power resources can then similarly be used by the state in acts of economic statecraft. The next subsection will now focus more on the network approach, already introduced by Emerson, and how the peculiarities of global supply chains affect the picture presented thus far.

2.3 Global Economic Networks

The discussion on trade and dependence has thus far modelled them as *bilateral*, or as that between two states. This subsection aims to go beyond this simplification in two ways: first, by focusing on the fact that bilateral relations always exist in the context of numerous other relations and potential relations, and second, that trade and dependence are not at their root located between nation states, but between individual economic actors such as firms. Key to this is understanding that trade in the 21st century is organized in global supply chains that can cross multiple national borders, and where production is rarely confined to just one or two countries (see e.g., R. Baldwin, 2016). Thus, the complex power structure resulting from the exchange relations involved in the production of even just one end-good can be conceptualized as a network of interdependence, in which multiple actors, including states, are intertwined.

2.3.1 International Networks

After the development and conceptualization of Complex Interdependence (Keohane & Nye, 1977/2012), a 'network approach' utilizing the language of networks and Network Analysis has started taking shape within IR scholarship (Kacziba, 2021). The network approach provides a tool kit for constructing a non-Waltzian structural account of international phenomena where structures, that are distinctly rooted in individual actors and their persistent interactions with each other, serve to enable and constrain the actions of those actors (Hafner-Burton et al., 2009, p. 561)[27].

The most basic units of analysis for this approach are the node and the links (or edges) between them. Nodes can represent anything from individual people to corporations and states, whereas links can stand for any type of relationship from social ties to flows of information or material resources (Kahler, 2009, p. 5). All the nodes and links taken together form a network, which can include innumerable patterns, such as clusters where nodes share multiple links with each other, bridges where one or more nodes connect separate clusters together, or hubs which are nodes that are far more connected than others (Maoz, 2010, p. 9). The combined pattern of the network forms a topology, a type of geography, in which the embedded actors have to navigate. This too can take the form of different general shapes that vary between the extremes of a highly centralized network, where only a few hubs control a large majority of all relations, and a distributed network, where the connections are balanced among the nodes (Kacziba, 2021, p. 165).

The characteristics of the nodes, their links, and the overall structure of the network, all have effects on the distribution of power resources and the use of power within the network. Between two directly connected nodes, the traditional tools and mechanisms of ES still apply, because the bilateral dependence-relation remains unchanged. Given the context of the network, however, additional sources of interdependence-based power are understood to be *the centrality* of a node and the ability of an actor *to exit* the network (Kahler, 2009, pp. 12–14; Burton et al., 2009, pp. 570–574). Centrality can come about in multiple ways, but the two most relevant ones are the node’s *connectedness*, or how many links to other nodes it has, and its *betweenness,* or the positioning it has as an intermediary between two or more nodes or clusters (ibid). *The ability to exit* the network on the other hand grants an actor the possibility to delink or completely decouple from the network, reducing the vulnerability it faces to others’ influence attempts (ibid.).

Comparing these forms of network power to the interdependence-based power discussed in the previous subsections, it can be seen that they all involve largely the same mechanisms of leverage: the gains and costs possibly inflicted on others. They also share the same sources of dependence, namely the opportunity costs of the relationship: connectedness increases the availability of outside options, betweenness lowers the options

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[27] An alternative approach to networks in IR (and not discussed here) understands networks as a type of actor that has distinct effects on its environment, in comparison to traditional hierarchically organized actors (Hafner-Burton et al., 2009, p. 561; Kahler, M., 2009, pp. 5–7).

of others, and a higher ability to exit indicates that the actor has low gains from the relationship or is otherwise able to reduce these gains by becoming more self-sufficient. Social Exchange Theory, like the one proposed by Emerson (1962), is in fact compatible with a network approach to power in (and only in) cases where the links between nodes are conceptualized as exchange relations, and with the condition that on top of centrality the value gained from the network position is taken into account (Cook & Whitmeyer, 1992).

There also exists another way by which networked interdependence can function as a power resource for ES, namely through what Farrell and Newman (2019b) have called 'weaponized interdependence'. Just like the network-based 'asymmetric interdependence'[28] described above, weaponized interdependence focuses on the network effects that flow from the central position of an actor in a network (Farrell & Newman, 2021). Additionally, however, weaponized interdependence allows for a central node to exert control over the whole of the network, as opposed to just another node it is in immediate contact with, such as through gatekeeping the actors allowed into the network and utilizing central positions within the network to control it (ibid.). Farrell and Newman name two effects by which weaponized interdependence operates: *the panopticon* and *the chokepoint.* The panopticon effect involves the ability of a hub or a bridge to monitor and gather information from the links and the flows going through the node, while the chokepoint effect grants it the ability to limit or penalize others' access to the central nodes such as hubs and bridges it controls (Farrell & Newman, 2019b).

Essentially, the concept of weaponized interdependence enables a more thorough understanding of secondary sanctions (Farrell & Newman, 2019b), or sanctions that are imposed by A but do not involve any link between A and another actor. In a situation where B has a relationship both with A and C but where A and C have no relationship between themselves, A has very little direct power to influence the behaviour of C because the mechanisms of asymmetric interdependence do not apply.[29] A can, however, weaponize its network position to compel other actors in the network (B) to impose

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[28] *Asymmetric interdependence* is the term Farrell and Newman use for bilateral influence attempts drawing from interdependence-based power resources. The way this is understood here includes all such influence attempts that involve the leveraging of an immediate link between two actors, whether or not this link exists in the context of a wider network.

[29] Note that here the power drawn from relationships (for example of exchange) is considered the only channel of influence. Outside of this, it is of course possible for A to have some other power resources it could use to influence C.

sanctions on C by threatening to impose regular primary sanctions on those not willing to comply. What determines A’s power over C in a network context, is thus the difference between the dependence of B on A and the dependence of B on C ($D_{ba} – D_{bc}$). Opened up this way the concept of weaponized interdependence is thus revealed to be very similar to regular interdependence-based ES, but with a focus on a longer and more complex mechanism that is nonetheless based on the same principles of leveraging asymmetrical interdependence.

Just like ‘regular’ ES, i.e., asymmetric interdependence, weaponized interdependence also has costs associated with its use. First, there are the costs associated with losing out on the gains from the relationship, or opportunity costs, which were discussed in sub-subsection 2.2. A second type of cost involved in weaponized interdependence is the loss of trust in the network. What this means is that after regular uses or threats of weaponized interdependence, A may lose standing in the network, and thus power, as other actors find it more beneficial to delink from A or to decouple from the network as a whole (Mastanduno, 2021).

Because of the obvious connection to secondary trade sanctions, many have noted that the network approach, including the concept of weaponized interdependence, could be an important tool for analysing power in networked international trade and production, as well as the supply chains involved in them (Farrell & Newman, 2019b, p. 44, 47; Özdamar and Shahin, 2021). The general network framework is, however, not readily applicable to the special case of supply chains because of central differences in how supply chains function compared to other networks. Because of this the following subsection will discuss how the network approach can be integrated with Global Value Chain analysis, the standard approach used for analysing global supply chains.

2.3.2 Global Supply Chains

While subsection 2.3.1 discussed how the network characteristics of trade impact the use of interdependence-based power in trade, this does not yet paint the whole picture of trade in the 21st century. Trade is not just affected by the network context; in many cases, the network *is* the trade. This is because starting in around the 1990s, as a result of the ICT revolution and the massively lowered costs in communication, and thus industrial coordination, most production has become organized in globe-spanning supply chains where much of the trade crossing national borders consists of intermediate goods, not of goods for final consumption (R. Baldwin, 2016, pp. 1–17, 79–111).

This has two major impacts on the way interdependence in trade should be understood. The first is a result of production fragmentation increasing the need for transnational coordination between producers and suppliers, drawing the focus of the analysis away from the international level to the level of the individual interlinked companies, who now more clearly emerge as global actors in their own right (see e.g., Gereffi, 1994; Arndt & Kierzkowski, 2001). In the supply chain world, the central links of interdependence should now be first and foremost understood to reside between consecutive chain 'segments', constituted by individual firms, responsible for specific tasks in the production process (Gereffi, et al., 2005; Fernandez-Stark & Gereffi, 2019).

Second, because supply chains are to a large extent constituted by firms whose function in the chain is geared toward the production of highly specific intermediate goods, firms also become interdependent on those firms in the chain that they have no direct relations with (see e.g., Ponte & Sturgeon, 2014). Consider a situation where B is dependent on its supplier C for the provision of an input for B to produce an output for A to process further. A would also become dependent on the functioning of the B–C -relationship to produce an output for B. In other words, in a network, such as a supply chain, the constituent nodes become dependent also on the proper functioning of the chain as a whole.

As was explored in subsection 2.2.1, the high interdependence between firms provides them with an incentive to control each other's actions. The theoretical discussion presented thus far provides a useful framework for understanding this as an interdependence-based structure of power, which enables states exercising jurisdictive authority over certain firms to exploit their position in that structure through acts of economic statecraft, both on the level of an individual link and the network as a whole. However, this description does not yet entirely explain how this power functions in the context of global supply chains. For this purpose, the framework provided by Global Value Chain analysis becomes useful.

Global Value Chain (GVC)[30] analysis[31] provides a multidimensional theory and methodology to analyse 21st-century economic globalization and development, but the

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[30] 'A value chain' is a concept slightly different from 'a supply chain', in that a value chain focuses on *the value-adding activities* of each segment of production (Fernandez-Stark & Gereffi, 2019). Here the latter term is used, but synonymously with the former.

[31] GVC analysis is an analytical framework developed in fields such as economic sociology, development studies and business studies (Gereffi, 2018) but it also has a large overlap with International Political Economy (Neilson, et al., 2014).

most salient aspect it has for understanding international power is its concept of ’governance’ (Fernandez-Stark & Gereffi, 2019). GVC governance can work as a theory of power in global supply chains by explaining how firms coordinate with each other and how this affects the distribution of gains in the chain (Dallas et al., 2019). Similar to the understanding of power used in the above subsections, GVC analysis has typically understood governance as coercive/bargaining power, in that it sees actors intentionally mobilize power resources to leverage incentives and sanctions to affect the behaviour of others (ibid.). This similarity also allows for the application of the exchange-theoretic concepts used above to understand interdependence-based power in global supply chains as well (e.g., Mahutga, 2014).

At its core, governance can be understood as consisting of a two-level process involving how individual firms *link* with each other as well as how the overall chain is *driven* (Ponte & Sturgeon, 2014). ‘Governance as linking’ builds on ‘the theory of the firm’-literature, where individual actors can work together either on the market without explicit organization, which enables tapping into the efficiency gains provided by a division of labour, or by organizing into a hierarchical firm to avoid various (transaction, information, bargaining etc.) costs involved in choosing the lower-hierarchy alternative (see Coase, 1937). Arndt and Kierzkowski (2001, p.4) extend this line of thought, arguing that the coordination of fragmented global production can be organized through separately owned and specialized firms on a market or through hierarchical vertically integrated corporations.

Gereffi et al. (2005) present a theory for link-level chain governance by positing three variables predicting the type of relationship two nodes in a chain will have with each other. The most central of these is *the complexity of transactions* required between the nodes, specifically the complexity of information and asset specificity[32]. Low complexity will lead to a *market*-type organization and high complexity to *hierarchical* organization. However, in cases of large geographical distances and thus higher transaction costs, the complexity of transactions needs to be managed by either a high *ability to codify transactions* or a highly *capable supply base*[33]. When the transactions are codifiable and

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[32] Asset specificity refers to how specific an asset (e.g., investment producing some good traded in a transaction) is to that relationship. I.e., specific assets produce what Hirschman calls ‘differentiated goods’ (Hirschman, 1945/1980, p. 32).

[33] Gereffi et al. work with the assumption that the supplier is the outranking participant in the chain compared to the outsourcing global buyer. However, the principle described could concern the capability of a distributor dealing with an outranking producer as well.

the supply base is highly capable, the linkage is described as *modular,* meaning that the supplier can receive detailed orders for specific products while retaining the ability to flexibly service multiple buyers with the same set of technology and capital. In a *relational* linkage type the supplier is highly capable but the transaction lacks codifiability, leading to a need to exchange tacit information between the nodes through a deeper and longer-lasting relationship. Finally, if the supply base lacks the capabilities to execute complex orders independently but the transaction can be codified, the link will exhibit *captive*-type characteristics, where the supplier retains its independence but is highly controlled and intervened upon by the buyer. (ibid)

While Gereffi et al. (ibid.) place these linkage types on a scale (in the order: market, modular, relational, captive, hierarchy) from the ones requiring the least explicit coordination, and thus exhibiting the lowest degree of power asymmetry, to the ones with the highest marks in both, Ponte and Sturgeon (2014) explicitly describe this scale, and thus power in supply chains, to be reflective of the costs of supplier switching[34]. Switching costs resemble what Power-Dependence theory describes as ‘investment costs’ (Molm, 1997, p. 16) and is virtually identical to what Hirschman (1945/1980, pp. 17–19) refers to as 'costs of adjustment’. As has been noted earlier, switching costs can be taken to be generative of interdependence-based power, also between supply chain nodes. This means that link-level interdependence should increase with the level of complexity required in a transaction and decrease with a higher codifiability of transactions and the capabilities of the transaction partner (assuming that other factors, namely the opportunity costs of the relationship, are held constant).

‘Governance as linking’ explains how the supply chain as a network is constituted by individual link-level interactions of firms and how switching costs shape the power structure of the chain. ‘Governance as driving’ on the other hand focuses on network-level power by introducing the concept of a *lead firm* which can exert control over the chain by ‘driving’ it. Gereffi (1994) differentiates two types of lead firms: producers (large multinational manufacturing firms) and buyers (such as large retailers and brand-name companies). Sturgeon (2009, p. 132) expands on this by clarifying ‘purchasing power’ as the ability to use leverage by choosing and replacing suppliers, and ‘supplier power’ as the capacity to leverage competence in a specific niche to achieve

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[34] Again, this could also, in theory, apply to distributor/buyer switching.

irreplaceability. An advanced level of supplier power can even enable a lead firm to set standards with their 'market and technological dominance' (ibid.).

As Mahutga (2014) has argued in an application of Power-Dependence theory to GVC analysis, this points in the direction of seeing driving power as a result of the control of a central network node by a lead firm that is less dependent on others than others are on it. He argues that 'driving power' is thus essentially a result of the positional power of a firm (ibid.), equalling what has here been called the structural position, power resources, or the opportunity costs faced by an actor involved with others in networked relations of interdependence. Aside from just the switching costs, high *barriers of entry*[35] also significantly affect this positional power by determining how much competition there will be on that segment of the chain (ibid.). A central barrier for firms entering into a supply chain is the requirement for it to have control over a resource needed in that segment: the higher the entry barriers, the less competition there is on that segment, and thus more power is concentrated in the hands of the few firms able to supply a needed resource (ibid.).

The resources demanded from buyers and suppliers can be very different and depend heavily on the specifics of the chain. Within the technology industry, the resources needed from producers are often highly specific as well as capital and technology-intensive (Sturgeon, 2009), making these the central entry barriers needed to be overcome by entrants. For buyers, a central resource forming a barrier of entry, and thus granting power to its holders, is intellectual property rights. Durand & Milberg (2020) argue that the increasing role of intangible assets such as intellectual property (copyrights, patents, trademarks, and trade secrets) at both ends of the supply chain (R&D and design, and marketing and after-sales; often controlled by the same firms) has had the effect of creating entry barriers and concentrating market power, a problem which has been exacerbated by institutional arrangements such as IP laws and trade agreement provisions.

As a summary, this subsection has argued that network theory and GVC analysis provide complimentary prescriptions about global production and trade networks. GVC analysis describes link-level dynamics and how these determine the structure of the larger network by focusing on the switching and entry costs faced by individual firms, while network theory can provide a more robust view of the network structure and how the patterns of the linkages form unique outcomes on the network-level. Especially the concept of positional power in supply chains should be understood as a case of network

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[35] As a concept 'barriers of entry' is functionally identical to 'investments costs.'

centrality, allowing central actors to leverage their position as a lead firm for outsized outcomes throughout the supply chain. The theory of weaponized interdependence, on the other hand, shows how these central nodes can be exploited by states for Economic Statecraft.

2.4 Summary

The above chapter has sketched an explanation of how power, including international power, works in global supply chains on a general level. Specifically, it has argued for a view that understanding the structure of supply chains is necessary to explain how economic statecraft is employed in the context of said supply chains. This last subsection of the theory section will summarise the theoretical perspective, which is later applied to the case of semiconductor supply chains.

Following D. A. Baldwin (e.g., 1980, 1985/2020, 2016) (applying Dahl) and Meierding & Sigman (2021), this thesis set out by conceptualizing international power as a combination of a power activity, a power resource, and a power mechanism. This view flows from a Dahlian conception of power: the capacity of A to have B do something B would not otherwise do (Dahl, 1957). The mechanism by which D. A. Baldwin (1985/2020), Power-Dependence theory (Emerson, 1962), Hirschman (1945/1980), and Global Value Chain analysis (e.g., Dallas et al., 2019) all understand power to function through, is the mechanism of leverage or the ability of actors to inflict costs (and benefits) on others.

For states engaging in economic exchange, the interdependence between exchange partners functions as the most central power resource (D. A. Baldwin, 1980). The way by which they go about leveraging this power is by using either punishments or rewards (D. A. Baldwin, 1985/2020, pp. 28–32). As a whole, this type of power activity falls under ‘economic statecraft’, which can be defined as a governmental influence attempt relying on instruments that have a reasonable semblance of monetary value (e.g., tariffs and quotas, export and import subsidies and licenses, boycotts and blacklistings) (ibid).

How exactly interdependence constitutes a power resource is clarified by Power-Dependence theory: the dependence of B on A equals the power of A over B (Emerson, 1962). The elements constituting interdependence are also well illustrated in Power-Dependence theory’s formula for calculating the relative dependence between A and B: $CO_b - FO_b = CO_a - FO_a$, (ibid.). It shows that dependence is born out of a high level of gains enjoyed as a result of a relationship, as well as the low outside options to it, i.e., the *opportunity costs* of the relationship (D. A. Baldwin, 1980; Hirschman, 1945/1980). Opportunity costs, however, are not the only type of cost affecting the level of interdependence. The costs of making changes to one's situation should also be taken into account. Central to this are *adjustment* (or *switching*) *costs* (Hirschman, 1945/1980; Ponte & Sturgeon, 2014) as well as the closely related *investment costs* or the *barriers of entry*[36] (Molm, 1997; Mahutga, 2014), of which the former refers to the costs involved in redirecting one's exchange toward another partner (e.g., swapping out suppliers) and the two latter concepts to the costs involved in the developing of new resources (i.e., entering a market).

Aside from economic statecraft (the using of power resources in an act of power), the building up of interdependence-based power resources, i.e., *power balancing* (or power maximisation), is the other state action central to the theory presented here. Such power balancing (/maximisation) is noted both by Power-Dependence theory (Emerson, 1962) and by Hirschman (1945/1980), and involves the state influencing the above-described cost structure by manipulating the opportunity costs of actual and potential relationships (namely the four values of *gains to self*, *gains to partner*, *outside options of the self*, and *outside options of the partner*) as well as the adjustment and investment costs. Such power balancing can function either through economic statecraft (using power to build up more power), or through domestic 'strategic economic policy', e.g., by orientating domestic production toward strategically important goods or by increasing the ability of the economy to adapt to foreign economic influence attempts. Importantly, Emerson (1962) also notes that balancing is not the only option available to a state, as it can also employ a strategy of cost-reduction by either accepting the use of power upon it by another state or by adjusting its values to be more in line with the more powerful party.

The distribution of power resources can be understood to constitute the power *structure* of a system, which works to both enable and constrain the actors embedded in it (Keohane & Nye, 1977/2012, pp. 17–18; Molm, 1997, pp. 29–39). Because power is here understood as relational, and because the power resource of interdependence is born out of relations of exchange, it is intuitive to conceptualize the power structure resulting from the interaction of multiple actors as a *network* of the relations between them (Emerson, 1962). How power resources are distributed, i.e., how independent/dependent some

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[36] For clarity, only the term 'investment costs' is used from here on out.

actors are relative to others, can thus be understood in terms of network topology. The network can be flat with low power differences, or uneven with peaks and valleys reflecting an uneven power structure (Farrell & Newman, 2019b).

This thesis argues that the primary constituent parts of the power structure working in the context of global trade and production are not states but rather independent economic actors such as firms. The strictly state-centric conception of economic statecraft is rejected in favour of a view that understands these independent economic actors as mediators for economic statecraft (see Norris, 2016). Thus, understanding this network structure is central to also understanding patterns of inter-state power.

Global Value Chain analysis provides a framework for understanding how exactly exchange relations between firms embedded in global supply chains bring about structures of interdependence-based power. On the level of interfirm links, it largely results from high switching costs, i.e., from how *complex* and *codifiable* the transactions in the relationship are and how *capable* the parties are at taking care of their individual productive functions in the chain (Gereffi, 2005). On the level of the chain, power can become concentrated in the hands of one or more lead firms as a result of low competition on that segment of the chain (Mahutga, 2014), what in network topological terms can be described as a pattern of *centrality* (e.g., Kahler, 2009). This centralized structure grants the firm controlling the central node significant power over the whole chain, i.e., the ability to *drive* the chain (Gereffi, 1994). This can then be exploited by states through measures of economic statecraft such as *weaponized interdependence* (Farrell & Newman, 2019b).

The modular theory developed in this section thus argues that (a1) the leveraging of supply chain interdependence, existing between interlinked independent economic actors, constitutes a mechanism for the mediated delivery of economic influence attempts between states, and that (a2) these instances of power use are to a significant extent co-constituted by the structure of the interdependencies in a supply chain and its network topology. This means that the distribution of dependencies structures how states can wield power in that context, and conversely, that the use of power itself is capable of further reproducing and reifying the power structure itself.

Following the development of a theoretical framework, this thesis will next move on to applying it to the empirical reality of the supply chains for semiconductor devices. Before this, however, the next section will further discuss the methods of inquiry that are involved in the following empirical investigation.

3 Methods

The next part of the thesis follows the research agenda laid out by Farrell and Newman (2021, pp. 309–310) and focuses on mapping the trade and production networks of the semiconductor industry by graphing the topological structure of its supply chain. Similar to how a precise understanding of physical geography is vital to analysing the geopolitical power of nations, so is an understanding of topology, the geography of networks, vital to analysing their use of economic statecraft.

The standard methods of Global Value Chain analysis form the template for how the semiconductor supply chain is mapped. This typically involves identifying (1) all the segments of a chain and its main functions, including its particular features and dynamics, (2) the geographic scope of a chain, and (3) the relations of governance between chain segments. This approach is useful even while understanding the supply chain as a type of network because it redirects the analysis from the level of the individual firm to the level of the supply chain segment. Because all nodes located within a particular segment are functionally similar and can only have exchange relations with firms located on adjacent segments there is no need to map every single firm individually. Instead, the mapped nodes are conceptualized as firm–nationality pairs, thus focusing on the most important aspect of the firm, namely its nationality, and the possibility of its position in the supply chain being weaponized by a state.

Aside from the typical steps in GVC analysis, the analysis here will additionally map the distribution of (in network terms) centralities in the chain, which, as was established in the theory chapter above, function as a power resource in a network of multiple interrelated actors.[37] Centralities are mapped on the segment level, which in practice entails looking at how geographically concentrated the market is on each segment of the chain. This is also the level of outside options faced by firms on adjacent segments of the supply chain. This is measured using the Herfindahl-Hirschman index (HHI), which is the standard measure used for assessing the competitiveness of a given industry.

The formula for HHI is:

$$HHI = \sum_{i=1}^{n} {s_i}^2$$

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[37] Alternatively, this could be understood as an expansion of step ‘3’ listed above.

where s is the market share of the firm i and n is the number of firm-nationality pairs present on the segment. As its name suggests, this simple measure was originally invented by Albert O. Hirschman (1945/1980) in his *National Power and the Structure of Foreign Trade* to measure national concentrations of imports and exports to study national dependencies.[38] This makes it more than suitable for this thesis. The HHI outputs a value ranging from 0 to 1, with a higher value indicating a more concentrated market. When a market has a value of 1, one actor maintains a perfect monopoly, a value over 0.250 usually indicates a monopolistic/oligopolistic position for the largest actor (or actors, if the market has more than one leader) whereas a value under 0.150 is considered highly competitive. Because this thesis is looking at national concentrations, these numbers will likely be higher. The brackets of concentration used here range from low (under 0.200) to fairly high (0.200–0.300), high (0.300–0.400), and very high (over 0.400).

The limitation of the HHI as a method for measuring the relational power of nodes vis a vis each other is that it is, from a social scientific realist point of view, fundamentally a statistical construct that only measures the market concentration on an abstracted level above the actor level. It does this only with one number, which abstracts away the differences in power between nodes on the same chain segment. Thus, while it is reasonable to correlate the output of the HHI with the outside options faced by highly connected nodes on adjacent segments, this does not hold in the case of 'marginalised' nodes, i.e., lowly connected nodes on a highly concentrated segment. Thus, an analysis solely relying on the HHI can only measure the relative power of the leading firm-nationality pairs. To measure outside options for 'marginalised' nodes, a more qualitative analysis needs to be employed.

Another limitation of the HHI, from the point of view of the theory employed here, is that it only measures one type of centrality: betweenness-type centrality, i.e., the outside options of others. To measure connectedness-type centrality, i.e., one's outside options, the HHI scores of adjacent segments need to be taken into account. Thus, in the analysis, to look at the power relations of the chain segments based on of their outside options, the HHI scores of adjacent segments are compared and given scores based on both imbalance (difference in scores) and coherence (sum of scores).

Additionally, to form a better perspective on the opportunity cost structure faced by firm-nationality pairs, the value that countries gain from their participation in the

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[38] Hirschman instead used the square root of the measure. Here the better-known squared version is used.

supply chain also needs to be measured. To estimate one aspect of this (the economic impact of the segment for the country in question), a simple measure of value added by a firm–nationality pair as a percentage of national GDP is used. Another aspect of gains from trade is the gains from access to the end product. This is measured by estimating the importance of chip-demanding industries for each of the countries in the chain.

To assess investment costs, the segment-typical research and development (R&D) and capital expenditure (Capex) contributions, relative to firm revenue, are looked at for each chain segment. Additionally, an estimate of the labour market is used to assess the capabilities for training and recruiting qualified workers. Similarly, qualitative data about firm governance relations are used for assessing switching/adjustment costs.

Factors relating to capital ownership are left outside the scope of this thesis. This includes both relations of ownership and acquisition between firms in the chain, as well as the national origin of capital ownership and the direction of capital flows. In place of using the national origin of capital, the nationality of a firm (and thus the composition of a nationality-firm pair) is factored based on the location of the firm headquarters. This is also the definition used in the data.

Data for the mapping is taken from various sources, with a major limiting criterion being that the data be freely and publicly available. This immediately excluded most private market research, which would have been the optimal source for data on private companies, and instead forced a reliance on secondary sources such as private research institute reports, academic sources, industry reports, publicly available market research, and white papers by public sector actors. The main sources for data were reports by the Semiconductor Industry Association (SIA, 2022a; 2022b; Varas et al., 2021), Kearney (Aurik et al., 2021), Accenture (Alam et al., 2022) and Stiftung Neue Verantwortung (Kleinhans and Baisakova, 2020; Kleinhans et al., 2021), market research from ICinsights[39] (2021a–2021c, 2022a–2022g) and Knometa (2022a, 2022b), an issue brief by the Center for Security and Emerging Technology (Khan et al., 2021), a report by the White House (2021), and a book-length empirical analysis by Yeung (2022).

The sources were selected to reflect the contemporary status of the semiconductor industry and they mostly use data from 2019; more contemporary data were used when available. The scope of the mapping includes companies from the six largest countries

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[39] Unfortunately, due to the acquisition of ICinsights (an extremely useful private market research company that also provided publicly available bulletins) by TechInsights after the period of this thesis' data collection, the data source is no longer available online. It can, however, be accessed using online archiving tools.

and markets in the chain, which make up the overwhelming majority of the market on most segments of the chain: the U.S., the EU[40], Japan, South Korea, Taiwan, and China.

4 The Structure of the Global Semiconductor Industry

Rapid innovation and growth in the semiconductor industry have been at the root of late 20th and early 21st-century technological, economic, and social developments. In its early years, it drove the innovation boom in modern electronics (computation, telecommunications, industrial automation, etc.), and the last decades of the 20th century saw the development and proliferation of both the personal computer and the mobile phone, as well as advancements in telecommunications technology culminating in the introduction of the internet.

As of today, semiconductors have grown into a 556-billion-dollar industry (SIA, 2022a). The industry has found its place in the digital economy at the base of an ecology of systems and platforms that are reliant on semiconductor devices (Holmström & Seppälä, 2020). Additionally, their continual increase in performance is a requirement to meet the promise of new technological applications such as the internet of things, artificial intelligence, and cloud computing (ibid.).

Semiconductor devices also have an important strategic dimension, aside from considerations of economic superiority, as dual-use goods. For example, military vehicles and weapons delivery systems often depend on sensors, actuators, and electro-optical systems powered by semiconductors to function (Gargeyas, 2022). Adding to this, the development and broader future application of autonomous weapons systems relying on artificial intelligence (see e.g., Hagström, 2019) will make the need for technological superiority a central security issue (Shivakumar & Wessner, 2022).

The driving force behind the speed of semiconductor development is ‘Moore’s law’, named after Intel co-founder and CEO Gordon Moore who in 1965 forecasted the annual doubling of the transistor count in integrated circuit (IC) chips and with it the continuing growth in computational capability (Moore, 1965/1998). Almost miraculously, these expectations have been met year after year, and in effect, Moore’s law has become a self-fulfilling prophecy enabled by the combination of continual technological innovation and ever-present demand for more powerful device applications (Mack, 2011).

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[40] Defined as EU28, which includes the UK. EU and Europe are used interchangeably throughout the text.

The industry's rapidly growing size (it is projected to become a trillion-dollar industry by 2030 [Burkacky et al., 2022]), together with its importance for the digital era, both as a commercial and as a strategic good, have made it the linchpin of global power politics, especially between the rising technological rivalry between China and the U.S. (Yan, 2020). This has become apparent, as was described in the introduction chapter, in the trade war between the two powers, where semiconductor supply chains have become weaponized as tools of economic statecraft.

This chapter next continues by taking the theoretical perspective on economic statecraft in global supply chains, developed in chapter 2. The basics of semiconductor technology and the particulars of the industry contributing to internal diversity are briefly touched upon before describing, first, the semiconductor supply chain itself, and second, the national contexts of the countries most involved in the supply chain.

4.1 The Semiconductor

Semiconductor devices are electronic components that work by utilizing the properties of semiconductor materials such as silicon to conduct electronic current. The basic composite part of a semiconductor device is the metal-oxide-semiconductor field-effect transistor (MOSFET) which can change conductivity depending on the voltage applied to it and can thus be used for the controlled transmission of electric current. Through a process called 'doping,' the MOSFET can be made to have either a positive (p-type) or a negative (n-type) electric charge. By utilizing both p-type and n-type MOSFETs, a complementary metal-oxide-semiconductor (CMOS) can implement switching circuits with exceptionally low power consumption and thus the integration of an extreme density of logic gates onto a small surface.

Unlike many other strategically important resources and goods, semiconductor devices are not significantly fungible and thus cannot be categorized as commodities, i.e., one device cannot necessarily be substituted for another. On the contrary, semiconductors are very diverse in the types of tasks they can perform. This means that the supply chains for semiconductors also exhibit a significant degree of complexity: different types of semiconductors are designed and manufactured by different firms and are consumed in different markets. This subsection will briefly describe the diversity inherent to the industry to adequately tackle this complexity.

The most common type of semiconductor device is the integrated circuit (IC), known also as 'a microchip' or 'a chip'. It is composed of possibly billions of transistors (as well as other devices and the connections between them) set on a flat piece of semiconductor material known as a wafer. It is these types of semiconductor devices that the following discussion primarily focuses on.

The SIA broadly categorizes semiconductor devices into three categories: Logic, Memory, and DAOs (Discrete, Analog, and Other) (Varas et al., 2021, p. 9). Of these, the first two fall under the category of ICs, whereas only some DAOs, such as analog ICs, can be categorized as such.

Logic chips include microprocessors (MPUs) such as central processing units (CPUs), graphics processing units (GPUs), and application processors (APs); general purpose logic products such as field programmable gate arrays (FPGAs); microcontrollers (MCUs); and connectivity products such as cellular modems, Wi-Fi or Bluetooth chips, and Ethernet controllers. Logic chips are found in anything that requires information computing: CPUs are at the core of personal computers (PCs) and smart mobile devices; GPUs are used for applications involving graphical images in everything from video gaming to deep learning and artificial intelligence; general purpose logic chips such as FPGAs are designed so that they can be configured after manufacturing for specific use cases; and MCUs come with processor, memory, and peripherals included and are used in cars, industrial automation, and consumer appliances.

Memory chips are ICs used for storing information. They can be categorized into two types: volatile and non-volatile. Volatile memory is used for short-term information storage with the most commonly used type being Dynamic Random Access Memory (DRAM), which is used in PCs, smart mobile devices, and servers. Non-volatile memory, on the other hand, is used for storing information for the long term. The most common chip of this type is the NAND flash memory used in memory cards and the solid-state drives (SSDs) that are found in PCs and mobile devices.

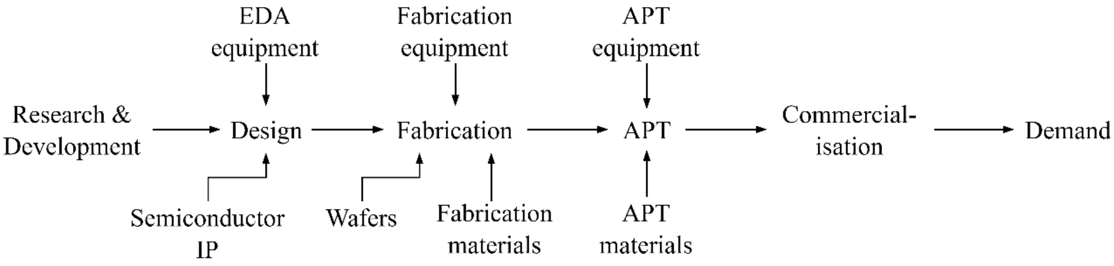
The third category includes *discrete, analog, and other* types of semiconductors. Discrete semiconductors are singular diodes or transistors and can thus have numerous use cases. Analog ICs are designed to transform analog signals into digital signals, and include, for example, the power supply chips used in most electronic devices and the radio frequency chips used in receiving and processing radio signals. Other products include sensors and actuators such as optoelectronics used in cameras.

Another type of diversity in the chip market is the classification of chips into higher and lower-end ICs by technology/process node. ‘A node’[41] or ‘node size’ refers originally to the size of the chip’s transistor gates in nanometres (nm) but has by now been reduced to a naming convention for the consecutive generations of chip architectures and manufacturing technologies. This constant development, following Moore’s law, of more advanced process nodes, also puts pressure to continually invest in new production facilities that can handle the new production process. Currently, 5 to 10 nm chips are considered to be leading-edge, with 3 nm beginning commercial production in 2023. Leading-edge chips, needed for the most advanced applications, are typically either logic or memory chips while lower-end ‘legacy nodes’ are still in use for the majority of chip production: DAOs and less demanding logic and memory applications. (Varas et al., 2021, pp. 17–18)

4.2 The Semiconductor Supply Chain

Even with the above-described complexity, the general structure of the semiconductor supply chain is pretty much identical regardless of the chip type. It involves *R&D, design, fabrication* (i.e., front-end manufacturing), *assembly, packaging and testing* (APT, i.e., back-end manufacturing), *commercialisation,* as well as the *demand* from consumers and various industries. The central design and manufacturing stages also involve several intermediary supply inputs such as equipment and materials. Below, Figure 1 visualises the segments of the chip supply chain, including the most important supplying segments.

Figure 1
The semiconductor supply chain



Note: EDA = electronic design automation, APT = assembly, packaging and testing, IP = intellectual property

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[41] Not to be confused with the concept of network nodes used in this thesis’ theoretical discussion.

One further level of complexity is provided by the categorization of firms into two based on the business model employed by the firm. The first of these business models is the traditional *integrated device manufacturer* (IDM) -model. IDM firms are vertically integrated to cover everything from the design and manufacturing (front- and back-end) to the commercialisation of their chips. This means that their production process is largely done in-house. This enables a high degree of coordination between design and manufacturing, resulting in an efficient technology transfer process, with the cost of lost efficiency in manufacturing specialization (Yeung, 2022, pp. 176–178).

However, as of the 1980s and 90s, the alternative *fabless foundry* model has become dominant. It is so named because it is based around *fabless* firms (firms without their own fabrications plants, or fabs), focused on chip design, coordinating together with ‘*pure-play*’ *foundries,* responsible for front-end manufacturing, as well as *outsourced semiconductor assembly and testing* (OSAT) -companies providing assembly, packaging, and testing services on the back-end. This fragmentation has allowed many new firms to enter the market and provided the industry with efficiency gains from specialization. In practice, many IDMs also employ the service of foundries and OSAT-companies for a portion of their manufacturing needs and sell out their production capacity to other companies (a model often called ‘fab-lite’). (Varas et al., 2021, pp. 24–25)

The following subsections will now discuss all the segments of the supply chain in turn, including all the different intermediate inputs going into the process, from the perspective of the firms involved. A special focus is put on the geography of the supply chain with the nationalities of the firms being of obvious interest. In the cases of firms controlling multiple segments of the chain directly through in-house production, i.e., in the case of IDMs, these firms are discussed together with fabless design firms. Also, because design firms also control the commercialisation of the chip product, this stage is not covered separately.

4.2.1 R&D and Knowledge Capital

The production of a chip starts with pre-competitive research and development (R&D), named so because it takes place before any commercial application and usually consists of basic research into the physical and chemical processes that could result in the improvement of the design and manufacturing of the next generations of chips. The results of this research might not immediately be commercially applicable, so private firms have little incentive in funding it to the extent that could be seen as necessary, instead leaving it to public and non-profit (e.g., universities) sectors. As a whole, 15–20% of the total industry R&D comes from pre-competitive R&D. (Varas et al., 2021, pp. 14–15)

An analysis by Kleinhans et al (2021) looks into the research papers submitted for the three leading academic semiconductor conferences from 1995 to 2020. Of the papers published in 2020, 40,9% come from the U.S., followed by the EU (24.9%), Taiwan (13.4%), South Korea (12.9%), China (10%), and Japan (9.6%). The rest of the world accounts for 7.9% of the papers.[42]

Another public good needed for chip production is knowledge capital, i.e., a professional workforce trained in science, technology, engineering, and mathematics (STEM), which is almost exclusively produced by higher education institutions such as universities, together with the learning-by-doing from actual working experience. Knowledge capital functions as an important input for basically all segments of the supply chain, with the exception of back-end manufacturing, but the skills needed can vary based on the segment. Based on a forecast of tertiary STEM education for the five leading semiconductor economies by Aurik et al. (2021), China comes out on top with a massive talent pool of 2.97 million annual graduates, followed by the EU (1.06M), the U.S. (804K), South Korea (188K), and Taiwan (125K). Even with this, all of the above are facing significant challenges in meeting the increasing need for skilled labour in the industry: China has a massive deficit of 300 thousand workers, and similar shortfalls apply to the U.S. (70–90K), Japan (35K), Taiwan and South Korea (both at 30K); only the EU has managed to avoid acute skill shortages (Shivakumar et al., 2022).

4.2.2 Design

The second chain segment covers the *design* of the chip. Design involves the research and engineering that goes into planning the layout and interconnections of electronic components on the chip and thus determines what type of chip is produced and what its capabilities and uses are. Firms working in this segment are usually in charge of not only the actual design but the commercialization of the chip as well, meaning that they interact both with foundry firms responsible for fabrication (in the case of fabless design firms) as well as the customers buying the chip. This means that design firms are often more public-facing and have their name on the box, so to say.

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[42] Due to a measuring quirk (some countries are measured twice due to international collaboration) the sum of the percentages equals over 100%.

Because chip design, especially at the high end, is such a large and complex undertaking, design firms depend heavily on long-term customer and manufacturer relations for their business (Yeung, 2022, pp. 196–217). Fabless design firms may have multiple foundry partners, but each relationship depends on the use of compatible production processes, which can vary greatly among foundries (Alam et al., 2022, p. 77). Switching out processes to change foundry partners thus requires a lot of testing and prototyping from the design firm, which brings up switching costs (ibid.).

Of all the chain segments, design is the most R&D intensive, with 53% of all industry R&D coming from the segment (Varas et al., 2021, p. 15). This typically accounts for 12% to 20% of a firm's annual revenue (for fabless firms) (ibid.). The costs of developing a new high-end design can thus well exceed $1 billion, and for derivatives recycling prior designs in mature nodes the price comes down to $20–$200 million; as a whole, the segment accounts for 13% of all industry Capex (ibid.). This investment is usually worth it to private investors (Yeung, 2022, p. 257), largely because chip design accounts for the largest revenue share in the chain (Alam et al., 2022, p. 18), as well as 50%[43] of the total value added (Varas et al., 2021, p. 15). This type of private competitive R&D is in contrast to the pre-competitive research described previously and aims primarily towards the development of new (protected) IP, thus increasing a firm's competitiveness through newer and better products. Aside from attracting customers, being an innovator can also put the design firm in a better position in relation to its manufacturer partners (Alam, 2022, p. 77).

Design Firms. IDMs control the majority of the design segment with 65.2% (2021) of the market (IC Insights, 2022g). Five of the ten largest semiconductor design firms are also IDMs, with Samsung (South Korea [SK]) and Intel (US) controlling 13.3% and 12.5% of the market, respectively, and with SK Hynix (SK, 6.1%), Micron Technology (US, 4.9%), and Texas Instruments (US, 2.8%) also making it into the top ten (IC Insights, 2022b). The most notable fabless firms are the American Qualcomm (4.8%), Nvidia (3.8%), Broadcom (3.4%), and AMD (2.7%), as well as the Taiwanese MediaTek (2.9%) (ibid.). Notable firms outside the top ten are, e.g., Kioxia and Renesas Electronics (JP), STMicroelectronics, Infineon Technologies and NXP Semiconductors (EU), and HiSilicon (China [CH]). The U.S. PC and mobile device maker Apple also has a presence

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[43] Another estimate, attempting to compensate for the fact that IDMs do not separately report their revenues per chain segment, puts the value added for the design segment (2021) at a more modest 30% (Aurik, 2021, p. 19).

in the IC design space with its own chips. As is evident, U.S. firms control a majority (54%; 2021), of the design market, followed by South Korea (22%), Taiwan (9%), Europe (6%), Japan (6%), and China (4%) (IC Insights, 2022a).

A more accurate picture is drawn, by taking into account market complexity in terms of different chip types. In logic chips, the U.S. is often the only game in town: according to SIA, 67% of value added in the logic chips value chain (2019) goes to the U.S., followed by Europe (8%), Taiwan (7%), China (5%), Japan (5%), and South Korea (3%) (Varas et al, 2021, p. 31). In CPUs and APs (2021), Intel controls 50.9% the market; Apple (13.0%), Qualcomm (9.1%), AMD (8.9%), and MediaTek (4.0%) also fit into the top five, while the rest of the top ten (Nvidia, Samsung, UNISOC [CH], HiSilicon, and NXP) collectively only accounted for 4,3% (IC Insights, 2022f). Specifically in CPUs for PCs (2020) Intel (78%) and AMD (22%) hold a complete duopoly (White House, 2021, p. 29). This is explained by the fact that these firms are the only ones that control the licence for the dominant x86 processor architecture required to manufacture leading-edge chips (Kleinhans & Baisakova, 2020, p. 10). In CPUs for mobile devices (2020), the market is more competitive, with Qualcomm (29%) and MediaTek (26%) in the lead and with HiSilicon (16%), Samsung (13%), and Apple (13%) all holding a significant market share (White House, 2021, p. 29). In GPUs (2020) Nvidia (82%) and AMD (18%) likewise have a duopoly (ibid.). In FPGAs (2020) the AMD subsidiary Xilinx controls the majority (52%) of the market, with Intel (36%), Microchip (US, 7%), and Lattice (US, 5%) being the main competition (ibid.). In MCUs (2021) the market is more competitive and less U.S.-centric, with the European NXP (18.8%), STMicroelectronics (16.7%), and Infineon (11.8%), as well as the Japanese Renesas (17.0%) all evenly splitting the market with the American firm Microchip (17.8%) (IC Insights, 2022e).

The story in the memory chip chain looks very different, with 59% of the value added coming from South Korean firms, and only 29% from the U.S., with Japan and Taiwan accounting for 8% and 4% respectively (Varas et al, 2021, p. 31). The DRAM market (2021) is largely controlled by Samsung (43.6%) with the competition coming from SK Hynix (27.7%) and Micron (22.8%) (IC Insights, 2022c). Samsung is also the leading player in the NAND market (2020) with a 33% share of the market, with Kioxia (20%), Western Digital (US, 14%), SK Hynix (12%), Micron (11%) and Intel (9%) forming a respectable competition (White House, 2021, p. 28).

The market for DAOs is more fragmented with 37% of the value added going to U.S. firms, followed by Japan (24%), Europe (19%), China (7%), South Korea (6%), and

Taiwan (3%) (Varas et al, 2021, p. 31). Specifically in analog ICs (2021), the market is more U.S.-dominated. Firms such as Texas Instruments (19.0%), Analog Devices (12.7%), Skyworks Solutions (8.0%), Qorvo (5.2%), ON Semi (2.9%), and Microchip (2.5%) collectively have a significant market share; EU firms such as Infineon Technologies (6.5%), STMicroelectronics (5.3%), and NXP (4.7%) are also major players; the Japanese Renesas (1.5%) also having presence in the market (IC Insights, 2022d).

Design Stage Input Suppliers. The semiconductor design stage is not dependent only on fabs (which will be discussed in the next subsection) but also on intermediate inputs. The most important inputs are electronic design automation (EDA) tools and semiconductor intellectual property (IP cores). Even though the suppliers of these inputs gain only 4% of the total value added in the chain (Varas et al., 2021, p. 19), the existence of independent EDA and IP firms allows for information codification between the design and fabrication stages that has enabled the fabless-foundry -model to function since the 1980s (Yeung, 2022, p. 56). Given the nature of these firms, their Capex, relative to their annual revenue, is marginal (<1%) (Varas et al., 2021, p. 19)

EDA tools are the automated design software used by semiconductor designers to plan and produce the increasingly complex chip designs needed today. Aside from dealing with design firms, EDA firms also closely coordinate with both fabs and manufacturing equipment providers to develop and improve upon new process nodes (Kleinhans & Baisakova, 2020, p. 13). Fabs also depend on EDA tools to coordinate chip production with design firms (Alam et al., 2022, p. 20). To stay competitive, EDA firms are thus required to spend massively, as much as 35% of their revenue, on R&D, as well as on the acquisitions of new IP (ibid.; Kleinhans & Baisakova, 2020, p. 13).

These dynamics have also resulted in the EDA market becoming very concentrated, with only three companies, Cadence Design Systems, Synopsys, and Siemens EDA, dominating the market (Kleinhans & Baisakova, 2020, p. 13). All three are based in the U.S.[44] and thus, as much as 95% (2019) of the EDA segment's value added goes to U.S. companies, distantly followed by Japan (3%) (Aurik et al., 2021, p. 19).

IP suppliers, on the other hand, supply chip designers with ready-made IP cores, i.e., the rights to design architectures and specific elements that designers can then modularly integrate into their chips (Alam et al., 2022, p. 19). This saves chip designers

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[44] Siemens EDA, formed after the acquisition of Mentor Graphics by Siemens, is a subsidiary of the European conglomerate Siemens, but due to the criteria of categorization chosen here (location of headquarters) it is seen as an American company.

millions in the R&D costs required to develop designs from scratch, instead allocating this work to IP firms who spend upwards of 40% of their revenue on R&D (ibid., p. 18). Like EDA firms, IP suppliers also coordinate intensively with both designers and fabs to ensure compatibility of design and fabrication nodes (Kleinhans & Baisakova, 2020, p. 14).

The semiconductor IP market is divided (2019) between the U.S. (52%) and Europe (43%) (Aurik et al., 2021, p. 19). Still, it is largely dominated (2021) by one actor, the British firm Arm (40.4%), followed by Synopsys (19.8%), Cadence (5,8%), Imagination Technologies (EU, 3.3%), Silicon Storage Technology (US, 2.5%), and Ceva (US, 2.3%) (Esteve, 2022). China has a minor presence in the market with Verisilicon (1.8%) and Taiwan with eMemory Technology (1.6%) (ibid.). Arm's dominance of the market is largely explained by its control of the ARM processor architecture, which is the only game in town for most chip designers, given that Intel and AMD do not license their x86 architecture out to competitors (Kleinhans & Baisakova, 2020, p. 10).

4.2.3 Semiconductor Fabrication

After the design stage, a fabrication facility (fab) sets out to produce the chips by printing the designs on a sheet of semiconductor material, called a wafer. The fabrication process involves multiple stages and is extremely complex, requiring the utmost precision provided by highly specialized manufacturing equipment, as well as highly controlled environments, and a very capable workforce. This stage is handled either by an in-house IDM facility or an independent pure-play firm. Fabrication is, after design, the most value-adding segment in the chain, providing 24%[45] of total value added (Varas, 2021, p. 13).

The intricate production process makes semiconductor fabrication extremely expensive. Starting a new node or expanding production can require an entirely new fab, which can cost anywhere from $5B (for mature analog fabs) to $20B (for high-end fabs working in the most advanced nodes) (Varas, 2021, p. 18). This comes with high capital intensity: foundry firms typically use around 37% of their revenue on capital expenditure (Alam et al., 2022, p. 18), accounting for 64% of the total industry Capex (Varas, 2021, p. 16). Supplier switching costs, regulatory compliance, and recruitment can also add up to over 2 years of lag time when opening a new fab (Alam et al., p. 76). The fabrication

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[45] Like with design, this estimate may be distorted by the presence of IDMs. Another estimate, taking this into account, puts the value added share for fabrication at 34% (Aurik, 2021, p. 19).

segment of the chain also commits a lot of resources to R&D, typically around 10% of their revenue, totalling 13% of total R&D spending in the chain (ibid., p. 13).

The fact that foundries need to maintain tight relationships with chip designers is largely based on this complexity and cost, making switching partners (for both pure-play and design firms) arduous (Yeung, 2022, p. 201). Bargaining space with powerful designers is achieved with innovation (Alam et al., 2022, p. 77) and the capability to provide exclusive treatment (Yeung, 2022, p. 205). IDMs on the other hand manage this complexity with their vertically integrated structure. They balance this control with efficiency by also outsourcing some of their orders to third parties (Varas, 2021, p. 24).

Foundry Firms. As a result of the high entry barriers and the difficult competitive environment, generated by the above features of semiconductor fabrication, the central dynamic of the front-end manufacturing segment is significant centralization. Measured by revenue (2021), the market is dominated by one firm, the Taiwanese giant TSMC with its 55% market share (Yeung, 2022, p. 54–55). Its nearest competitor is Samsung (17%), distantly followed by UMC (TW, 7%), GlobalFoundries (US, 6.7%), SMIC (CH, 4%), Powerchip (TW, 1.1%), TowerJazz (Israel, 1.1%), Vanguard (TW, 1.1%), HHGrace (CH, 1.1%), and Dongbu (SK, 1.1%) (ibid.). All of these companies, except for Samsung, are pure-play foundry firms. Thus, as a whole, Taiwanese companies control as much as 64.2% of the fabrication market, followed by South Korea (18.1%), the U.S. (6.7%), and China (5.1%).

Alternatively, measuring the segment by fabrication capacity (2021), the lead is instead taken by Samsung (19%), with TSMC (13%) falling second, followed by Micron (US, 10%), SK Hynix (SK, 9%), and Kioxia (JP, 6%) (Knometa, 2022b). All of these firms, except for TSMC, are IDMs. In the previous year (2020), these firms were followed by Intel (4.2%), UMC (3.7%), as well as GlobalFoundries, Texas Instruments (US), SMIC, and Power Chip (IC Insights, 2021a). Geographically, fabrication capacity (2021) is divided between South Korea (23%), Taiwan (21%), China (16%), Japan (15%), the Americas (11%), and Europe (5%) (Knometa, 2022a).

The stark difference between these two measurements, the concentration of market share by revenue and the more even distribution of global fabrication capacity can be explained by the high yield provided by leading-edge manufacturing when compared to legacy nodes. In 2019, 92% of the global wafer capacity for sub-10 nm logic chips was located in Taiwan and the rest (8%) was in South Korea (Varas, 2021, p. 35). In the 10–22 nm range, the U.S. was dominant with 43%, followed by Taiwan (28%), Europe

(12%), South Korea (5%), and China (3%); in the 28–45 nm range, Taiwan led with 47%, followed by China (19%), South Korea (6%), the U.S. (6%), Japan (5%), and Europe (4%); in over 45 nm chips Taiwan had the most capacity (31%), followed by China (23%), Japan (13%), South Korea (10%), the U.S. (9%), and Europe (6%) (ibid.). For memory chips South Korea led with 44%, followed by Japan (20%), China (14%), Taiwan (11%), the U.S. (5%), and Europe (2%) (ibid.). For DAOs, Japanese legacy firms were in the lead with 27% of the market, followed by Europe (22%), the U.S. (19%), China (17%), South Korea (5%), and Taiwan (3%) (ibid.).

As of 2022, the highest end of semiconductor fabrication is the 3 nm process, with only TSMC and Samsung being capable of producing chips at this level (IC Insights, 2021b). As the closest competitor, Intel is at what it calls the Intel 4 node (basically comparable to TSMC's and Samsung's 5 nm) (ibid.; Cutress, 2021). The Chinese SMIC was also surprisingly found to be able to produce 7 nm node equivalent chips already in 2021 (Alcorn, 2022). The market share of Intel, and especially of SMIC, is still very difficult to estimate. Other companies, including every European and Japanese firm, are all producing chips only at 10 nm or higher (Aurik et al., 2021, p. 20).

Front-End Suppliers. Firms engaged in semiconductor fabrication require multiple inputs: fab materials such as photomasks, photoresists, and chemicals, as well as the silicon wafers themselves. These firms account for around 5% of the total value added, 6% of Capex, and just 1% of R&D spending in the chain (Varas et al., 2021, p. 21).

Taken as a whole, fab materials are produced by Japanese (32%), Taiwanese (20%), American (19%), South Korean (18%), and European (5%) firms (Aurik et al., 2021, p. 19), but by considering the diversity among materials, geographic concentrations become more apparent. Photomasks are produced mostly (65% of the market) by captive mask shops controlled by chipmakers such as Intel (US), Samsung (SK), TSMC (TW), GlobalFoundries (US), and SMIC (CH); as well as by independent, mostly Japanese (53%; e.g., Dai Nippon, Toppan, Hoya) and American firms (40%; e.g., Photronics), as well as some Taiwanese (4%; e.g., Taiwan Mask Corporation) ones (Khan et al., 2021, p. 58). The market for photoresists is controlled by Japan (e.g., JSR, Tokyo Ohka Kogyo, Shin-Etsu Chemical) with 90% of the market, together with some U.S. (e.g., Dupont) and South Korean (e.g., Dongjin) firms (ibid., p. 59). The numerous chemicals and other materials used in the fabrication process are produced by companies in Japan (e.g., JX Nippon, Tosoh, Praxair), the U.S. (e.g., Dupont, Cabot, KMG, Honeywell), Europe (e.g., Merck, Air Liquide, BASF), and China (e.g., Anji, KFMI, Jiangsu Nata Opto-Electronic

Material) (ibid., pp. 59–60). Wafer production is even more concentrated in Japan (56% of the market), which is then followed by Taiwan (16%), Europe (14%), South Korea (10%), and China (4%) (Aurik et al., 2021, p. 19). In the case of the most used 300mm silicon wafer specifically (2021), the Japanese firms Shin-Etsu Chemical (29.8%) and SUMCO (24.8%) control most of the market, followed by SK Siltron (SK, 18.1%), Siltronic AG (EU, 14.1%), and GlobalWafers (TW, 11.6%) (Jung & Lee, 2022).

In addition to materials, semiconductor manufacturers are dependent on external equipment manufacturers for over 50 types of highly specialized semiconductor manufacturing equipment. Developing this high-precision equipment requires significant R&D investments, as much as 10–15% of annual firm revenues (Varas et. al, 2021, pp. 19–20). These firms also account for 3% of the total Capex and 11% of the total value added in the supply chain (ibid.).

The production of fab equipment is largely done (2019) by U.S. (44% of market share), Japanese (29%), and European (23%) firms (Aurik et al., 2021, p. 19). Wafer manufacturing, marking, and handling equipment are mostly done by Japanese firms (75,3%; e.g., Daifuku, Rorze, Accretech), but their production is of low complexity and thus has low entry barriers (Khan et al., 2021, pp. 26–28). Ion implanters are produced largely by U.S. firms (90.4%; e.g., Applied Materials, Axcelis), as are process control equipment (71.2%; e.g., KLA, Applied Materials), chemical mechanical planarization equipment (67.5%; e.g., Applied Materials), and deposition equipment (63.8%; e.g., Applied Materials, Lam Research) (ibid., pp. 25–45); in all these cases the runner up competitors are Japanese firms (ibid., p. 26.). Etch and clean equipment is produced both by American (53.1%; e.g., Lam Research, Applied Materials) and Japanese (41.6%; e.g., Hitachi, Tokyo Electron, Screen) firms (ibid., pp. 26, 39–40).

Lithography equipment marks an important exception to the dominance of American and Japanese firms in the provision of semiconductor production equipment. EU firms (e.g., ASML, SUSS MicroTec) account for ~70% of the lithography equipment market share, followed by Japan (28,3%; e.g., Nikon, Cannon, Tokyo Electron) (Khan et al., 2021, pp. 30–35). Importantly, the Dutch firm ASML holds a complete monopoly (100%) on the production of extreme ultraviolet lithography equipment, which is needed for producing the highest-end (5nm or above) chips (Khan et al., 2021, p. 30). This monopoly came as a result of a decades-long R&D endeavour in cooperation with partners such as Intel, TSMC, and Samsung (Varas et al., 2021, p. 29), a success story which is unlikely to be replicated by competitors anytime soon (Lapedus, 2020). Even with this dominance, ASML itself is still very much dependent on the overall equipment ecosystem and on its main partner company TSMC (Alam et al., 2022, p. 31), as well as its large chain of suppliers (Varas et al., 2021, pp. 29–30).

The above market shares include only the sale of equipment. An important part of an equipment manufacturer's business model is also to sell accompanying services such as training and maintenance, the market for which is estimated to be larger than that of any individual equipment category ($15.3 billion) (Khan et al., 2021, p. 25).

4.2.4 Assembly, Packaging and Testing (APT)

After the designs have been printed on the silicon wafers at the fabrication stage, the chips have to be assembled into finished products. This involves cutting the wafers into individual chips, packaging them into cases, and lastly testing them for manufacturing and design errors. The assembly, packaging, and testing (APT, often also abbreviated as 'ATP') stage accounts for 6% of the total value added in the chain (Aurik et al., 2021, p. 19). While it still requires major investments into facilities and equipment, amounting to 15% of a firm's annual revenue in Capex (Varas et al., 2021, p. 19), APT is comparatively labour-intensive, which also translates into lower profit margins (Kleinhans & Baisanova, 2020, p. 19). This means it also requires less R&D, which amounts only to ~5% of a firm's annual revenue (Alam et al., 2022, p. 18).

APT is done by both IDMs, who partially do their own APT in-house, and independent outsourced semiconductor assembly & test (OSAT) companies (ibid.). Even though outsourcing enables supplier switching for IDMs and fabs, these relations also have some general switching costs associated with long-term relationship building (Yeung 2021, p. 202).

As of 2019 47% of all APT was done by IDMs and pure-play firms, largely from the U.S. (43% of total in-house APT; e.g., Intel, Micron), followed by South Korea (23%; e.g., Samsung, SK Hynix), Japan (13%), Europe (10%), and China (6%); even with TSMC, Taiwanese IDMs' in-house APT accounted for only 4% of total in-house APT (Khan et al., 2021, p. 24). Additionally, it is good to note that the industry trend appears to be in the direction of consolidating more and more APT into in-house facilities within fabs (Kleinhans & Baisanova, 2020, p. 20).

The market share of OSAT firms, on the other hand, is mostly controlled by Taiwanese (52%; e.g., ASE, Powertech), Chinese (21%; e.g., JCET, TongFu, Tianshui), and American (15%; e.g., Amkor) firms, and followed by some Malaysian (4%), Singaporean

(3%), South Korean (3%) and Japanese (2%) competitors (ibid.). Even though the market has been steadily consolidating (Kleinhans & Baisanova, 2020, p. 20), the presence of companies from Southeast Asia, and the significant Chinese foothold, shows the APT segment to be easier to enter for firms not located in traditionally semiconductor-strong countries. This has much to do with labour costs, which has resulted in OSAT firms from elsewhere also starting to build capacity in these countries (Varas 2021, p. 35).

APT Suppliers. Both in-house APT shops and OSAT firms are reliant on specialized APT equipment as well as materials such as specific chemicals to fulfil their function in the supply chain. APT equipment accounts for just 2% of the total value added to the supply chain (Aurik et al., 2021, p. 19). Likewise, compared to front-end equipment markets (worth $53 billion), the market for back-end equipment is far smaller ($8.5 billion) (Khan et al. 2021, pp. 25). $5.5 billion of this comes from assembly and packaging equipment such as bonding, dicing, packaging, and assembly inspection equipment (ibid.). The firms making this equipment come from a diverse set of countries, including those outside the usual suspects: Japan (35.7%; e.g., DISCO, TOWA), China (22.9%; e.g., ASM Pacific), Singapore (~13%; e.g., Kulicke & Soffa), Europe (~14%; e.g., Besi), South Korea (~8%; e.g., HANMI), and the U.S. (4.9%; e.g., KLA) (ibid, pp. 45–48). The rest of the APT equipment market is in testing tools, such as specific testing tools for different chip types, as well as burn-in testing tools and handlers and probers. The companies in this space are largely Japanese (48.6%; e.g., Advantest, Accretech) and American (33.5%; e.g., Teradyne, Cohu) (ibid.).

In 2019, the market for back-end material inputs for packaging the chip was worth around $19 billion (Varas 2021, p. 21), accounting for 4% of value added in the chain (Aurik et al., 2021, p. 19). These materials include lead frames, bonding wires, ceramic packages, plastic substrates, encapsulation resins and die-attach materials (Khan et al. 2021, p. 61). Firms producing these inputs are largely from Japan (28%; e.g., Ibiden, SH Material) and China (20%; e.g., ASM Pacific, Doublink), followed by South Korea (10%; e.g., Samsung) and Taiwan (5%; e.g., NanYa). Firms from the rest of the world, however, hold the biggest portion of the market (35%) in this segment, which is far more than in any other segment in the chain (ibid.).

4.2.5 Demand

Semiconductor firms are key suppliers for brand-name companies that produce a wide range of products that rely on semiconductor devices for them to work. While the average consumer might not be familiar with major semiconductor brands such as Intel, AMD, Nvidia, etc., they are sure to know the products of these brand-name companies, such as HP, Lenovo, and Dell for PCs; Samsung, Huawei, and Apple for smartphones; Samsung, LG, and TCL for TVs; or Volkswagen, Toyota, and Ford for cars.

These large buyers often form deep and lasting relationships with their chip suppliers, making supplier switching more difficult. These relationships enable deeper coordination between the parties (e.g., better product customization to customer specifications, dedicated features, roadmap alignment, specific production facilities for efficiency/security) and more capacity for risk sharing, which ends up benefiting both parties as opposed to a pure market solution. (Yeung 2022, pp. 173–220)

This need for deep cooperation between chip design by semiconductor design companies and application design by brand-name companies has also resulted in an alternative supply chain configuration, namely brand-name companies designing their own chips using an existing architecture (i.e., ARM), and dealing directly with fabs. Examples of this have been Samsung, with its significant and successful in-house sourcing of both designs and manufacturing capacity; Huawei, with its subsidiary chip designer HiSilicon; and Apple with its in-house designed A-series (as of 2010) and M-series chips (as of 2020) produced by TSMC (Ibid., pp. 181, 188).

According to SIA (2022b, pp. 18-19), the majority of global semiconductor demand in 2021 came from computers (31.5%) and communications (30.7%)[46], followed by the automotive industry (12.4%), consumer electronics (12.3%), industrial applications (12%), and government (1%). Looking at forecasts, it is expected that the demand for semiconductors from the automotive and general industrial sectors will continue to grow in the future (Alam et al, 2022, p. 55), most likely due to the increasing adoption of automation, internet of things applications, and various other ‘smart’ features.

Geographically the origin of semiconductor demand can be sourced in multiple ways. By looking at the headquarters of the companies purchasing semiconductor devices, the U.S. (33%) and China (26%) are clear demand leaders, followed by South Korea (11%), Japan (10%), Europe (10%), and Taiwan (9%). Alternatively, by looking at where the manufacturing facilities for these companies are located, China (35%) comes ahead, followed by the U.S. (19%), Taiwan (15%), South Korea (12%), Europe (10%),

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[46] These numbers, when compared to previous reports (Varas et al. 2021, p. 10), most likely also include the demand from ICT infrastructure, e.g., data centres and communications networks.

and Japan (9%). Lastly, looking at semiconductor demand based on the location of end users of the manufactured devices, the U.S. (25%), China (24%), and Europe (20%) all clearly emerge as the main hubs for demand, with other semiconductor manufacturing countries having much less of a footprint: Japan at 6%, South Korea at 2%, and Taiwan at only 1%. Additionally, the rest of the world accounts for a total of 22% of consumer demand. (Varas et al. 2021, p. 11)

5 Results & Discussion

In the introduction, two questions were posed: *How does economic statecraft within the supply chain for semiconductors work?* and *What is the structure of power in the global supply chain for semiconductors?* The theoretical perspective developed in section 2 argues that answering the former question is possible only by first answering the latter: the distribution of power resources, in the form of asymmetrical interdependencies, structures (i.e., constrains and enables) the use of economic statecraft in the context of networks like global supply chains. This section will now show that there indeed are significant interdependencies in the semiconductor supply chain that constitute an uneven power structure and that these interdependencies, functioning as a power resource, enable states to use tools of economic statecraft against each other.

The second part of the chapter will return to the case of the U.S.–China trade war. Actual instances of economic statecraft and strategic economic policy by China and the U.S. related to the chain are here used as examples of how the potential for power use has been actualized in recent years.

5.1 Structure of Power in the Chain

Mapping the distribution of interdependence-based power resources in the supply chain for semiconductors (i.e., its power structure) requires recalling the factors constituting power and interdependence that were discussed in section 2: the gains to self (COa), the gains to partner (COb), the outside options of the self (FOa), and the outside options of the partner (FOb); as well as switching costs and investment costs. Their effects will now be discussed in turn.

Outside options can be alternatively described in terms of network centrality. The leading nodes (firm-nationality pairs) on some Segment A can be said to exhibit betweenness centrality to the extent that Segment A is concentrated, meaning that the outside options for the nodes on an adjacent Segment B are limited. Betweenness centrality is not enough for the leading nodes on Segment A to be considered powerful, however. For this to be true these nodes also need to exhibit connectedness centrality and have outside options themselves. For this to be true, Segment B needs to either have a low level of concentration, or else the looked-at power relation must be between a leading node on Segment A and a 'marginalised' node (i.e., a node not categorized as 'leading' on a concentrated segment) on Segment B.

Table 2
National Herfindahl–Hirschman indexes (HHI) per semiconductor supply chain stage

Segment	**HHI**	**Leading node**	Segment	**HHI**	**Leading node**
R&D	0.198	US & EU	**Fab materials**	0.213	JP, TW, US & SK
Design - total	0.357	US	Photomasks	0.446	JP & US
Logic – total	0.466	US	Photoresists	0.815	JP
Logic – CPUs & APs	0.688	US	Chemicals	NA	US, EU, JP & CH
Logic – PC CPUs	1.000	US	**Wafers**	0.370	JP
Logic – Mobile CPUs	0.287	US & TW	300mm wafers	0.364	JP
Logic – GPUs	1.000	US	**Fab equipment**	0.331	US, JP & EU
Logic – FPGAs	1.000	US	Wafer equipment	0.588	JP
Logic – MCUs	0.285	EU	Ion implanters	0.824	US
Memory - total	0.440	SK & US	Process control equipment	0.535	US
Memory – DRAM	0.560	SK	CMP equipment	0.547	US
Memory – NAND	0.358	SK & US	Deposition equipment	0.459	US
DAOs – total	0.240	US & JP	Etch and clean equipment	0.456	US & JP
DAOs – Analog ICs	0.280	US & other(s)	Lithography equipment	0.570	EU
EDA	0.903	US	EUV lithography equipment	1.000	EU
IP	0.456	US & EU	**APT** – in-house	0.270	US & SK
Fabrication – total	0.452	TW	OSAT	0.338	TW
by capacity - total	0.160	SK, TW, CH & JP	**APT materials**	0.131	other(s), JP & CH
Logic (< 10 nm)	0.853	TW	**APT equipment** – A&P	0.207	JP & CH
Logic (10-22 nm)	0.281	US& TW	Testing tools	0.359	JP & US
Logic (28-45 nm)	0.268	TW	**Demand**		
Logic (> 45 nm)	0.188	TW & CH	by headquarters location	0.217	US & CH
Memory	0.268	SK	by manufacturing location	0.214	CH & US
DAOs	0.190	JP, EU, US & CH	by end user location	0.164	US, CH, EU, others

Note: Countries in the 'leading node' column are listed in descending order based on market share; countries with ½ or more of the leading node's market share are included. US= United States, EU = Europe, JP = Japan, SK = South Korea, TW = Taiwan, CH = China; R&D = (pre-competitive) research and development; EDA = electronic design automation; IP = intellectual property; CMP = chemical mechanical planarization; APT = assembly, packaging, and testing; A&P = assembly and packaging; OSAT = outsourced semiconductor assembly and testing. Data from: Alam et al. (2022), Aurik et al. (2021), ICinsights, Jung and Lee (2022), Khan et al. (2021), Kleinhans and Baisanova (2020), Kleinhans et al. (2021), Knometa, SIA, Varas et al. (2021), and Yeung (2022), White House (2021).

When the data from the previous section is analysed using the Herfindahl–Hirschman index (HHI), it points clearly to significant levels of market concentration and thus centralities within multiple segments of the chain. The data on supply chain market shares discussed in the previous section, together with segment concentrations calculated using the HHI, are collected in Appendix 1. The HHI scores are also shown in Table 2. The HHI score shows how concentrated the segment is toward one or more firm-nationality pairs. The 'Leading node' -column shows the firm-nationality pair the segment is concentrated toward.

From Table 2, it can be seen that the level of concentration varies greatly based on the supply chain segment. Most segments have a fairly high HHI score (above 0.250) indicating some level of concentration. This reflects the fact that the semiconductor industry is concentrated in just a few countries[47]. Lowest concentrations are found in pre-competitive R&D[48], design of non-IC DAOs, manufacture of oldest legacy node logic chips and DAOs, chemicals used by fabs[49], APT materials and equipment, as well as in demand based on all counts. This indicates that these activities are fairly spread out between countries.

Very high concentrations (HHI over 0.400) in the U.S. can be observed in the design of various types of logic chips (mainly PC CPUs, GPUs, and FPGAs) and most types of fab equipment, and in EDA equipment. Similar concentrations in Europe are found only in lithography equipment. Segments similarly concentrated in Japan are found in fab materials, especially photoresists, and in wafer equipment. The manufacture of high-end chips is a clearly Taiwanese-dominated segment. Concentration into South Korea is found in the design of memory chips, especially DRAM. None of the chain segments is clearly concentrated in China. The segments that are highly concentrated (HHI over 0.300; indicating a duopoly) into just two countries are the design of NAND memory (South Korea and the U.S.), semiconductor IP (the U.S. and Europe), photomasks (Japan and the U.S.), etch and clean equipment (the U.S. and Japan), and testing tools (Japan and the U.S.).

By looking at the HHI scores of adjacent chain segments, power relations based on centrality (i.e., outside options only) can be uncovered. These relations can vary on two dimensions: the level of power balance and the level of relationship cohesion

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[47] The European Union is counted as equal to one 'country,' and it includes the UK.

[48] Pre-competitive R&D only accounts for 15–20% of the total industry R&D, however. A majority (53%) comes from the design segment, which is heavily U.S.-dominated.

[49] Even without direct data, this can be inferred from how concentrated other fab material segments are.

(indicating a durable bond) between the two nodes. A table of all possible chain segment connections and the relationships of their leading nodes can be found in Appendix 4.

As a whole, the design segment can be seen as the most important in terms of the capability for generating interdependence-based power, because it is itself the most connected to other segments (see Figure 1). Most importantly, it is connected to the semiconductor fabrication segment and, due to the design firms also dealing in product commercialisation, to the buyers of semiconductor devices. On top of this, it is connected to its EDA equipment and semiconductor IP suppliers. This centrality gives the leading nodes, the U.S. and South Korea, a significant power position over others in these adjacent segments.

Relative to the actors making up semiconductor demand, the U.S. holds significant leverage over the trade in PC CPUs, GPUs, and FPGAs. Similarly, South Korea can leverage its leading position in the DRAM memory market. Together these countries also have significant sway in the NAND memory market. This puts many types of downstream industries in a vulnerable position. Much of the demand for chips comes from the six markets discussed here, but China especially falls at the losing end of the power imbalance, hosting much of the world's demand for semiconductors (on all three metrics), but not enough for it to become an impossibility for semiconductor designing countries to stop supplying chips there. The U.S. is similarly reliant on South Korea, for its supply of DRAM.

The U.S. and South Korean chokeholds on chip design also carry over to the relationship between design firms and fabs. Here, however, the complexity of the chain, and its division into the IDM and fabless-foundry verticals is important, because IDM fabs are typically located domestically. Still, South Korea is in a powerful position over DRAM memory fabs located in Japan and China. The U.S. also has significant leverage over logic chip fabs located in Europe, Japan, Taiwan, and China. However, Taiwan, the largest overall manufacturer of chips, is largely able to balance the power of U.S. designers (or any designers for that matter) at the high end, thanks to the dominant position of TSMC as the market leader in leading-edge chips. Only the U.S. can achieve parity with this centrality, making the relationship between the Taiwanese and American industries highly cohesive.

When it comes to its suppliers, the dominance of design segment nodes is less of a reality. The U.S. has a practical monopoly on EDA equipment, making that avenue for possible vulnerability null for the country's leading chip design industry. For others engaging in semiconductor design, however, this centrality is still a vulnerability. Only the South Korean DRAM design firms Samsung and SK Hynix might have enough sway to balance out the power relation. In semiconductor IP, both the U.S. and the EU show up as leading nodes. However, this should be corrected with the fact that the American x86 chip infrastructure, which makes up a large part of the U.S. share of the pie in the market, is not licenced out by its owners, Intel and AMD. This makes the British Arm infrastructure largely the only game in town for all other chip designers, leaving even the otherwise powerful U.S. firms very reliant on it.

The fabrication segment is likewise central, having connections with the design and APT segments, along with its material, wafer, and equipment suppliers. This centrality, however, is very unevenly distributed among the different chip types' supply chain verticals. The fabrication markets for memory chips, DAOs, and mature logic chips are in fact very geographically diverse, with multiple countries hosting fabrication capacity. Where the concentration truly lies is at the high end, in the fabrication of leading-edge chips, which is extremely concentrated in Taiwan and TSMC especially.

This means that while the fabrication segment may function as a vulnerability to external influence, for Taiwan it can work as a source of interdependence-based power. This was already noted in the relationship between TSMC and leading chip designers, but it also works in the direction of the APT segment, where the otherwise balanced relationship is turned into an imbalanced one in favour of Taiwan. This imbalance is made even higher, given the fact that Taiwan holds also much of the OSAT market. At the losing end of this are especially U.S. and Chinese-based OSAT firms.

This variance in power based on chip type applies to the fabrication segment's relations with its suppliers as well. The supply of fab materials is largely controlled by the U.S. and Japan, with the Japanese dominance in photoresists being an especially vulnerable relationship for all semiconductor manufacturing countries. This, again, comes with the exception of TSMC, for whom the relationship is highly cohesive. Together, Japan and the U.S. are also in firm control of the photomask market which makes it a source of possible influence against the most mature node fabs. In addition, while the chemicals supply segment is highly diversified geographically, it is worth noting that the major chip manufacturing hubs of South Korea and Taiwan are both dependent solely on external supply. Japan also controls much of the production and supply of silicon wafers, but due to its supply being otherwise diversified, there exist no significant levels of dependence.

In the case of fabrication equipment, the relations are more complex. Like in the production of wafers, Japan is also central in the supply of wafer equipment to fabs, which might work as an avenue of influence in the case of all but the top fabs. Otherwise, the U.S. is the leading country in supplying fab equipment from ion implanters, process control equipment, chemical mechanical planarization equipment, and deposition equipment, to etch and clean equipment (with Japan). All of these, especially the U.S. dominance in providing ion implanters, are clear relations of dependence for manufacturing countries, except for Taiwan. The relationship between TSMC and the U.S. ion implanter suppliers is also highly cohesive.

An important exception to the U.S.-Japanese dominance in fab equipment is the case of lithography equipment. While Japan also has a foothold in this market, it is otherwise completely dominated by Europe. This is the case in the supply of extreme ultraviolet lithography machines which are produced exclusively by the Dutch ASLM that are irreplaceable for all high-end fabs. This position gives Europe important leverage within the semiconductor supply chain, as well as a highly cohesive relationship with Taiwan's TSMC.

The last segment of the supply chain is the APT stage. Where this is not controlled in-house by IDMs it is taken care of by so-called OSAT firms working together with fabs and pure-play design firms. OSAT firms are moderately concentrated in Taiwan, placing TSMC in a secure position, but this is not enough for it to work as a source of external influence for Taiwan. The same goes for APT suppliers in materials and equipment relative to the main APT segment. This generally low centralisation produces a low level of power imbalance at back-end of the chain and places OSAT-node-controlling countries, mainly China, in a precarious position relative to both Taiwanese fabrication and American design.

Another important factor in measuring supply chain interdependencies is the gains from the trade to oneself. For firms these gains vary: for big conglomerates, profits from the semiconductor industry, relative to total profits, might be far less than for companies fully specialized in servicing some function in the supply chain. More important than looking at individual firms, however, is to look at the importance of semiconductor firms to their respective national economies. The national gains from the supply chain are difficult to measure exactly but in terms of economic impact, they can be estimated by looking at the value added from the industry for each country. The national distribution of value added from the semiconductor supply chain is shown in detail in Appendixes 2 and 3. Based on this, Table 3 below shows value added as a percentage of a nation's GDP.

Table 3

Value added as a percentage of national GDP (2019) per country and main chain segment

Segment	United States	EU	Japan	Taiwan	South Korea	China
Total	0.41 %	0.11 %	0.66 %	13.29 %	2.69 %	0.10 %
Design	0.22 %	0.03 %	0.10 %	1.28 %	1.16 %	0.02 %
EDA	0.03 %	-	0.00 %	-	-	-
IP	0.01 %	0.01 %	-	0.01 %	-	0.00 %
Fabrication	0.03 %	-	-	10.38 %	1.08 %	0.04 %
Fab materials	0.01 %	0.00 %	0.07 %	0.38 %	0.13 %	-
Wafers	0.00 %	0.01 %	0.10 %	0.23 %	0.05 %	0.00 %
Fab equipment	0.09 %	0.05 %	0.25 %	0.07 %	0.03 %	0.00 %
APT	0.02 %	0.00 %	0.02 %	0.83 %	0.14 %	0.02 %
APT materials	0.00 %	0.00 %	0.06 %	0.10 %	0.07 %	0.02 %
APT equipment	0.01 %	0.00 %	0.05 %	0.02 %	0.03 %	0.00 %

Note: GDP = Gross domestic product; EDA = electronic design automation; IP = intellectual property; APT = assembly, packaging, and testing. EU also includes the UK (EU28). Data from: Alam et al. (2022), Aurik et al. (2021), ICinsights, Jung and Lee (2022), Khan et al. (2021), Kleinhans and Baisanova (2020), Kleinhans et al. (2021), Knometa, SIA, Varas et al. (2021), and Yeung (2022), White House (2021). GDP data from: World Bank, Trading Economics.

From the above table, it is clear that in terms of its direct economic impact, the semiconductor industry is only moderately important for most countries in the chain. However, major exceptions to this are South Korea and especially Taiwan. For South Korea, both the design and fabrication segments account for over a per cent of the nation's GDP. For Taiwan, fabrication alone accounts for an astonishing 10.38% of GDP, with the total from the industry being as much as 13.29%. This makes the semiconductor industry a disproportionately massive part of the island nation's otherwise moderately sized economy.

For these countries, the semiconductor industry can serve as a potentially significant source of vulnerability. For South Korea, this vulnerability is minimized by the fact that much of the country's semiconductor industry is vertically integrated domestically under the IDM Samsung. The Taiwanese semiconductor industry on the other hand is far too large not to be exposed to the risk of external influence. This means that while Taiwan's leading-edge fabrication segment is powerful by its centrality to the supply chain, it is also weak in that it cannot be weaponized in economic statecraft without inflicting damage also on the Taiwanese economy. Similarly, import dependence also makes the industry a potentially effective leveraging point for those wishing to inflict harm on the island nation.

Another important aspect of gains from trade is the gains enjoyed from having access to semiconductors as inputs for various industries at the demand end. As is clear from Table 2 and Appendix 1, the six countries most involved in the semiconductor supply chain, are also the ones designing and manufacturing end products using chips as inputs. Of the top seven mobile handset device firms (phones, tablets, etc.) four are Chinese, two are South Korean, and one is American; of the top six PC firms three are American, two are Taiwanese, and one is Chinese; and of the top five TV firms three are Chinese and two are South Korean (Yeung, 2022, pp. 6–7).

Some of the largest companies in the U.S. are dependent on the supply of chips: Apple for its mobile devices and PCs, the tech giants Amazon, Alphabet and Microsoft for their server infrastructure, and the car manufacturers Ford and General Motors for the complex computing systems of contemporary personal vehicles. The defence and aerospace company Raytheon likewise requires top chips for the development of modern weapons systems. The European economy is likewise dependent on chips through its automobile industry. Companies such as Volkswagen, Mercedes-Benz, Stellantis, and BMW account for as much as 7% of the EU GDP (European Commission, n.d.-a).

The dependence on the supply of semiconductors is likely even higher for the East Asian manufacturing economies[50] than for the West. Both the electronics and automotive industries are dominant in Japan and South Korea. Toyota, Honda and Nissan in Japan, and Hyundai and Kia in South Korea are all in their respective countries' top 15 largest companies, with a large part of the surrounding economy also working to service them as suppliers (see Forbes. 2022, May 12). Japanese conglomerates such as Mitsubishi, Itochu, Hitachi, Sony, Panasonic, and SoftBank also have large stakes in manufacturing consumer electronics and industrial machinery (ibid.). In South Korea, Samsung reigns as the by far largest company in the country, with it and LG being some of the largest electronics manufacturers in the world (ibid.). For Taiwan, its massive semiconductor industry services its likewise large electronics industry. These are mostly manufacturers for foreign device designers, i.e., Foxconn, Pegatron, Quanta and Compal. Producing its own designs, Asus is also a major economic powerhouse (ibid.; Yeung, 2022, passim).

China's economy is less dominated by semiconductor-dependent industries, and the car manufacturer SAIC Motor could be considered the largest singular consumer of

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[50] All the East-Asian countries have much higher manufacturing/GDP -ratios (Japan, 20%; South Korea, 25%; China, 27% and Taiwan, >30%) than the U.S. (11%) or the EU (15%). (World Bank, n.d.; Taipei Times, 15th Nov 2022, for Taiwan).

chips in the country. Semiconductors are invaluable for the country's growing tech sector, however. The tech giants Alibaba and Tencent need a supply of semiconductors to expand the county's growing digital infrastructure, and large consumer electronics companies such as Lenovo, Huawei, Xiaomi, Oppo, TCL, and BOE require chips as regular inputs. (ibid.; Yeung, 2022, passim)

The dependence on semiconductors is difficult to measure just with its direct economic impact, however. The semiconductor industry typically has much larger economic secondary and tertiary effects (SIA, 2022b), and their ever-increasing performance can act as a developmental bottleneck for further technological (and thus economic) development (Holmström and Seppälä, 2020). Chips are also needed for modern weapons systems and so are subject to being valuable also for national security reasons (Shivakumar & Wessner, 2022), which in turn can place supply chains under increased scrutiny (see i.e., Lapedus, 2018). For these reasons, access to the highest-performance semiconductors has become central in the accelerating race toward 'technological leadership' between China and the U.S. (Yan, 2020).

Outside of just looking at concentrations, another important factor shaping the power structure in the supply chain is the nodes' investment costs, or how easily new firms may enter the chain and/or how easily existing firms may increase their market share. This is determined largely by the availability of capital, IP rights, and capable labour. The demand for all of these has continued to grow along with technological advancement following Moore's law.[51]

The shortage of capable labour is an acute issue in all major countries active in the supply chain. China, the U.S., Japan, Taiwan, and South Korea all have shortfalls, with only the EU managing to somewhat match the huge demand for skilled workers. This need for highly skilled labour is lower in the APT segment, however. In the case of R&D (the development of new IP) and capital expenditure, the different parts of the supply chain are highly specialized. The design segment, together with EDA and IP firms, have extremely high levels of R&D spending, which is an especially acute requirement for firms at the very cutting edge of chip design. The proliferation of the ARM processor architecture as a competitor to the dominant x86 is, however, equalizing the field by reducing the requirement for in-house IP development. High development costs are also the

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[51] Another important barrier to entry is government policy. Exploring this further, however, is outside the purview of this thesis.

case at the highest end of equipment manufacturing, such as in EUV lithography. The other side of the specialisation coin is the extreme capital expenditures required from firms at the fabrication segment of the chain. This is especially the case with new fabs at the cutting edge. Similarly, fab materials, wafers, and APT processes require their fair share of ready capital. In both cases, economies of scale also apply, further privileging larger firms and driving chain concentration.

High investment costs make it difficult for new firms to enter the market, thus upholding the existing balance of power in the chain. For example, the ability of competitors to develop lithography technology at the level of ASLM’s EUV is highly unlikely. This works to further entrench the European position as the only option for high-end fabrication equipment. In many cases investment costs can also further strengthen the power position of certain firms and countries by making it more difficult to keep up with the rate of technological development and/or capital investment required to effectively compete against market leaders. An example of this is the high-end fabrication segment, where the number of competitive companies diminishes with every new process node.

Another important factor for the chain’s power structure isthe high switching costs brought about by the level of cooperation between chain segments. High switching costs are prevalent especially within the IDM model, resulting from vertical integration, intrafirm trading, and direct coordination of production. They can also prevail in the more flexible fabless-foundry model between leading-edge design firms and fabs. There it largely results from the complexity of the transaction due to asset specificity: the need for compatible production processes between the fab and the design, the switching out of which could become highly expensive. The role of EDA and IP firms is to lessen this complexity by codifying specific processes, thus easing cooperation. A similar relationship exists between fabs and their equipment suppliers. The dynamic between designers and buyers is likewise complex, in that the buyer has specific needs for the product that the designer needs to fulfil. Front- and back-end manufacturers have a more dynamic relationship resulting from modular OSAT firm capabilities. Low levels of cooperation are also seen between materials and low-level equipment suppliers and their clients.

High switching costs serve to entrench the power relations in the chain. Like investment costs, switching costs can create barriers of entry for new firms entering the chain and for existing firms in creating new partnerships. Switching costs also function to increase the existing relations of dependence by making disruptions to the relationship that much more costly. This serves to increase the cohesion of the relationship, because switching costs are typically symmetrically distributed, and the possible damage inflicted by uses of economic statecraft on those chain segments.

5.2 State Action in the Semiconductor Supply Chain

Having described the structure of power within the semiconductor supply chain, the following subsections show that this structure does affect how states operate with each other. This is done by focusing on a contemporary trade conflict and its background from the perspective of the semiconductor supply chain: the U.S.–China trade war.[52]

The trade war has seen active uses of both (trade-related) tools of economic statecraft (specifically tariffs/quotas, license provision, and export/import restrictions through blacklisting) and strategic economic policy measures (e.g., public investment, public-private partnerships, subsidies etc.). Crucially, they have been both motivated by and aimed at either improving one’s own or impairing another’s position in the chain, i.e., by strategies of power balancing or power maximisation.

5.2.1 Strategic Economic Policy – China’s Semiconductor Strategy

As the discussion above shows, China has a major dependency on foreign-designed and manufactured semiconductor inputs for its tech, automotive, and electronics industries. Even though there is a capacity to both design and manufacture domestic (mostly mobile) chips, this has to be complemented by imports to match the huge demand. The concentration of global chip design in the U.S., South Korea and Japan, and chip manufacturing in Taiwan and South Korea, puts China in a vulnerable position, given that all of these Asia-Pacific countries are considered central U.S. regional partners and ‘major, non-NATO allies’ (Tow & Limaye, 2016). Likewise, China’s own semiconductor industry is heavily dependent on foreign inputs of EDA equipment, fab materials, wafers, fab equipment, testing tools, and rights to semiconductor IP, from these same countries as well as from the EU.

In the face of these vulnerabilities, China has for a long time pursued an industrial policy of import substitution and the expansion of its internal markets in both semiconductors and high-tech manufactured/capital goods (Majerowicz & Medeiros, 2018). The most recent and visible example of such planning has been the ‘Made in China 2025’

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[52] The U.S.–China trade war is not the only contemporary trade conflict weaponizing the semiconductor supply chain: the Japanese–South Korean trade dispute has also seen Japan leveraging its powerful position over South Korea in the supply of fabrication materials (for a discussion, see Kim, 2021).

industrial policy plan, the stated aim of which is to turn China into a self-sufficient high-tech manufacturing superpower through a strategy of large-scale technology substitution, including a 70% domestic market share target in semiconductor supply by 2025 (Wübbeke et al., 2016, pp. 20–21, 38). It is complemented by the 2016 ‘New Generation AI Development Plan’, aiming to make China a leader in AI technology (Webster et al., 2017). These policies aiming to lessen China’s dependent position in the semiconductor supply chain are very much in line with the optimal power balancing operations for a dependent exchange party discussed in this thesis.

Given that China is limited in its ability to increase its outside options by, e.g., fostering semiconductor design and manufacturing in friendly countries, it is left with three operational possibilities for strategic economic policy, which are all matched in its chosen industrial policy. Thus, China has solidified its position as a manufacturing hub for electronics, and thus as a central driver of semiconductor demand, through both intentional state action (as was described above) and as the unintended consequence of the country’s economic development trajectory. This has had two consequences for other countries dealing in semiconductor design: it has increased their gains from trade with China relative to production elsewhere (including domestically) and decreased the available outside options for this trading relationship. This has granted China market power at the demand end, balancing its external dependence. If the plan to make China a leading designer and manufacturer of high-tech goods and equipment is effective, this power would only increase. However, the country’s semiconductor industry itself is still in a marginal position and is unlikely to be a source of this type of power, at least not by 2025 (see Wübbeke et al., 2016, pp. 22–28).

While the decrease in dependence as a result of a more balanced, cohesive external relationship might function as a source of power balancing, this has not been the main goal of the Chinese leadership and can mainly be described as a side-effect of the chosen course. The main policy line has been to grow less dependent through ‘indigenous innovation’ and ‘self-sufficiency’ (Wübbeke et al., 2016, pp. 20–21). This is more in line with what in the theory is called ‘lessening one’s own gains’ from trade.

An important part of this is the securing of the supply chain by either having all the chain segments be under the control of Chinese companies or (as a second-best option) in friendly nations. This would involve growing the share that Chinese companies control on all segments of the chain, which is no easy feat given the major investment costs associated with many chain segments. Redirecting the manufacturing of leading-edge chips away from Taiwan onto the mainland will not only require a massive upfront investment but also the development of substitutes for high-end EDA and fabrication equipment. The EUV technology crucial for high-end fabrication alone is unlikely to be replicated by Chinese companies anytime soon. China will also have to develop domestic alternatives for the segments it has no previous presence in from scratch. On top of EDA and fab equipment, this includes GPU, FPGA and MCU design, memory chip design, and fabrication materials such as photomasks and photoresists.

To achieve this type of supply chain upgrading, China needs to invest massively throughout the high-end technology value chain (see ibid.). Policies used have included tax incentives, direct capital injections from publicly controlled funds, and the preference for domestic firms in public procurement (ibid. pp. 38–39). The Made in China strategy also includes significant public R&D investments (ibid. p. 38). However, given its disadvantaged starting position, it is unlikely that catch-up will be achieved without international technology acquisition through spillover encouragement, foreign investment, acquisition of foreign IP, and involuntary technology transfer (ibid. pp. 40, 64).

Outside of the power-balancing strategy, an alternative course for China could have also been the strategy of cost-reduction and the acceptance of the realities of international interdependence. This has been the position of the Chinese ‘market reform school’, which has advocated for the avoidance of direct confrontation with the U.S. and its partners in favour of mutually beneficial economic ties (Li, 2019, pp. 543–547, 552–555). This viewpoint has lost voice in the face of calls for decoupling and the creation of a ‘new type of whole nation system’ however (ibid.).

This shift has largely been the result of a deterioration in the relations between China and the U.S. since the 2010s. A reason for this has been the perceived threat that China’s technological, economic, and military advancement poses for the U.S. and its position in the world order, coupled with the Xi administration’s more abrasive foreign policy stance (see Foot & King, 2019; Kwan, 2019). The Made in China 2025 plan especially was largely criticised in the West as embodying unfair trade practices such as forced IP transfers and even outright IP theft (ibid.; Brown & Singh, 2018). The relationship achieved a boiling point with the U.S.–China trade war, which was initiated by the Trump White House and continued by the Biden administration.

5.2.2 Economic Statecraft – The U.S.–China Trade War

Against the above-described background conditions, the trade war started by U.S. President Donald Trump in 2018 has seen extensive uses of economic statecraft measures such as tariffs, export restrictions and blacklisting, against China. These measures have leveraged Chinese import dependence in its semiconductor industry in an attempt to both slow down the development of China's high-tech industry and to have China cease its use of (what the U.S. calls) unfair trade practices.

Following two reports by the U.S. Trade Representative on China's use of subsidies, encouragement of forced and below-market IP transfers, and state-sponsored industrial espionage tactics, the White House imposed tariffs (25%) on all semiconductor imports from China (packaged with other tariffs) (Bown, 2020, p. 374). The Chinese response was to impose tariffs of their own, but these notably did not include chips or semiconductor manufacturing equipment (ibid), without a doubt because of the significant dependence on the U.S. for these goods.

Considering that more semiconductors are designed and manufactured in the U.S. than in China, the tariffs alone were unlikely to be an effective economic statecraft measure (see SIA, 2018, Jun 15). To address this, the U.S. introduced export control measures in May/August 2019 by designating Huawei and its subsidiary chip designer HiSilicon as national security threats (White House, 2019). Subsequently, they and their affiliates were added to the so-called Entity List (Export Administration Regulations, 2019a; Export Administration Regulations, 2019b), which makes trade with a listed firm conditional to a government-issued license for all U.S. firms. This was costly for the American design and EDA companies themselves because trade with Huawei constituted a significant portion of their profits (Varas & Varadarajan, 2020). Bown (2020) notes that the protestation of U.S. firms is a break from the traditional alignment of public and private interests in the U.S. semiconductor industry. This distinguishes between protectionism and the use of economic means specifically to deliver international influence attempts.

For Huawei, the restrictions made it impossible to access American-designed chips and cut HiSilicon off from its supply of crucial EDA equipment. This left Huawei with few options outside of using up its stockpiles of U.S. chips (which it had started building up in 2018 [Li & Cheng, 2020]), importing some chips from other countries (e.g., memory chips from South Korea), and continuing to manufacture the chips HiSilicon had already designed, both in Taiwan and with its domestic partner SMIC.

Realising these leakages in its export controls, the U.S. announced another round of measures in May 2020, this time targeting companies in third countries, mainly TSMC and Samsung, to stop them from trading with Huawei (Export Administration Regulations, 2020a). Thus, instead of the traditional bilateral mechanism, the U.S. resorted to secondary sanctions through the use of its Foreign Direct Product Rule (FDPR). The FDPR is in essence a tool of weaponized interdependence, authorizing the U.S. to regulate trade among non-U.S. companies when the traded good utilizes U.S. technology, software, or equipment. In effect, the U.S. leveraged its central position in supplying fab equipment to pressure TSMC and Samsung to cease producing chips for Huawei (Bown, 2020, p. 379). In December, it also added HiSilicon's foundry partner, and China's largest semiconductor manufacturer, SMIC to the Entity List (Export Administration Regulations, 2020b).

The effects of the export restrictions on Huawei were significant. It saw a 30% drop in profits and a 47% drop in phone sales in the first half of 2021, as its stockpiles started to run out (Hille, et al., 2021). Its ability to upgrade its server infrastructure in line with the development of semiconductor technology was likewise disrupted (ibid.). Huawei was still able to access older U.S. technology, but not the leading edge, which is also harder to replicate domestically. This has forced China to refocus its semiconductor effort elsewhere and uplift new national champions such as YMTC (Cheng & Li, 2021) and UNISOC, the latter of which has largely taken over Huawei's previous market share in mobile chips (Cheng, et al., 2022).

Despite the restrictions, SMIC is reported to have achieved the ability to manufacture sub-10nm node chips domestically (Alcorn, 2022). In wake of this and China's continued success in the semiconductor industry, the Biden administration has toughened its licensing requirements for Huawei and affiliated companies (Langley & Waters, 2022), and in 2023 has halted licensing entirely (Sevastopulo & Hille, 2023). It also extended the U.S. FDPR licencing requirements to include advanced computing, semiconductor, and semiconductor manufacturing items, and to encompass all Chinese companies, not just Huawei; and restricted the right of U.S. persons to work with Chinese semiconductor industry companies (Export Administration Regulations, 2022). In December the U.S. additionally placed YMTC, along with multiple other Chinese companies, on the Entity List (Sevastopulo, et al. 2022). To also block Chinese companies from fabrication equipment suppliers, the Netherlands and Japan have also joined the U.S. in restricting manufacturing tool trade with China (Sevastopulo & Fleming, 2023). The British Arm has also interpreted its technology to be of U.S. origin, stopping its trade in semiconductor IP cores with Chinese companies (Liu, et al., 2022).

This new round of economic statecraft is likely to further damage China's advancement in the high-tech sector, including its road to semiconductor self-sufficiency. The U.S. has been adamant in cutting China off from both U.S. inputs and from suppliers in other countries, utilizing a combination of weaponized interdependence and diplomatic manoeuvring. As a result, it has also been increasingly transparent in its intentions: a hostility towards Chinese technological and military development, not just its unfair economic practices.

To continue its semiconductor development, China is forced in the future to rely on domestically sourced chips, EDA, fabrication equipment, and semiconductor IP. Considering investment costs required for developing the capacities to do this, it is likely to be a long process, especially given that the country is currently battling with a nationwide resurgence of Covid-19, which has forced the government to freeze the massive investments it pledged for the semiconductor industry (Bloomberg News, 2023).

This is all while both the U.S. (White House, 2022) and the EU (European Commission, n.d.-b) have passed their respective 'Chips Acts,' investing especially in domestic semiconductor manufacturing. This push in both markets has been to a significant extent motivated by security concerns. In the EU, the union's position in the semiconductor supply chain has been noted as, what it calls, 'a strategic dependency' (European Commission, 2022) and the billions in financial support provided by the EU Chips Act as a way to achieve 'strategic autonomy' (Timmers, 2022). In the U.S., the Biden administration has put the security aspects of its semiconductor policy at the forefront of its 'Chips for America' program, including the CHIPS and Science Act industrial policy plan (see e.g., Raimondo, 2023).

6 Conclusions

This thesis has been motivated by the emergence of new a 'geoeconomic' paradigm in international relations, which is exemplified in the weaponization of the semiconductor supply chain in the trade and 'tech war' between the U.S. and China. Thus, this thesis has focused on answering two research questions, the first of which was: *How does economic statecraft within the supply chain for semiconductors work?*

In the absence of an already developed theoretical framework, section 2 took up a modular approach to answering this question, first on the general level. Drawing from multiple existing sources this thesis has formulated a unique theoretical framework for understanding asymmetric interdependencies in global supply chains and their use for economic statecraft. It posits that the cost structure faced by the firms in their exchange relations with each other produces asymmetric interdependencies within the supply chain. The distribution of these interdependencies, and the network topology formed by them, constitutes a power structure that both constrains and enables the actions of states embedded in it. States that are well situated in the chain can tap into this power resource by leveraging the interdependencies against more vulnerable others in instances of economic statecraft. This leveraging serves to explain the mechanism by which economic statecraft in supply chains works by. To better their position in the chain states can also pursue strategies of power maximisation or power balancing by utilizing economic statecraft and ‘strategic economic policy’.

In applying this theoretical framework to the semiconductor supply chain, section 4 focused on mapping the chain, its constituent firms, and their relations. In this, the thesis follows the research agenda set forward by Farrell and Newman (2021). This aimed to answer the second research question: *What is the structure of power in the global supply chain for semiconductors?* Sub-section 5.1 presented the results of the mapping and analysed them with the aid of the Herfindahl-Hirschman index.

By the virtue of its significant control over the supply chain, the United States was shown to be the most dominant country in the chain. It holds a high level of control over the crucial design segment, as well as important supply segments such as EDA and fabrication equipment. South Korea and Taiwan are likewise well situated in the design and manufacture of memory chips, and in high-end fabrication, respectively. Both of these countries, especially Taiwan, were also shown to be vulnerable as a result of their economies’ high level of concentration around the semiconductor industry. Japan’s position as a supplier for the manufacturing segments, and Europe’s monopoly over EUV equipment, also put both in a powerful position. Of the countries looked at, China was shown to be the only one that does not have a dominant position on any segment of the chain. This, together with its high demand for semiconductors, leaves it in a vulnerable position relative to the U.S. and Taiwan.

Aside from its topological characteristics, another central structural feature of the semiconductor supply chain was shown to be its rigidity. This is largely the result of both the high investment costs and switching costs faced by firms in the chain. This has the effect of decreasing competition, which cements the power position of the actors in place.

With this knowledge about the supply chain’s structural character, subsection 5.2 circled back on the first research question by providing a description and analysis of the ways economic statecraft and strategic economic policy have been employed in the chain by both China and the U.S. For China, its positioning in the chain has prompted a push toward ‘semiconductor independence,’ which has involved state planning, incentive setting, and public investment aimed at developing a more robust domestic chip industry. With this, it has followed a strategy of power balancing. It was also pointed out that this was not the only possible option. An alternative, cost-reduction approach could have focused on accepting dependence together with peaceful economic development. China likely chose power balancing over this alternative because of changed priorities under the Xi administration as well as the U.S.’s more hostile foreign policy stance under the Trump and Biden administrations.

One expression of this U.S. stance was described in subsection 5.2.2, with a description of the economic statecraft measures the U.S. has deployed against China in the context of the semiconductor industry. It has since 2018, systematically made use of China’s dependence on both it and its strategic partners for semiconductor inputs by employing import and export restrictions, blacklistings, and secondary sanctions against the Chinese chip industry. While the results of this are yet to be fully seen, the U.S. sanctions combined with the rigidity of the supply chain are likely to significantly hinder China’s plans for semiconductor independence.

As a whole, this thesis has served as a unique contribution to the study of economic statecraft and geoeconomics, by focusing on how the network topology of global supply chains structures state action. This is especially in response to the research agenda set forward by Farrell and Newman (2021) on mapping global networks in the context of ‘weaponized interdependence’. First, this thesis has introduced a new framework for understanding economic statecraft in the domain of global supply chains. This includes synthesizing insights from Global Value Chain analysis into International Relations theory, which serves to fill deficiencies in both GVC analysis regarding the role of international politics (see Horner, 2016) and in IR regarding the role of global supply chains. By explaining the mechanism by which economic statecraft in supply chains works, this thesis also contributes towards a more social scientific understanding of international politics.

Second, this thesis has provided possibly the first systematic analysis of the semiconductor supply chain done primarily from the perspective of international power and politics. In this, it has presented a novel application of the Herfindahl-Hirschman index to analyse interdependence-based power in supply chains. Third, this thesis has provided theoretical grounding and context for the actions taken by both China and the U.S. in and around the U.S.–China trade war. Both of these contributions serve to build a better understanding of the importance of the semiconductor industry for international politics.

That being said, this thesis still has limitations that can hopefully be addressed and amended in future research. One of these is the focus exclusively on the exchange of material goods and capital in supply chains, which delimits the analysis of financial capital and ownership relations outside the purview of the thesis. The ownership relations between firms, foreign direct investment, etc., introduce an important factor into the analysis of economic statecraft in supply chains that would need to be taken into account in future research.

Another limitation is brought about by the use of the HHI to analyse the outside options of firms from data gathered on the segment level. While this has the upside of being both efficient from a research perspective and simple from an analysis perspective, it, unfortunately, hides a lot of possibly important information. Most importantly it cannot tell about the outside options faced by ‘marginalized’ nodes. While the HHI remains a good tool for future research, data for it would be gathered from the national or even the firm level. A third limitation is that the analysis here only focuses on a cross-section of the most current data on firm market shares. A future study could look at the composition of the supply chain across time to see how the topology of interdependencies changes, e.g., as a result of state action.

The last two limitations are largely a result of the constraints this thesis has had to contend with as a result of data availability. A future study that has access to data of greater quality and quantity could amend many of the limitations noted here. Still, the findings in this thesis should be fairly reliable, especially when it comes to the estimated power of leading nodes, which arguably forms the core of the analysis and argument.

Appendices

Appendix 1

Table of semiconductor supply chain concentrations per country and chain segment.

Segment	United States	EU	Japan	Tai-wan	South Korea	China	Other[2]	HHI
R&D[1]	0.342	0.208	0.080	0.112	0.108	0.084	0.066	0.198
Design – total	0.540	0.060	0.060	0.090	0.220	0.040	0.000	0.357
Logic – total	0.670	0.080	0.050	0.070	0.030	0.050	0.050	0.466
Logic – CPUs & Aps[4]	0.828	0.009	-	0.040	0.009	0.018	0.096	0.688
Logic – PC CPUs	1.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Logic – Mobile CPUs	0.420	-	-	0.260	0.130	0.160	0.030	0.287
Logic – GPUs	1.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Logic – FPGAs	1.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Logic – MCUs	0.178	0.474	0.170	-	-	-	0.178	0.285
Memory – total	0.290	0.000	0.080	0.040	0.590	0.000	0.000	0.440
Memory – DRAM	0.228	-	-	-	0.713	-	0.059	0.560
Memory – NAND	0.340	-	0.200	-	0.450	-	0.010	0.358
DAOs – total	0.370	0.190	0.240	0.030	0.060	0.070	0.000	0.240
DAOs – Analog ICs	0.503	0.165	0.015	-	-	-	0.317	0.280
EDA equipment	0.950	-	0.030	-	-	-	0.020	0.903
Semiconductor IP	0.520	0.430	-	0.016	-	0.018	0.016	0.456
Fabrication – total	0.067	-	-	0.642	0.181	0.051	0.059	0.452
by capacity – total[6]	0.110	0.050	0.150	0.210	0.230	0.160	0.090	0.160
Logic (< 10 nm)	0.000	0.000	0.000	0.920	0.080	0.000	0.000	0.853
Logic (10-22 nm)	0.430	0.120	0.000	0.280	0.050	0.030	0.090	0.281
Logic (28-45 nm)	0.060	0.040	0.050	0.470	0.060	0.190	0.130	0.268
Logic (> 45 nm)	0.090	0.060	0.130	0.310	0.100	0.230	0.080	0.188
Memory	0.050	0.020	0.200	0.110	0.440	0.140	0.040	0.268
DAOs	0.190	0.220	0.270	0.030	0.050	0.170	0.070	0.190
Fab materials – total	0.190	0.050	0.320	0.200	0.180	-	0.060	0.213
Photomasks	0.400	-	0.530	0.070	-	-	0.000	0.446
Photoresists	0.050	-	0.900	-	0.050	-	0.000	0.815
Chemicals	yes	yes	yes	no	no	yes	NA	NA
Wafers – total	0.000	0.140	0.560	0.160	0.100	0.040	0.000	0.370
300mm wafers	-	0.141	0.546	0.116	0.181	-	0.016	0.364
Fab equipment – total	0.440	0.230	0.290	0.010	0.010	0.010	0.010	0.331
Wafer equipment	0.100	0.100	0.753	-	0.030	-	0.017	0.588
Ion implanters	0.904	0.000	0.080	0.016	0.000	0.000	0.000	0.824
Process control equipment	0.712	0.090	0.142	0.000	0.000	0.014	0.042	0.535
CMP equipment	0.675	0.000	0.302	0.000	0.009	0.014	0.000	0.547

Appendix 1 *(continued).*

Deposition equipment	0.638	0.077	0.209	0.000	0.040	0.018	0.018	0.459
Etch and clean equipment	0.531	0.002	0.416	-	0.020	0.017	0.014	0.456
Lithography equipment	0.008	0.700	0.283	0.000	0.000	0.002	0.007	0.570
Lithography – EUV equipment	0.000	1.000	0.000	0.000	0.000	0.000	0.000	1.000
APT	0,280	0,050	0,070	0,290	0,130	0,140	0,040	0,206
In-house APT	0.430	0.100	0.130	0.040	0.230	0.060	0.010	0.270
OSAT	0.150	0.000	0.020	0.520	0.030	0.210	0.070	0.338
APT materials	0.000	0.020	0.280	0.050	0.100	0.200	0.350	0.131
APT equipment	0.230	0.060	0.440	0.020	0.090	0.090	0.070	0.267
Assembly and packaging equipment	0.049	0.140	0.357	0.010	0.080	0.227	0.137	0.207
Testing tools	0.335	-	0.486	0.030	0.100	0.013	0.036	0.359
Demand	-	-	-	-	-	-	-	-
by headquarters location	0.330	0.100	0.100	0.090	0.110	0.260	0.010	0.217
by manufacturing location	0.190	0.100	0.090	0.150	0.120	0.350	0.000	0.214
by end user location	0.250	0.200	0.060	0.010	0.020	0.240	0.220	0.164

Note: Measurements based on the market shares of firms headquartered in each country. Accuracy of measurements varies based on data source (some data is rounded down to two decimal points, some up to 3). Some of the data is estimated based on data visualizations and rounded to the closest 0.5.

HHI = Herfindahl–Hirschman index; R&D = research and development; EDA = electronic design automation; IP = intellectual property; CMP = chemical mechanical planarization; APT = assembly, packaging, and testing; OSAT = outsourced semiconductor assembly and testing.

Data from: Alam et al. (2022), Aurik et al. (2021), ICinsights, Jung and Lee (2022), Khan et al. (2021), Kleinhans and Baisanova (2020), Kleinhans et al. (2021), Knometa, SIA, Varas et al. (2021), and Yeung (2022), White House (2021).

[1] Because the sum of the percentages in the R&D data is over 100%, the table shows recounted percentages and measures the HHI based on these.

[2] 'Other' encompasses both other firms and countries depending on if the used source lists market shares based on firm or country. Country shares are used whenever possible. Thus, the concentrations of the listed countries in a segment might vary upwards depending on if firms of that nationality are listed under 'other'. Because 'other' accounts for multiple countries, its share of the market is not counted toward the HHI. This has a marginal effect of slightly lowering the HHI score for that segment.

[3] The lower bound value is estimated from the lower bound value of the total value added in the design segment. This variation is due to measurement difficulty related to intrafirm trade by IDMs.

[4] The only data from firms six through ten on the top ten is that their market share adds up to 4,3%. Here this is distributed evenly among all five firms and allocated to their respective countries.

[5] The italicised percentages refer to the percent of total global manufacturing capacity used for the production of each chip type.

[6] The source for total manufacturing capacity lists 'The Americas' as one region. Here this is counted under the U.S., as the U.S. is by far the dominant semiconductor manufacturing country in the Americas.

Appendix 2

Amount of value added as a % of total value added per country and main chain segment.

Segment	**Total**	**United States**	**EU**	**Japan**	**Taiwan**	**South Korea**	**China**	**Other**
Total	100 %	30.4 %	6.8 %	11.6 %	28.0 %	15.3 %	5.0 %	4.2 %
Design	30 %	54.0 %	6.0 %	6.0 %	9.0 %	22.0 %	4.0 %	0.0 %
EDA	2 %	95.0 %	-	3.0 %	-	-	-	2.0 %

Appendix 2 *(continued).*

IP	1 %	52.0 %	43.0 %	-	1.6 %	-	1.8 %	1.6 %
Fabrication	34 %	6.7 %	-	-	64.2 %	18.1 %	5.1 %	5.9 %
Fab materials	4 %	19.0 %	5.0 %	32.0 %	20.0 %	18.0 %	-	6.0 %
Wafers	3 %	0.0 %	14.0 %	56.0 %	16.0 %	10.0 %	4.0 %	0.0 %
Fab equipment	15 %	44.0 %	23.0 %	29.0 %	1.0 %	1.0 %	1.0 %	1.0 %
APT	6 %	28.0 %	5.0 %	7.0 %	29.0 %	13.0 %	14.0 %	4.0 %
APT materials	4 %	0.0 %	2.0 %	28.0 %	5.0 %	10.0 %	20.0 %	35.0 %
APT equipment	2 %	23.0 %	6.0 %	44.0 %	2.0 %	9.0 %	9.0 %	7.0 %

Note: Same data as in Appendix 1 but showing only main chain segments.
EDA = electronic design automation; IP = intellectual property; APT = assembly, packaging, and testing. EU also includes the UK (EU28). EDA = electronic design automation; IP = intellectual property; APT = assembly, packaging, and testing. EU also includes the UK (EU28).
Value added totals are from Aurik et al. (2022, p. 19). Data from: Alam et al. (2022), Aurik et al. (2021), ICinsights, Jung and Lee (2022), Khan et al. (2021), Kleinhans and Baisanova (2020), Kleinhans et al. (2021), Knometa, SIA, Varas et al. (2021), and Yeung (2022), White House (2021).

Appendix 3

Amount of value added ($Billion) per country and main chain segment.

Segment	**Total**	**United States**	**EU**	**Japan**	**Taiwan**	**South Korea**	**China**	**Other**
Total	290.0	88.2	19.7	33.6	81.1	44.3	14.6	12.3
Design	87.0	47.0	5.2	5.2	7.8	19.1	3.5	0.0
EDA	5.8	5.5	-	0.2	-	-	-	0.1
IP	2.9	1.5	1.2	-	0.0	-	0.1	0.0
Fabrication	98.6	6.6	-	-	63.3	17.8	5.0	5.8
Fab materials	11.6	2.2	0.6	3.7	2.3	2.1	-	0.7
Wafers	8.7	0.0	1.2	4.9	1.4	0.9	0.3	0.0
Fab equipment	43.5	19.1	10.0	12.6	0.4	0.4	0.4	0.4
APT	17.4	4.9	0.9	1.2	5.0	2.3	2.4	0.7
APT materials	11.6	0.0	0.2	3.2	0.6	1.2	2.3	4.1
APT equipment	5.8	1.3	0.3	2.6	0.1	0.5	0.5	0.4

Note: EDA = electronic design automation; IP = intellectual property; APT = assembly, packaging, and testing. EU also includes the UK (EU28).
Calculated based on data in Appendix 2. Total value added from the chain is from Varas et al. (2021, p. 13). Chain segment data from: Alam et al. (2022), Aurik et al. (2021), ICinsights, Jung and Lee (2022), Khan et al. (2021), Kleinhans and Baisanova (2020), Kleinhans et al. (2021), Knometa, SIA, Varas et al. (2021), and Yeung (2022), White House (2021).

Appendix 4

All possible chain segment connections and their power relations measured by HHI.

Segment A	HHI A	Relation	Segment B	HHI B	Dif. in HHIs	Sum of HHIs
Design - CPUs & APs	0.688	<*	Electronic design automation	0.903	-0.216	0.591
Design - PC CPUs	1.000	=***	Electronic design automation	0.903	0.097	0.903
Design - Mobile CPUs	0.287	<***	Electronic design automation	0.903	-0.617	0.190
Design - GPUs	1.000	=***	Electronic design automation	0.903	0.097	0.903
Design - FPGAs	1.000	=***	Electronic design automation	0.903	0.097	0.903
Design - MCUs	0.285	<***	Electronic design automation	0.903	-0.618	0.188
Design - DRAM	0.560	<*	Electronic design automation	0.903	-0.343	0.464
Design - NAND	0.358	<**	Electronic design automation	0.903	-0.545	0.262
Design - Analog ICs	0.280	<***	Electronic design automation	0.903	-0.623	0.184
Design - CPUs & APs	0.688	>*	Semiconductor IP	0.456	0.232	0.144
Design - PC CPUs	1.000	>**	Semiconductor IP	0.456	0.544	0.456
Design - Mobile CPUs	0.287	=*	Semiconductor IP	0.456	-0.169	-0.258
Design - GPUs	1.000	>**	Semiconductor IP	0.456	0.544	0.456
Design - FPGAs	1.000	>**	Semiconductor IP	0.456	0.544	0.456
Design - MCUs	0.285	=*	Semiconductor IP	0.456	-0.171	-0.259
Design - DRAM	0.560	=**	Semiconductor IP	0.456	0.104	0.016
Design - NAND	0.358	=*	Semiconductor IP	0.456	-0.098	-0.186
Design - Analog ICs	0.280	=*	Semiconductor IP	0.456	-0.175	-0.264
Design - CPUs & APs	0.688	=***	Fabrication - Logic (< 10 nm)	0.853	-0.165	0.540
Design - PC CPUs	1.000	=***	Fabrication - Logic (< 10 nm)	0.853	0.147	0.853
Design - Mobile CPUs	0.287	<**	Fabrication - Logic (< 10 nm)	0.853	-0.566	0.139
Design - GPUs	1.000	=***	Fabrication - Logic (< 10 nm)	0.853	0.147	0.853
Design - FPGAs	1.000	=***	Fabrication - Logic (< 10 nm)	0.853	0.147	0.853
Design - MCUs	0.285	<**	Fabrication - Logic (< 10 nm)	0.853	-0.568	0.138
Design - CPUs & APs	0.688	>**	Fabrication - Logic (10-22 nm)	0.281	0.407	-0.031
Design - PC CPUs	1.000	>***	Fabrication - Logic (10-22 nm)	0.281	0.719	0.281
Design - Mobile CPUs	0.287	=*	Fabrication - Logic (10-22 nm)	0.281	0.005	-0.432
Design - GPUs	1.000	>***	Fabrication - Logic (10-22 nm)	0.281	0.719	0.281
Design - FPGAs	1.000	>***	Fabrication - Logic (10-22 nm)	0.281	0.719	0.281
Design - MCUs	0.285	=*	Fabrication - Logic (10-22 nm)	0.281	0.004	-0.434
Design - CPUs & APs	0.688	>**	Fabrication - Logic (28-45 nm)	0.268	0.419	-0.044
Design - PC CPUs	1.000	>***	Fabrication - Logic (28-45 nm)	0.268	0.732	0.268
Design - Mobile CPUs	0.287	=*	Fabrication - Logic (28-45 nm)	0.268	0.018	-0.445
Design - GPUs	1.000	>***	Fabrication - Logic (28-45 nm)	0.268	0.732	0.268
Design - FPGAs	1.000	>***	Fabrication - Logic (28-45 nm)	0.268	0.732	0.268
Design - MCUs	0.285	=*	Fabrication - Logic (28-45 nm)	0.268	0.017	-0.447
Design - CPUs & APs	0.688	>**	Fabrication - Logic (> 45 nm)	0.188	0.500	-0.125
Design - PC CPUs	1.000	>***	Fabrication - Logic (> 45 nm)	0.188	0.812	0.188
Design - Mobile CPUs	0.287	=*	Fabrication - Logic (> 45 nm)	0.188	0.099	-0.526
Design - GPUs	1.000	>***	Fabrication - Logic (> 45 nm)	0.188	0.812	0.188
Design - FPGAs	1.000	>***	Fabrication - Logic (> 45 nm)	0.188	0.812	0.188
Design - MCUs	0.285	=*	Fabrication - Logic (> 45 nm)	0.188	0.097	-0.527
Design - DRAM	0.560	>*	Fabrication - Memory	0.268	0.292	-0.171
Design - NAND	0.358	=*	Fabrication - Memory	0.268	0.090	-0.374
Design - Analog ICs	0.280	=*	Fabrication - DAOs	0.190	0.091	-0.530
Design - CPUs & APs	0.688	>**	Demand by headquarters location	0.217	0.471	-0.096
Design - PC CPUs	1.000	>***	Demand by headquarters location	0.217	0.783	0.217
Design - Mobile CPUs	0.287	=*	Demand by headquarters location	0.217	0.070	-0.497
Design - GPUs	1.000	>***	Demand by headquarters location	0.217	0.783	0.217
Design - FPGAs	1.000	>***	Demand by headquarters location	0.217	0.783	0.217
Design - MCUs	0.285	=*	Demand by headquarters location	0.217	0.068	-0.498
Design - DRAM	0.560	>*	Demand by headquarters location	0.217	0.344	-0.223
Design - NAND	0.358	=*	Demand by headquarters location	0.217	0.141	-0.425
Design - Analog ICs	0.280	=*	Demand by headquarters location	0.217	0.064	-0.503
Design - CPUs & APs	0.688	>**	Demand by manufacturing location	0.214	0.474	-0.099
Design - PC CPUs	1.000	>***	Demand by manufacturing location	0.214	0.786	0.214
Design - Mobile CPUs	0.287	=*	Demand by manufacturing location	0.214	0.073	-0.500
Design - GPUs	1.000	>***	Demand by manufacturing location	0.214	0.786	0.214
Design - FPGAs	1.000	>***	Demand by manufacturing location	0.214	0.786	0.214
Design - MCUs	0.285	=*	Demand by manufacturing location	0.214	0.071	-0.501
Design - DRAM	0.560	>*	Demand by manufacturing location	0.214	0.347	-0.226

Appendix 4 *(continued).*

Design - NAND	0.358	=*	Demand by manufacturing location	0.214	0.145	-0.428
Design - Analog ICs	0.280	=*	Demand by manufacturing location	0.214	0.067	-0.506
Design - CPUs & APs	0.688	>**	Demand by end user location	0.164	0.523	-0.148
Design - PC CPUs	1.000	>***	Demand by end user location	0.164	0.836	0.164
Design - Mobile CPUs	0.287	=*	Demand by end user location	0.164	0.122	-0.549
Design - GPUs	1.000	>***	Demand by end user location	0.164	0.836	0.164
Design - FPGAs	1.000	>***	Demand by end user location	0.164	0.836	0.164
Design - MCUs	0.285	=*	Demand by end user location	0.164	0.121	-0.551
Design - DRAM	0.560	>*	Demand by end user location	0.164	0.396	-0.275
Design - NAND	0.358	=*	Demand by end user location	0.164	0.194	-0.478
Design - Analog ICs	0.280	=*	Demand by end user location	0.164	0.116	-0.555
Fab. - Logic (< 10 nm)	0.853	>**	Photomasks	0.446	0.407	0.299
Fab. - Logic (10-22 nm)	0.281	=*	Photomasks	0.446	-0.165	-0.273
Fab. - Logic (28-45 nm)	0.268	=*	Photomasks	0.446	-0.178	-0.286
Fab. - Logic (> 45 nm)	0.188	<*	Photomasks	0.446	-0.258	-0.367
Fab. - Memory	0.268	=*	Photomasks	0.446	-0.178	-0.286
Fab. - DAOs	0.190	<*	Photomasks	0.446	-0.256	-0.365
Fab. - Logic (< 10 nm)	0.853	=***	Photoresists	0.815	0.038	0.668
Fab. - Logic (10-22 nm)	0.281	<**	Photoresists	0.815	-0.534	0.096
Fab. - Logic (28-45 nm)	0.268	<**	Photoresists	0.815	-0.547	0.083
Fab. - Logic (> 45 nm)	0.188	<***	Photoresists	0.815	-0.627	0.003
Fab. - Memory	0.268	<**	Photoresists	0.815	-0.547	0.083
Fab. - DAOs	0.190	<***	Photoresists	0.815	-0.625	0.005
Fab. - Logic (< 10 nm)	0.853	>***	Chemicals	NA	NA	NA
Fab. - Logic (10-22 nm)	0.281	=*	Chemicals	NA	NA	NA
Fab. - Logic (28-45 nm)	0.268	=*	Chemicals	NA	NA	NA
Fab. - Logic (> 45 nm)	0.188	=*	Chemicals	NA	NA	NA
Fab. - Memory	0.268	=*	Chemicals	NA	NA	NA
Fab. - DAOs	0.190	=*	Chemicals	NA	NA	NA
Fab. - Logic (< 10 nm)	0.853	>**	300mm wafers	0.364	0.489	0.217
Fab. - Logic (10-22 nm)	0.281	=*	300mm wafers	0.364	-0.083	-0.355
Fab. - Logic (28-45 nm)	0.268	=*	300mm wafers	0.364	-0.096	-0.367
Fab. - Logic (> 45 nm)	0.188	=*	300mm wafers	0.364	-0.177	-0.448
Fab. - Memory	0.268	=*	300mm wafers	0.364	-0.096	-0.368
Fab. - DAOs	0.190	=*	300mm wafers	0.364	-0.175	-0.446
Fab. - Logic (< 10 nm)	0.853	>*	Wafer equipment	0.588	0.265	0.441
Fab. - Logic (10-22 nm)	0.281	<*	Wafer equipment	0.588	-0.307	-0.131
Fab. - Logic (28-45 nm)	0.268	<*	Wafer equipment	0.588	-0.320	-0.144
Fab. - Logic (> 45 nm)	0.188	<**	Wafer equipment	0.588	-0.400	-0.224
Fab. - Memory	0.268	<*	Wafer equipment	0.588	-0.320	-0.144
Fab. - DAOs	0.190	<*	Wafer equipment	0.588	-0.398	-0.222
Fab. - Logic (< 10 nm)	0.853	=***	Ion implanters	0.824	0.029	0.677
Fab. - Logic (10-22 nm)	0.281	<**	Ion implanters	0.824	-0.543	0.105
Fab. - Logic (28-45 nm)	0.268	<**	Ion implanters	0.824	-0.556	0.092
Fab. - Logic (> 45 nm)	0.188	<***	Ion implanters	0.824	-0.636	0.011
Fab. - Memory	0.268	<**	Ion implanters	0.824	-0.556	0.092
Fab. - DAOs	0.190	<***	Ion implanters	0.824	-0.634	0.014
Fab. - Logic (< 10 nm)	0.853	>*	Process control equipment	0.535	0.317	0.388
Fab. - Logic (10-22 nm)	0.281	<*	Process control equipment	0.535	-0.254	-0.183
Fab. - Logic (28-45 nm)	0.268	<*	Process control equipment	0.535	-0.267	-0.196
Fab. - Logic (> 45 nm)	0.188	<*	Process control equipment	0.535	-0.348	-0.277
Fab. - Memory	0.268	<*	Process control equipment	0.535	-0.267	-0.196
Fab. - DAOs	0.190	<*	Process control equipment	0.535	-0.346	-0.275
Fab. - Logic (< 10 nm)	0.853	>*	CMP equipment	0.547	0.306	0.400
Fab. - Logic (10-22 nm)	0.281	<*	CMP equipment	0.547	-0.266	-0.172
Fab. - Logic (28-45 nm)	0.268	<*	CMP equipment	0.547	-0.279	-0.185
Fab. - Logic (> 45 nm)	0.188	<*	CMP equipment	0.547	-0.360	-0.265
Fab. - Memory	0.268	<*	CMP equipment	0.547	-0.279	-0.185
Fab. - DAOs	0.190	<*	CMP equipment	0.547	-0.357	-0.263
Fab. - Logic (< 10 nm)	0.853	>*	Deposition equipment	0.459	0.394	0.311
Fab. - Logic (10-22 nm)	0.281	=*	Deposition equipment	0.459	-0.177	-0.260
Fab. - Logic (28-45 nm)	0.268	=*	Deposition equipment	0.459	-0.190	-0.273
Fab. - Logic (> 45 nm)	0.188	<*	Deposition equipment	0.459	-0.271	-0.354
Fab. - Memory	0.268	=*	Deposition equipment	0.459	-0.190	-0.273
Fab. - DAOs	0.190	<*	Deposition equipment	0.459	-0.269	-0.352

Appendix 4 *(continued).*

Fab. - Logic (< 10 nm)	0.853	>*	Etch and clean equipment	0.456	0.397	0.309
Fab. - Logic (10-22 nm)	0.281	=*	Etch and clean equipment	0.456	-0.175	-0.263
Fab. - Logic (28-45 nm)	0.268	=*	Etch and clean equipment	0.456	-0.187	-0.276
Fab. - Logic (> 45 nm)	0.188	<*	Etch and clean equipment	0.456	-0.268	-0.357
Fab. - Memory	0.268	=*	Etch and clean equipment	0.456	-0.188	-0.276
Fab. - DAOs	0.190	<*	Etch and clean equipment	0.456	-0.266	-0.355
Fab. - Logic (< 10 nm)	0.853	>*	Lithography equipment	0.570	0.283	0.423
Fab. - Logic (10-22 nm)	0.281	<*	Lithography equipment	0.570	-0.289	-0.149
Fab. - Logic (28-45 nm)	0.268	<*	Lithography equipment	0.570	-0.302	-0.162
Fab. - Logic (> 45 nm)	0.188	<*	Lithography equipment	0.570	-0.383	-0.242
Fab. - Memory	0.268	<*	Lithography equipment	0.570	-0.302	-0.162
Fab. - DAOs	0.190	<*	Lithography equipment	0.570	-0.380	-0.240
Fab. - Logic (< 10 nm)	0.853	=***	EUV lithography equipment	1.000	-0.147	0.853
Fab. - Logic (10-22 nm)	0.281	<***	EUV lithography equipment	1.000	-0.719	0.281
Fab. - Logic (28-45 nm)	0.268	<***	EUV lithography equipment	1.000	-0.732	0.268
Fab. - Logic (> 45 nm)	0.188	<***	EUV lithography equipment	1.000	-0.812	0.188
Fab. - Memory	0.268	<***	EUV lithography equipment	1.000	-0.732	0.268
Fab. - DAOs	0.190	<***	EUV lithography equipment	1.000	-0.810	0.190
Fab. - Logic (< 10 nm)	0.853	>**	APT - OSAT	0.338	0.515	0.191
Fab. - Logic (10-22 nm)	0.281	=*	APT - OSAT	0.338	-0.057	-0.381
Fab. - Logic (28-45 nm)	0.268	=*	APT - OSAT	0.338	-0.070	-0.393
Fab. - Logic (> 45 nm)	0.188	=*	APT - OSAT	0.338	-0.151	-0.474
Fab. - Memory	0.268	=*	APT - OSAT	0.338	-0.070	-0.394
Fab. - DAOs	0.190	=*	APT - OSAT	0.338	-0.149	-0.472
APT - In-house	0.270	=*	APT materials	0.131	0.139	-0.599
APT - OSAT	0.338	=*	APT materials	0.131	0.207	-0.530
APT - In-house	0.270	=*	A&P equipment	0.207	0.062	-0.523
APT - In-house	0.270	=*	Testing tools	0.359	-0.090	-0.371
APT - OSAT	0.338	=*	A&P equipment	0.207	0.131	-0.454
APT - OSAT	0.338	=*	Testing tools	0.359	-0.021	-0.302
APT - OSAT	0.338	<*	Design - CPUs & APs	0.688	-0.349	0.026
APT - OSAT	0.338	<***	Design - PC CPUs	1.000	-0.662	0.338
APT - OSAT	0.338	=*	Design - Mobile CPUs	0.287	0.052	-0.375
APT - OSAT	0.338	<***	Design - GPUs	1.000	-0.662	0.338
APT - OSAT	0.338	<***	Design - FPGAs	1.000	-0.662	0.338
APT - OSAT	0.338	=*	Design - MCUs	0.285	0.053	-0.377
APT - OSAT	0.338	<*	Design - DRAM	0.560	-0.222	-0.101
APT - OSAT	0.338	=*	Design - NAND	0.358	-0.020	-0.304
APT - OSAT	0.338	=*	Design - Analog ICs	0.280	0.058	-0.381

Note: The table shows the power relations between all possible chain segment connections in the semiconductor supply chain. Segments are listed as ‘Segment A’ and ‘Segment B’, with their corresponding HHI scores being listed as ‘HHI A’ and ‘HHI B’.

Legend: Symbols in the ‘relationship’ –column represent two relationship dimensions: level of (im)balance, measured by the difference in HHIs (‘=’: 0.0–0.2; ‘>*’: 0.2–0.4; ‘>**’: 0.4–0.6; ‘>***’: >0.6; negative values correspondingly: ‘<*’, ‘<**’, and ‘<***’), and the level of coherence, measured by the sum of HHIs (-1) (‘=’: <0; ‘=**’: 0.0–0.5; ‘=***’: 0.5–1).

The relation between the chemicals segment and various fabrication subsegments was estimated with the assumption that the former’s HHI score would be around 0.250 based on the information available about the geographic distribution of chemicals production.

HHI = Herfindahl–Hirschman index; IP = intellectual property; CMP = chemical mechanical planarization; APT = assembly, packaging, and testing; A&P = assembly and packaging; OSAT = outsourced semiconductor assembly and testing.

HHIs calculated based on data in Appendix 1. Data from: Alam et al. (2022), Aurik et al. (2021), ICinsights, Jung and Lee (2022), Khan et al. (2021), Kleinhans and Baisanova (2020), Kleinhans et al. (2021), Knometa, SIA, Varas et al. (2021), and Yeung (2022), White House (2021).

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