Supplemental Material: PROCEDURES AND RESULTS OF APPLYING SC-RI TO MICROCHIP SC

Microchip SC general description

The manufacturing of microchips is complex, involving thousands of suppliers and hundreds of different raw materials or middle products. For simplicity and feasibility of this study, microchip manufacturing processes were categorized into three key areas: (1) design, (2) front-end fabrication in a semiconductor fabrication plant (fab) and (3) back-end ATP (Platzer et al,2020). Key elements of the microchip SC based in the U.S., including entities and commodity flows involved in fab were included in this analysis. The end product of the microchip SC is the semiconductor wafer (WAFE). The ATP plants (ATPPs) are assumed to be the end customers. For the existing microchip SC, the capacity of domestic fabs was set equal to the related domestic capacity at the end of 2020 (0.73 million 12-inch equivalent wafers per month (IC Insights, 2021)). Nationwide, demand was set to the capacity of all fabs of companies headquartered in the U.S., or 1.65 million 12-inch equivalent wafers per month (IC Insights, 2021). Domestic capacity was expanded to satisfy this demand for the reshoring SC scenario.

SC-RI Module 1: SC-Profiling

Existing and Potential Entities and Connections

In this microchip SC, the domestically produced wafer (WADP) begins with the chemicals (CHEM) produced by domestic chemical suppliers and raw wafers (RAWW) imported from overseas (Khan, 2021). In fabs, CHEM and RAWW are processed into WADP, which flow to the distributors and, finally, for ATP, creating the final microchip end-products. Any unsatisfied demand was assumed to be filled by imported wafer (WAIP) arriving through one or more of the 48 modeled U.S.-based ports. The microchip SC in this study, thus, consists of the direct suppliers of CHEM, direct suppliers of RAWW, fabs, ports handling the WAIP, distributors, ATPPs, along with the major commodity flows, as depicted in Figure S1. The sources of data used in creating this SC materials flow representation are given in Table S1.

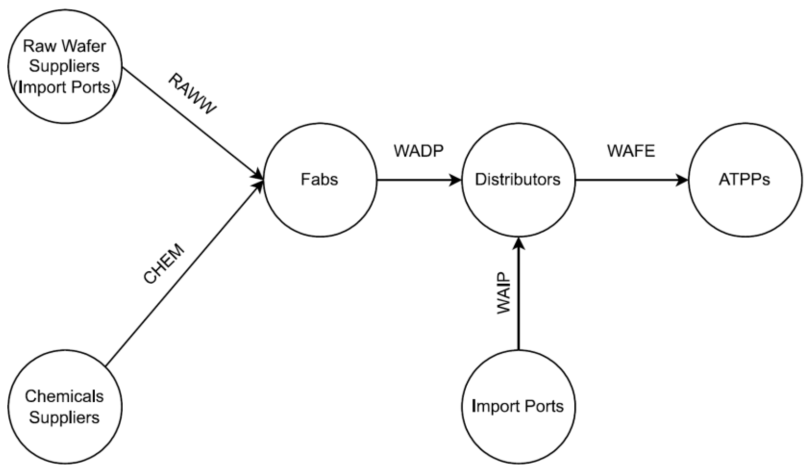


Figure. S1. General layout and Material flow in microchips Front-end fabrication SC network

Supply and Demand Attributes

All suppliers of raw or middle-products, except fabs, were assumed to have unlimited capacity. The capacities at the identified fabs are listed in Table S2. The demand for WAFE of each inhouse ATP (IATP) is assumed equal to the current total capacity of the fabs owned by the IATP's parent company, and the demand for the only outsourced ATP (OSAT) in the U.S. is assumed to be the difference between the nationwide demand and the sum of all IATP demand.

Parameters for Cost Estimation

Parameters for microchip SC cost estimation are listed in
Table S3.

Bill of Material (BOM)

According to TSMC (2012), to produce 14 million WADP, 15.4 million RAWW, 1.6

million cubic meters of process chemicals and 0.1 million tons of bulk chemicals are needed. Raw materials flow required for 12-inch equivalent wafer manufacturing is shown in Figure S2.

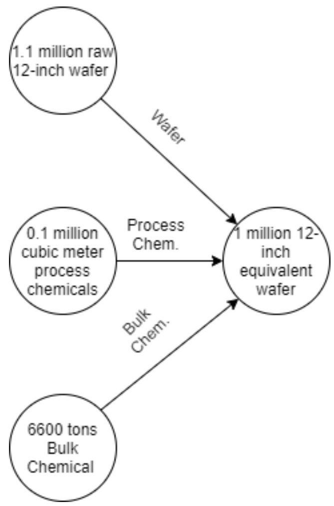


Figure S2. Major Material flow and BOM in microchips Front-end fabrication of 12-inch equivalent wafer

SC-RI 2: SC Structure and Commodity Flow Analysis

The SC as it exists currently and the SC as restructured or expanded for production growth, along with related commodity flows through the SC, if not known, are approximated through solution of a pair of mathematical models multi-commodity, multi-echelon, fixed-charge facility location problems in the SC-structure and commodity flow analysis submodule, an approach used in prior works that have replicated SCs for strategic applications (e.g., Smith et al., 2017, Ottemöller and Friedrich, 2019) and design (Hajibabai et al., 2014) efforts. This modeling approach determines an idealized SC network structure with flows of goods and materials given potential suppliers of raw materials and middle products, manufacturing plants, and distribution facilities. In expansion applications, added capacity levels are also determined. An objective of minimizing total costs guides these models. Detailed equations of the modeling are provided in the Appendix in the main manuscript.

After solving the two facility location problems, the layout (selected entities and commodity flows) of the existing microchip and post-reshoring SCs are presented in Figure and S6, respectively. Note the emphasis on expanding operations in California, New Mexico, Arizona, Texas and portions of the Northeast. This aligns well with recent announcements for plant expansion (e.g., Wu and King (2020) and Sohn (2021)). The maps show the commodity flows in the microchip SC in 5 colors. The dominant result is shown in red and represents chemicals (CHEM) used in large quantities. The remaining lines associated with other commodity types are present in the figure, but with significantly lower flow volumes that are difficult to visualize. Thickness of these lines are tripled for visibility.

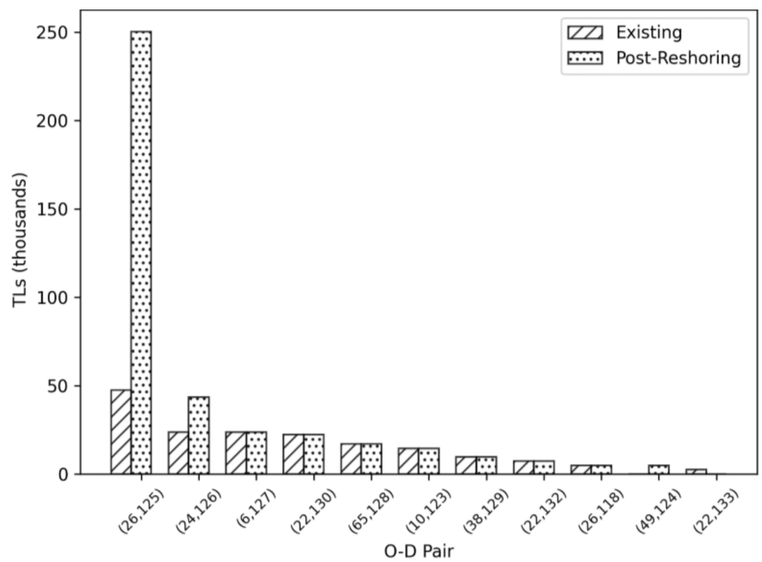
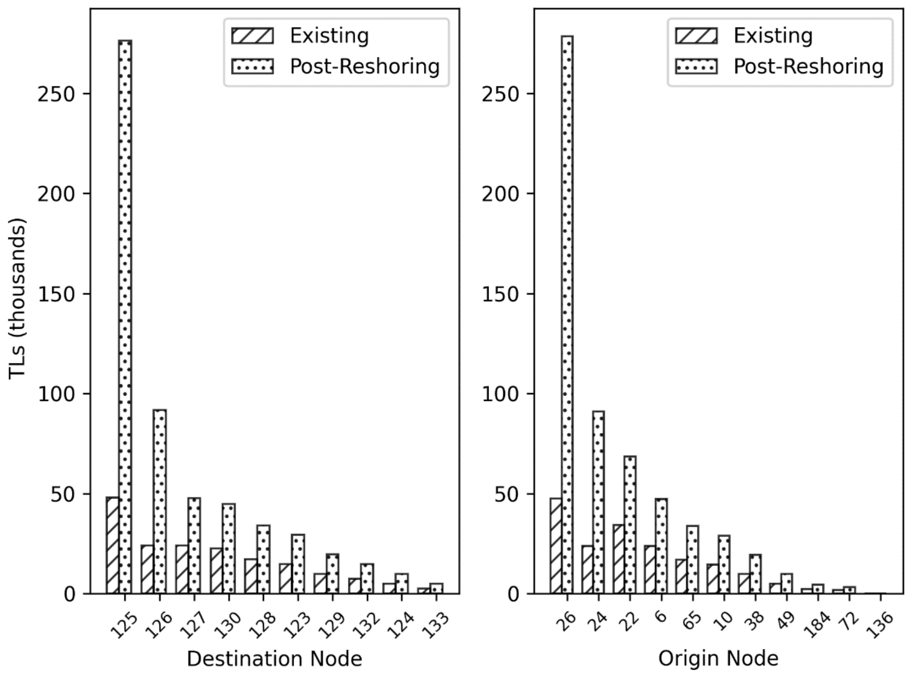


Figure S3. Comparison of Top 10 O-D pair flows in exiting and post-reshoring microchip SC



(a) (b)

Figure S4. Comparison of top 10 inbound (a) and outbound (b) flows in existing and post-reshoring microchip SC

The aggregated value of the top 10 O-D pair commodity flows (Figure S3) and top 10 inbound ((a) of Figure S4) and outbound ((b) of Figure S4) flows during the 2-year case study period are provided (with involved cities provided in Table S5).

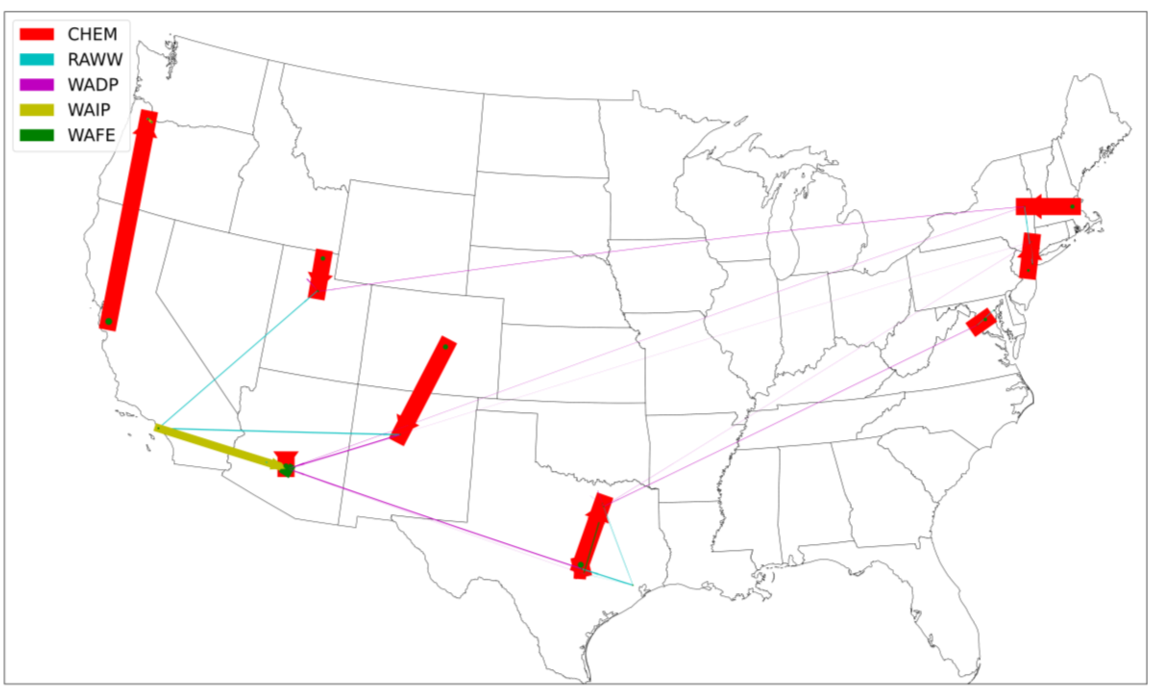


Figure S5. Layout of existing microchip SC

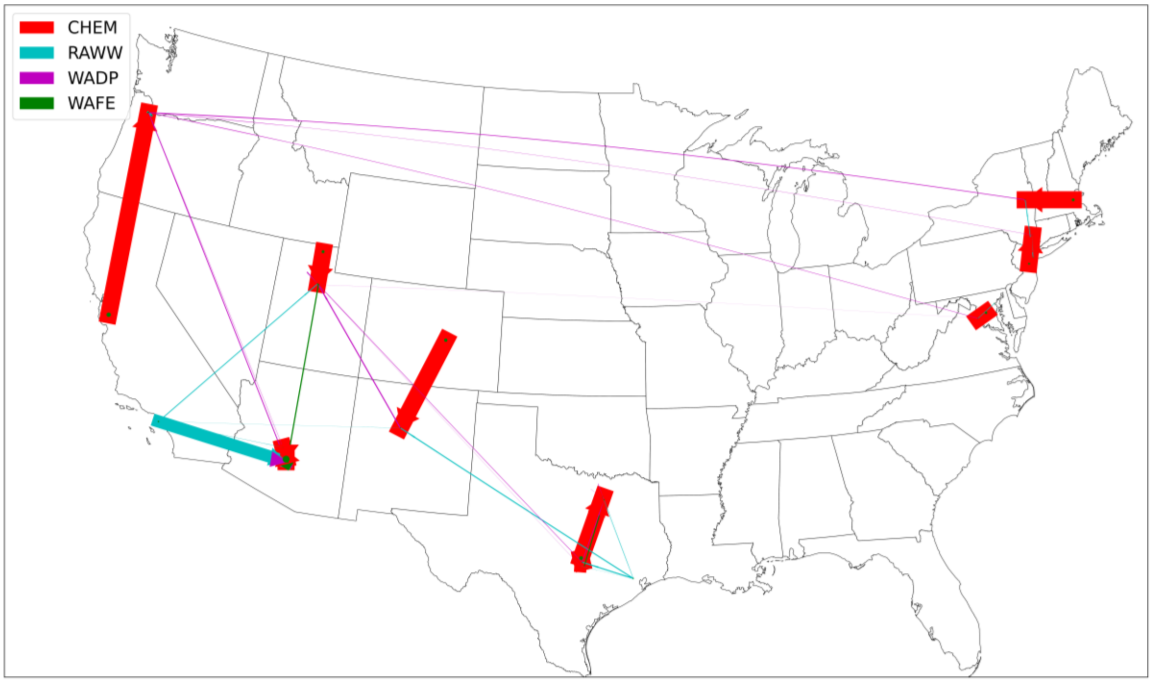


Figure S6. Layout of post-reshoring microchip SC

SC-RI 3: Impact Analysis

The Impact Analysis module quantifies the impacts of increasing domestic production on national roadways. These impacts include: (1) traffic congestion, (2) roadway maintenance costs, (3) domestic fuel consumption and related emissions, and (4) truck accidents and hazmat incidents (Chen et al., 2023).

TMs and TLs of different SC segments for microchip SC are provided in Table S3.

Table S1. Data sources for the location of entities in each echelon

Entity echelon	Data source	Comments
Container ports	HIFLD database (U.S. DHS, 2020).	They are the 48 continental ports in the Major Ports file with GRAND_TOTAL value over 10 million.
Chemical suppliers	Khan(2021)	Locations for Entegris (24 locations), Emdgroup (9 locations), and Dupont (39 locations) are identified from the official website of each corresponding company.
Fabs	Platzer et al.(2020)	Plants names and locations in Table S2
ATPPs	Khan(2021)	In-house ATPPs owned by the fabs' parent company are assumed at the same locations of the fabs.

Table S2. Capacity for the major U.S.-based fabs

Company	Number of fabs	Location	Current Capacity (12-inch equivalent)	Comments
TSMC	1	Phoenix, AZ	0	According to (Shilov, 2020), TSMC currently has no production in Phoenix, AZ
Samsung	0	Talyor,TX	0	According to (Sohn, 2021), these are 4 possible locations Samsung may setup new fabs.
Samsung	0	Queens_Creek,AZ	0	
Samsung	0	Genesee_County,NY	0	
Samsung	0	Goodyear,AZ	0	
GlobalFoundries	2	Malta, NY	60,000	(Encyclopedia, 2021b)
GlobalFoundries	1	East Fishkill, NY	20,000	(Moorhead, 2019)
Intel Corporation	2	Chandler, AZ	98,000	(Flaherty, 2021)
Intel Corporation	4	Hillsboro, OR	197,000	
Intel Corporation	2	Albuquerque, NM	98,000	
Micron Technology	1	Lehi, UT	70,000	(Encyclopedia, 2021a)
Micron Technology	2	Manassas, VA	40,000	(Robertson, 2003)
Samsung	2	Austin, TX	92,000	(Encyclopedia, 2021a)
Skorpios	1	Austin, TX	10,000	
Texas Instruments	1	Richardson, TX	30,000	(Lammers, 2003)
Texas Instruments	1	Dallas, TX	10,000	

Table S3. Cost estimation for microchip SC

Cost type	Cost parameter	Parameter value	Comments
Investment cost	Fabs fixed opening cost	$800 million	Assumed
	Other facility fixed opening cost	$240,000 per year	For a $12/year/sqft. rental price (LoopNet.com, 2021) with the industry space for a typical plant at roughly 20,000 sqft. (Schmidt, 2020)
	Fixed expansion cost for all facilities	$2 per day	Ivanov (2017)
	Fabs expansion cost (a unit of 20,000 wafer per month)	$2.72 billion	Estimated based on TSMC fab18 (capacity at 120,000 WPM) with total investment cost at $17.08 billion
	Other facilities	$2 per day	Ivanov (2017)

	expansion cost		
Transportation cost	TL rate	\$3.2/mile	(Williams, 2020)
	Truck Capacity	22.7 m^3	(SafeRack's Industrial Index, 2020)
	Chemical's density	1000 kg/m^3	Most of the chemicals are fluids in normal pressure.
	Wafer packaging	0.34m*0.42m*0.33m (25 unit)	(Entegris, 2020)
Procurement cost	Raw wafer and chemical	\$117 per wafer	Based on material cost at \$1.18 billion, with shipments at 10.1 million for year 2019 (TSMC, 2020)
Production cost	Fabs labor cost	\$1776 per wafer	Based on manufacturing cost at \$17.94 billion, with shipments at 10.1 million for year 2019 (TSMC, 2020)

Table S4. Comparison of TMs and TLs for microchip SC

	TMs (Thousand)			TLs		
Commodity	Existing	Post-reshoring	Increase	Existing	Post-reshoring	Increase
CHEM	47171	46589	-582	174773	402091	227318
RAWW	485	1389	904	1691	3885	2194
WADP	780	1160	380	1541	3535	1994
WAIP	644	0	-644	1995	0	-1995
WAFE	58	58	0	3529	3529	0
Raw/Mid.	47656	47978	322	176464	405976	229512
Final prod.	1482	1218	-264	7065	7064	-1
Total	49138	49196	58	183529	413040	229511

Table S5 Selected entities in the microchip SC with host cities

Entity ID	City Name	Company name	Facility description
125	Chandler, AZ	Intel Corporation	Fab plant
126	Hillsboro, OR	Intel Corporation	Fab plant
127	Albuquerque, NM	Intel Corporation	Fab plant
130	Austin, TX	Samsung	Fab plant
128	Lehi, UT	Micron Technology	Fab plant
123	Malta, NY	GlobalFoundries	Fab plant
129	Manassas, VA	Micron Technology	Fab plant
132	Richardson, TX	Texas Instruments	Fab plant
124	East Fishkill, NY	GlobalFoundries	Fab plant
133	Dallas, TX	Texas Instruments	Fab plant

26	Tempe, AZ	Versum Materials US, LLC	Chemical supplier
24	San Jose, CA	Intermolecular, Inc.	Chemical supplier
22	Round Rock, TX	Entegris	Chemical supplier
6	Colorado Springs, CO	Entegris	Chemical supplier
65	Logan, Utah	DuPont Holographics	Chemical supplier
10	Bedford,MA	Entegris	Chemical supplier
38	Washington, D.C.	Micron Technology	Chemical supplier
49	Parlin, New Jersey	DuPont Holographics	Chemical supplier
184	Tempe, AZ	Amkor	Processed wafer distributor
72	Los Angeles, CA	Port	Raw wafer supplier
136	Los Angeles, CA	Port	Import port
118	Phoenix,AZ	TSMC	Fab plant

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