MIT INDUSTRIAL PERFORMANCE CENTER

Innovation. Productivity. Competitiveness.

Supply chain resilience and smart reshoring in massively modular industries: The case of ICT*

*Based on preliminary results from the project: *The prospects for decoupling in massively modular industries*

Eric Thun, Oxford Saïd Business School

Daria Taglioni, World Bank Development Research Group

Timothy Sturgeon, MIT Industrial Performance Center (presenter, contact: sturgeon@mit.edu)

Mark P. Dallas, Union College Political Science Department and International Affairs Fellow, Council on Foreign Affairs

Virtual Forum for Risks in the Information Communication Technology Supply Chain
Department of Commerce, Bureau of Industry and Security

October 29, 2021

9:00 a.m. to 12:00 p.m. EDT

Context: special features of the ICT industry

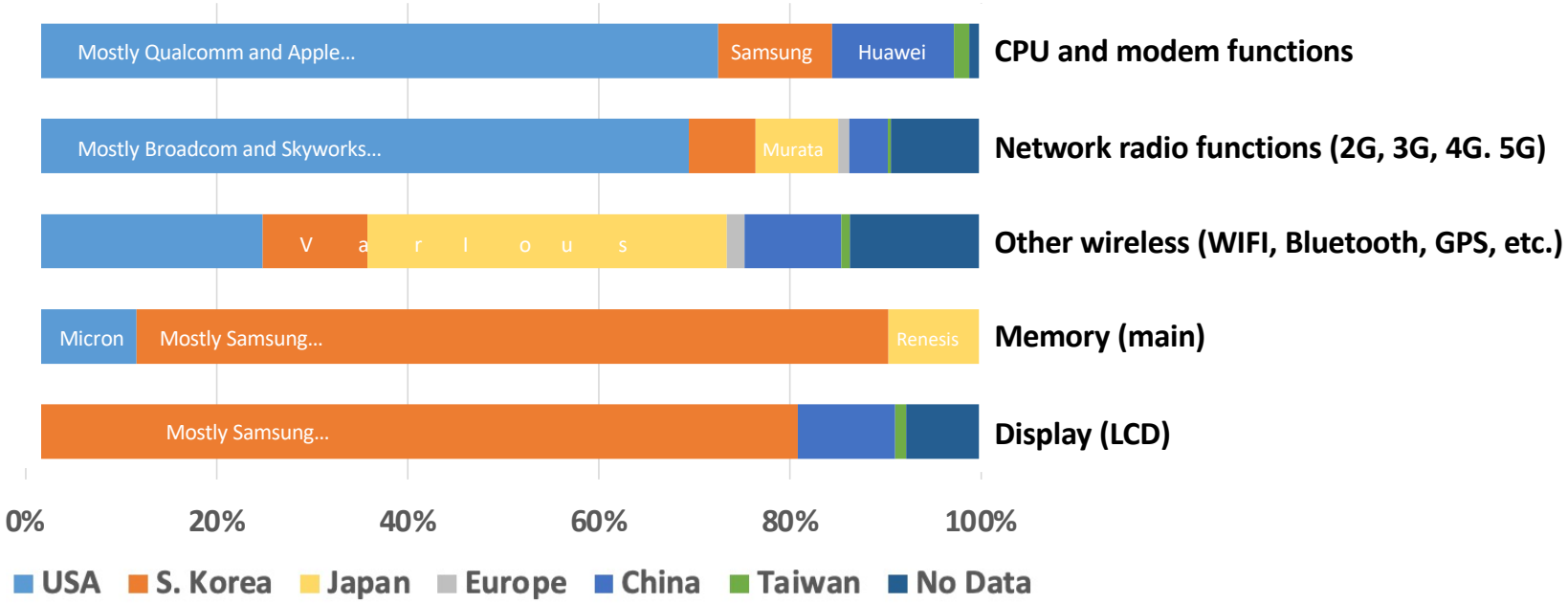
- U.S. ICT supply chains began outsourcing in the 1960s
  - IBM 360 series computer establishes a series of *de facto* industry standards that allow other firms to connect peripheral equipment
  - 1990s sees outsourcing wave, especially for product assembly
  - Fabless model gradually comes to dominate in the semiconductor industry, with some outliers (Intel, memory)
- U.S. ICT supply chains began offshoring in the 1960s
  - E.g., Fairchild and National Semiconductor established chip assembly in Penang, Malaysia in early 1970s
  - Penang has a vibrant chip assembly sector to this day
  - Epochal shift of final assembly to China for high volume products
  - By 2011, China accounted for 41% of ICT hardware exports in the 2000s
  - But an estimated 50% of export value is from imported inputs, up to 80%+ for key products ("thin industrialization")
- Hardware is modular, and software is designed in a modular fashion from the beginning
  - Software engineers share code unofficially and officially -> free software movement and open source
  - Programming languages, compilers, porting, etc. allows software to run inside and over the top *ad infinitum*
- Today, massive complexity managed via massive, layered modularity, achieved through:
  - Multi-stakeholder, *de facto*, platform APIs, or competing proprietary standards at transaction interfaces
  - Actuated by platforms/complementors, but also dominant designs and market leaders in vertical segments
  - Often build via open source resources and standard-setting processes
  - These spawn dense ecosystems consisting of platform owners, third party complementors, and open source contributors
  - Multiple, nested layers, with modularity all the way down (systems, products, sub-systems, components and software)
- The ICT industry has evolved to be highly vertically and **geographically** specialized

Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, "The prospects for decoupling in massively modular industries."

Mobile phone handsets – an example of a massively modular final goods industry:

Huge complexity, strong standards, vertical specialization, geographic specialization, global integration

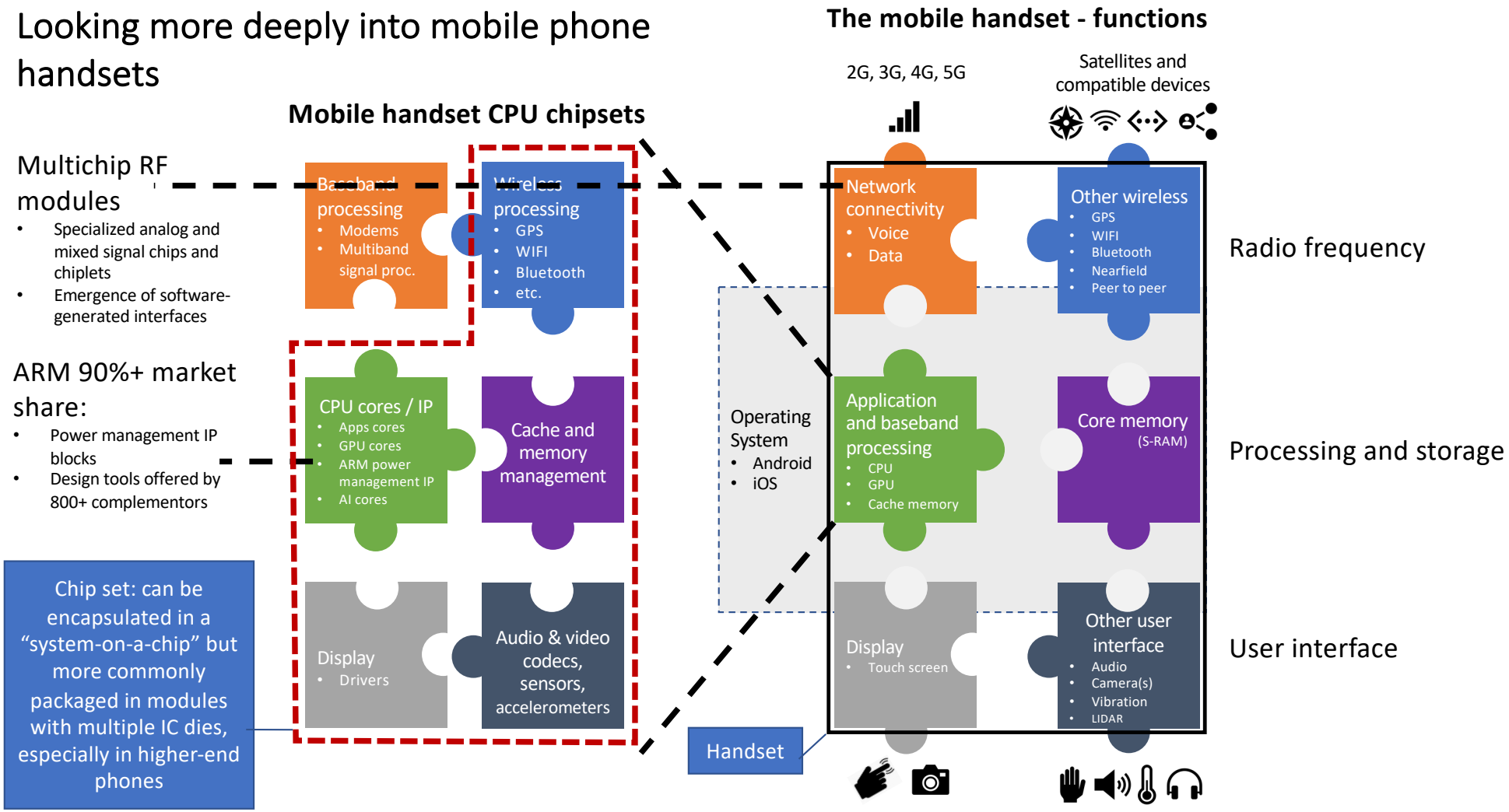
Mobile handset share of value added in main function, by geography of ownership, 2019



Data from IHS Markt device teardown reports for 40 mobile phone handsets in produced in 2019

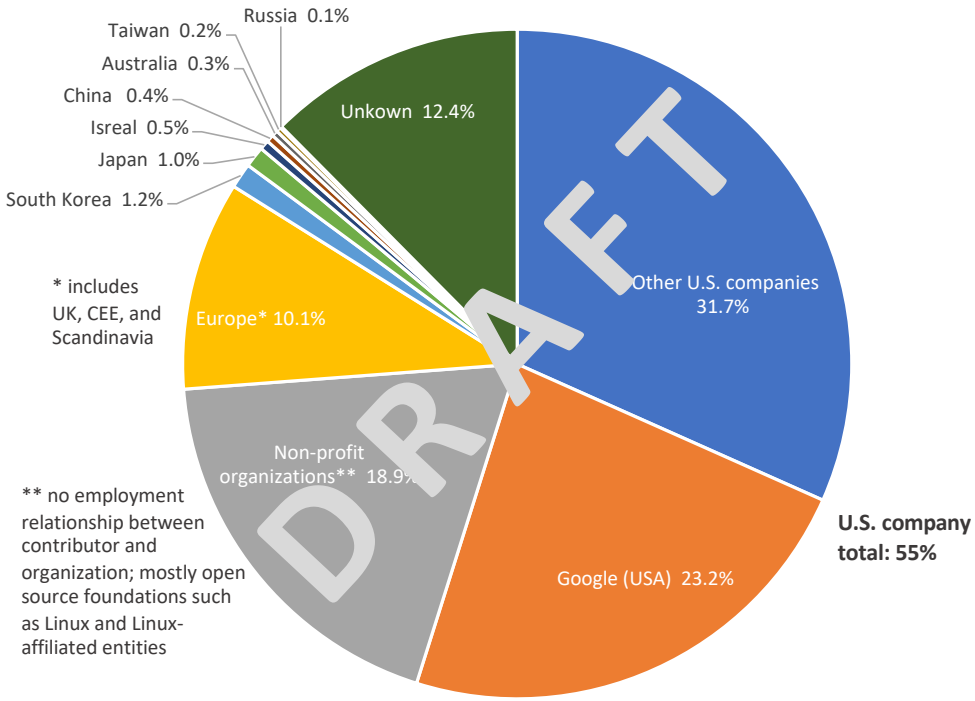
Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, “The prospects for decoupling in massively modular industries.”

Looking more deeply into mobile phone handsets



Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, "The prospects for decoupling in massively modular industries."

Contributions (code “commits”) to Google’s distribution of Android mobile phone OS
(many millions since 2008)



* includes UK, CEE, and Scandinavia

** no employment relationship between contributor and organization; mostly open source foundations such as Linux and Linux-affiliated entities

U.S. company total: 55%

- Android is open/not open
  - Android is "open" in terms of revealing source code but Google ensures users remain anchored to its ecosystem by controlling releases, contributing key code, writing app APIs, and providing key apps and functions such as maps, search, GooglePlay, and security.
  - It is possible to make phones using a non-Google version of Android, but it is difficult to gain user acceptance outside of China
- Corporate contributors get
  - Faster time to market for Android compatible products
  - Major contributors (681 contributors have more than 900 commits) may receive beta versions from Google
  - Deeper understanding of a key technology
- Major individual contributors get
  - Glory among peers
  - Stronger resumes

Android OS is used in about 85% of the world’s touchscreen smartphones

Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, “The prospects for decoupling in massively modular industries.”

Massive modularity relies on a variety of standard-setting mechanisms

Standards and standard-setting in mobile telecom (a partial list…)

Function	Standard establishment process	Examples	Key actor(s)	Key benefit
Operating systems	*De facto* standard platform ecosystem APIs	Android & Google Play iOS & App Store	Google partially open Apple proprietary	Provides network scale effects from two-sided platforms
Network connectivity	Multistakeholder standard setting body	2G, 3G, 4G, 4G 5G	3GPP 3GPP and OpenRAN alliance	Public goods Faster time to market Generates license fees from standard essential patents
Application processors (CPUs)	Internal designs *De facto* dominant designs (2 main choices)	Apple A-series Huawei Kirin Samsung Exynos Qualcomm (high & low end) MediaTEK (low end)	Internalization Market competition	Allows higher performance (high end) Facilitates product design (low end)

Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, “The prospects for decoupling in massively modular industries.”

There are many more open source initiatives and multistakeholder standard-setting bodies supporting functionality in mobile telecom and the ICT industry more broadly

Open source operating systems

- Linux used as an OS in most servers, TVs, watches, cameras, routers, printers, home appliances, and some automotive sub-systems
- Linux Foundation and offshoots; commercial implementations and tools (e.g., Red Hat) etc.

Wireless connectivity (with the internet)

- WIFI Alliance (1k+ companies)

Wireless connectivity (with compatible devices)

- Bluetooth Special Interest Group (36k companies)

Proximate communication (nearfield)

- E.g., mobile payment
- ISO/IEC JTC 1 (international standard setting body, 1 member from each country)

Geolocation

- US/Russian/Chinese/etc. government agencies (GPS/GLONASS/BeiDou/etc.)

Physical connection between devices

- Universal standard bus (USB): physical connection to devices
- USB Implementers Forum - 1,100 company members

Semiconductor packaging and circuit board assembly roadmapping

- Methods for defining and describing interconnects to substrates
- Assembly technology road mapping, technical planning, test deployment projects, etc.
- International Electronics Manufacturing Initiative (iNEMI, 92 company members)

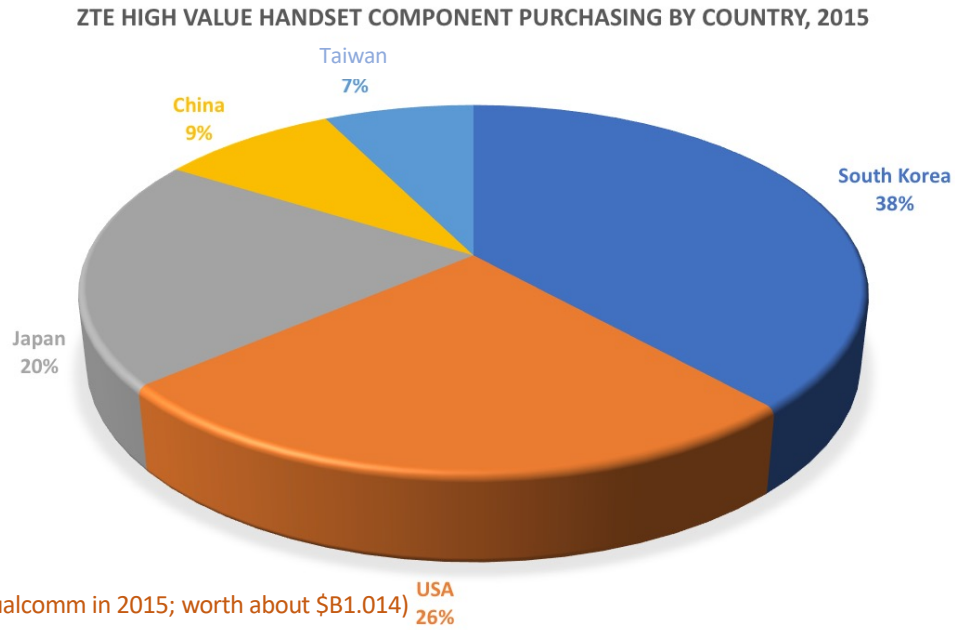
…and so on: ALL are globally distributed

Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, “The prospects for decoupling in massively modular industries.”

Geopolitical context: the ICT industry developed this massive global technology, standards, and business ecosystem during in the context of neoliberal geopolitics

- Multinational enterprises, standard-setting organizations, and individual technologists in the ICT sector perceive themselves to be relatively stateless (1990-2017)
  - Global operations, global markets
  - ICT enables distributed work, global supply chains, and some level of global coordination
- Corporations are reminded that headquarters location matters a lot (2018-present)
  - ZTE operations shut down overnight by U.S. Commerce Department action
  - Has not filtered down to open source technology resources…(yet)
  - Has not filtered down to multistakeholder standard-setting organizations…(yet; but, Open RAN in 5G?)

This situation changed dramatically after 2018

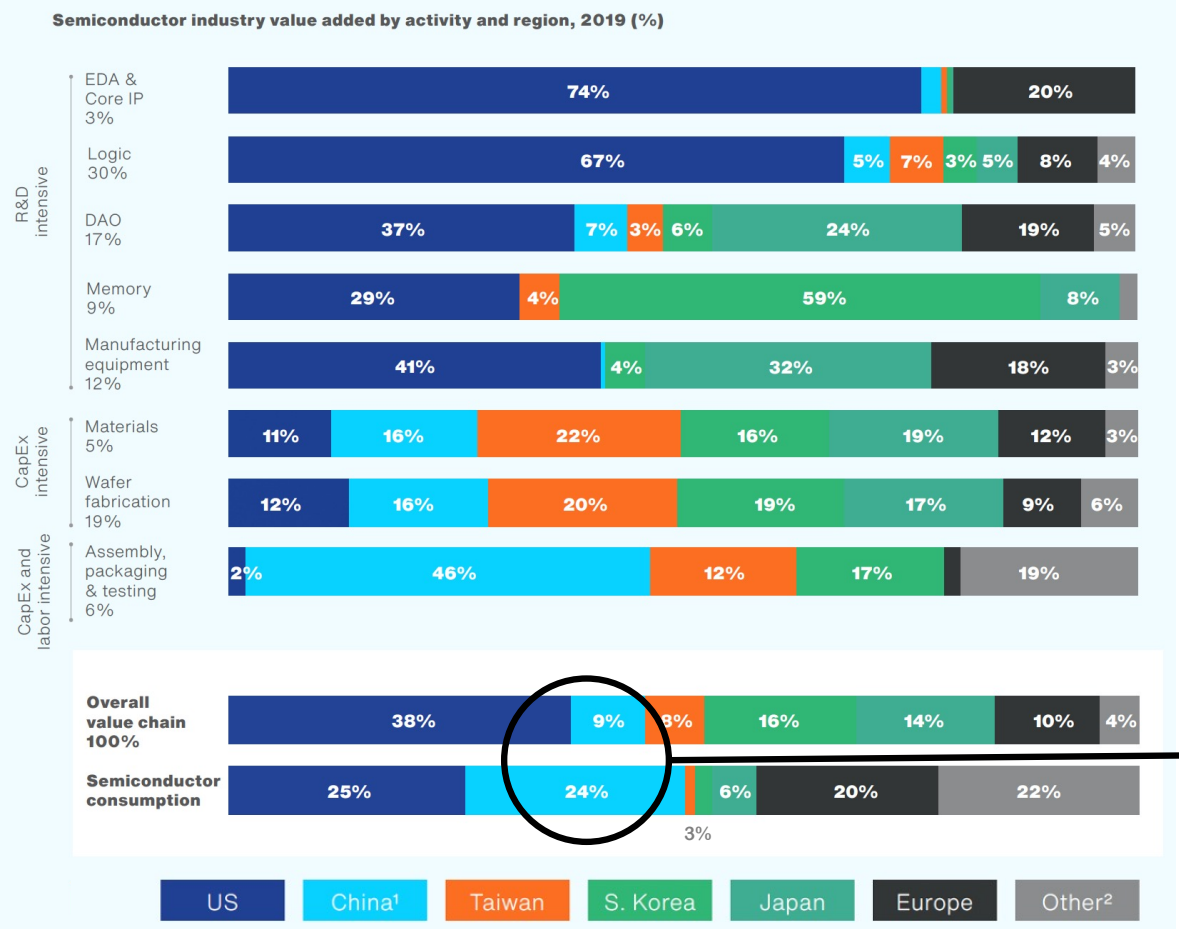


(94.7% of CPUs were from Qualcomm in 2015; worth about $B1.014)

Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, "The prospects for decoupling in massively modular industries."

Semiconductors as a massively modular intermediate input industry:

Huge complexity, strong standards, vertical specialization, geographic specialization, global integration



Design tools

CPUs etc. (digital chip design)

Discrete, analog, optical, and other

Memory

Chip production equipment

Materials (wafers, chemicals, etc.)

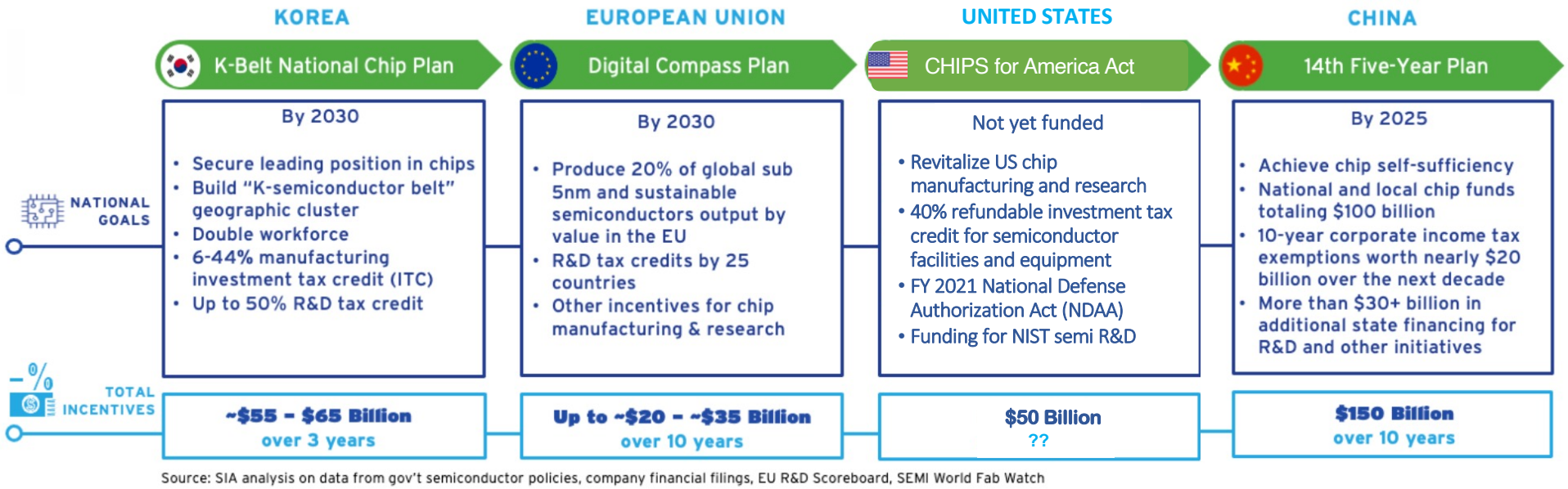
Chip production

Chip assembly and test

Mismatch between value added and consumption creates geopolitical tensions and pressure for import substitution by China

Source: BCG and SIA, 2021

And so, state intervention ramps up: current semiconductor industrial policy push



Source: SIA analysis on data from gov't semiconductor policies, company financial filings, EU R&D Scoreboard, SEMI World Fab Watch

Massive Modularity: industry examples

- Semiconductors
  - Began with the outsourcing and offshoring of chip assembly in the 1970s
  - Increased with the rise of the fabless business model in the 1980s
  - Specializations developed with new capabilities in Japan in the 1980s and S. Korea in the 1990s
- Mobile telecom
  - Standards-driven commonality in national and regional markets
  - Increased outsourcing with deregulation on the 1980s
  - The rise of mass consumer products with the mobile handset in the 1990s
  - Encapsulation of handset system design by Android in the mid-2000s
- Computers and servers
  - Began with IBM opening come of its architecture to 3rd parties in the 1970s (system 360)
  - Increased with the IBM and Apple PCs in the 1980s
- Digital services, IoT, and software in general
  - Software-based products and services have been modular from the outset, especially with software for Apple and IBM compatible PCs in the early 1980s
  - JAVA, open source programming languages, HTML, etc.
  - Google BERT and other open source training data for natural language processing, visual classifications, and machine learning
  - And so on…

Special features of the ICT industry are becoming more generalized

- Digitization of business processes across the broad economy…. **Nuff said for now!**

Implications for policy

1) If industries are moving in the direction of Massive Modularity, then the trend is moving in the opposite direction of policies that assume (or hope) that they are easy to decouple or replicate

- China's attempts to recreate the entire semiconductor and telecom value chains domestically will very likely fail and/or come at an excruciatingly high cost in terms of:
    - CAPEX
    - Product and system functionality
    - Loss of export scale/revenue
    - Ongoing technological learning
    - Human resource development
- The U.S.'s intention to engage in "smart reshoring" in highly complex, massively modular industries will require:
    - The crafting of industry and niche-specific interventions that may not be manageable through policy and,
    - come with its own extremely high price tags, even for selective ("smart") reshoring

2) U.S. based companies and organizations are in a very strong position in ICT, and when close U.S. allies are included, can be considered dominant across the entire ecosystem with only a few exceptions

3) Accretion of massive vertical and horizontal scope, with requirements for backward compatibility and interoperability, and encapsulation of legacy technologies and IP, allow a series of cybersecurity nightmares

- Solarwinds, JBS, infrastructure ransomware attacks, etc.
- Does not appear to be solvable through patching
- Can we have secure ICT without tearing software-based systems (and the Internet) down and starting over?

Some rules of thumb for understanding ICT-driven, Massively Modular industries

Scale:

- Digital technologies allow systems to exhibit "functional accretion" over time
- Digital technologies are usually backwardly compatible with older systems
- Digital systems and ecosystems are highly scalable

} Digital ecosystems systems are hugely complex and can grow to hyperscale

Specialization:

- Hyperscale ecosystems require hyper-specialization within modular industry architectures (no firm can do everything)
- Hyper-specialization can lead to market concentration within specialties (few firms can do the specialty well)
- Specialties tend to be rooted in particular countries (technical specializations tend to be deeply rooted)

} Geographic vertical specialization can give rise to geopolitical tensions and pressures

Pay attention to the glue (standards) that hold ICT ecosystems together, not only the building blocks (hardware and software)

Source: Thun, Taglioni, Sturgeon, and Dallas, forthcoming, "The prospects for decoupling in massively modular industries."