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The Semiconductor Industry in the Age of Trade Wars, Covid-19, and Strategic Rivalries*

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Abstract

Semiconductors are vital for countless applications. The pandemic generated a surge in IT spending and produced a shortage of semiconductor devices. The semiconductor industry also faces geopolitical challenges as many fear the concentration of production in East Asia. This paper examines the challenges the industry faces and considers possible solutions.

Keywords: Semiconductors, Coronavirus crisis, Geopolitical risk

JEL classification: F13, F23

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1. Introduction

Integrated circuits are vital not only for smartphones, computers, and other electronic goods but also for countless other products. Microchips power automobiles, toasters, robots, refrigerators, and airplanes. In addition, cutting-edge chips drive artificial intelligence and other applications that are crucial to national defense. It is little wonder that policymakers focus on securing a stable supply of semiconductor devices.

In 2017 President Trump launched a trade war against the Chinese semiconductor industry. The Trump Administration initiated an unfair trade investigation into opaque subsidies to Chinese semiconductor firms. It then tightened the screws for national security reasons, forbidding sales by U.S. firms to Huawei, Semiconductor Manufacturing International Corporation (SMIC), and other Chinese firms. It also restricted the sale of U.S. technology to firms abroad that supplied semiconductors to these entities.

As Trump's actions were sewing uncertainty in the semiconductor industry, the COVID-19 pandemic whipsawed the sector. When coronavirus news hit the world stage in February 2020, the bleak macroeconomic outlook caused semiconductor stock prices to fall by 30 percent in Taiwan and by more in South Korea and Japan. Automakers facing lockdowns canceled orders for chips. As individuals began working from home, spending on information and communication technology (ICT) soared. This increased the demand for chips. When demand for automobiles recovered later in 2020, semiconductor manufacturers lacked devices to sell to automakers. The shortage of these devices that might cost only 2 dollars forced car plants to shutter production (see, e.g., Jung-a, 2021).

The next section recounts the history of the semiconductor industry from its founding until the present. Section 3 presents evidence of how the COVID-19 crisis has impacted this sector. Section 4 draws policy lessons.

2. A Brief History of the Semiconductor Industry

The transistor was invented at Bell Labs in New Jersey in 1946. Tadashi Sasaki was in New Jersey at the time. Sasaki had studied electrical engineering at Kyoto University and Dresden University and worked with Karl Spangenberg from Stanford University on minimizing the space between a cathode emitting negatively charged electrons and the gate leading to the electrode (Aspray, 1994). Sasaki grasped the potential of the transistor and sought applications for consumer goods. While U.S. electronics firms serviced lucrative military contracts, Japanese firms were not allowed to and focused instead on hyper-competitive consumer markets.

Sasaki envisioned revolutionizing consumer electronics by adding transistors to an integrated circuit. This would enable goods to be miniaturized. He encouraged his company, Hayakawa, to produce pocket calculators (Aspray, 1994). His engineers doubted his plan but studied the technology at Osaka University (Johnstone, 1999). Hayakawa decided they needed to use complementary metal oxide semiconductors (CMOS) chips to save power. Japanese companies were unwilling to produce this, so Sasaki turned to the American company Autonetics. Autonetics provided inputs to missiles, fighter jets, and other weapons. These applications were lucrative, and producing integrated circuits for calculators offered low margins. Sasaki nevertheless convinced Autonetics by arguing that they would learn by doing, improving yields and increasing profits. In 1969 Hayakawa introduced the

Sharp QT-8D calculator with four integrated circuits produced by Autonetics that each contained 900 transistors. Hayakawa then asked RCA to produce liquid crystal displays (LCDs) for Hayakawa's calculators to save energy. RCA refused because it considered consumer electronics to be unprofitable. Hayakawa thus had to master producing LCDs itself and Sasaki stated that this was one reason why Hayakawa succeeded (Aspray, 1994). By 1975 Hayakawa (renamed Sharp) would produce 10 million calculators.

As calculator production soared, Japanese semiconductor companies that had previously refused to supply Hayakawa now complained to the Ministry of International Trade and Industry (MITI) that Japanese producers were purchasing integrated circuits from the U.S. MITI then prohibited Japanese companies from buying U.S. microchips (Johnstone, 1999). Autonetics, that had been promised the benefits of the learning curve, was thus no longer able to produce for Sharp.

Sharp and other Japanese companies mastered CMOS technology while U.S. companies preferred PMOS (positive channel MOS) and NMOS (negative channel MOS) chips. CMOS was developed by the U.S. company Fairchild Semiconductor. Sasaki and other Japanese engineers saw the potential of CMOS to reduce power requirements and facilitate miniaturization. U.S. firms missed the potential that CMOS offered for the consumer market and focused on the more powerful PMOS and CMOS technologies and military applications. When the industry standard in the 1980s turned to CMOS, Japanese firms were in the pole position.[i] Bown (2020) reported that in 1980 three of the four leading semiconductor firms by revenues were American while in 1990 three of the top four were Japanese. Bown also noted that Japanese firms leapfrogged in the Dynamic Random Access memory (DRAM) sector, with their share the market rising from less than 30 percent in 1978 to over 75 percent in 1986 (see also Irwin, 1996).

As Bown (2020) noted, U.S. manufacturers responded to the Japanese juggernaut by lobbying for protectionism. They initiated a Section 301 case against Japan, arguing that U.S. firms lacked access to the Japanese market. One of their complaints was that the Japanese government in the past had overtly excluded U.S. semiconductor firms from the Japanese market. The case of Autonetics not being allowed to supply Hayakawa was an example of this. The U.S. government also launched three antidumping case claiming that Japanese firms sold chips in the U.S. below their fair value. Bown reported that the U.S and Japan reached an agreement in 1986 hinting that Japan would allocate 20 percent of the Japanese semiconductor market to U.S. firms and that Japanese firms would limit export quantities and raise prices. Determining market shares by government decree represented a sea change for U.S. trade policy (Irwin, 1996).

The voluntary export restraint that Japan agreed to opened a door for South Korean firms. South Korea faced the constant threat of invasion from North Korea. South Korean President Chung-Hee Park prioritized economic development as a means of facing this threat. His government allocated bank loans to firms in order to export, and only continued directing loans to successful exporters. Korean workers took the export imperative seriously, and worked hard to make their companies successful (Pecht et al., 1997).

Samsung founder Byung-Chull Lee prioritized DRAM chips as an area where Samsung could export and succeed. Investment requirements are heavy for semiconductors, and Samsung was able to borrow because of the implicit government guarantees. Samsung purchased DRAM technology in 1983 from the American company

Micron. Korean engineers then studied semiconductor technology day and night in the U.S. On their return to Korea they attained high yields. While Japanese firms were constrained to export at higher prices and limited quantities to the U.S., Korean firms could sell at these higher prices without any quantitative restrictions. Samsung channeled the revenues that resulted into research and development (R&D) and capital formation, and in the early 1990s became the leading producer of DRAMs. It retains this distinction in 2021. Korea's SK Hynix in 2021 is the second leading producer.

While Korea dominates in DRAM and other memory chips, Taiwan has focused on logic chips. As South Korea faced the threat of invasion from North Korea when it developed its semiconductor industry, Taiwan faced the threat of war with China. Taiwan in the 1970s also was decimated by inflation following the 1973 oil crisis and lost access to Japanese capital goods in 1974. In this crisis environment it turned to economic development as a means of national survival. Many Chinese researchers in the U.S. sympathized with Taiwan, and shared their expertise free of charge. Wen-yuan Pan, director at RCA's David Sarnoff Laboratories, chaired the Technical Advisory Committee (TAC) of researchers from leading U.S. universities and firms.

Pan recommended that Taiwan develop a semiconductor industry, and the TAC advised that Taiwan begin with a mature technology. As Lin and Rasiah (2014) noted, Pan recommended that Taiwan spend an enormous sum for its economy ($10 million). Taiwan established the Industrial Technology Research Institute (ITRI) to oversee its technology development. Taiwan purchased semiconductor technology from RCA, and ITRI recruited 40 engineers. Some had PhDs from U.S. universities. These engineers worked hard to master the technology, and ITRI spun off United Microelectronics Corporation (UMC) in 1979. The ITRI continued to nurture technological development, and in 1987 spun off the Taiwan Semiconductor Manufacturing Company (TSMC). As Lin and Rasiah discussed, TSMC did not design integrated circuits itself but rather made these based on its customers' specifications. According to Bown (2020), in 2020 TSMC is the third largest semiconductor firm by revenue in the world.

Malaysia sought to imitate Korea and Taiwan in using industrial policy to develop a cutting-edge semiconductor industry. However, unlike Korea and Taiwan, Malaysia faced no existential threats.[ii] Malaysia established the Malaysian Institute of Microelectronics Systems (MIMOS) in 1985 to function as ITRI did in Taiwan. MIMOS created the semiconductor firm Silterra in 2000. However, as Rasiah (2017) documented, the Malaysian government did not choose the most qualified candidates to lead Silterra and other institutions. Since the 1970s Malaysia sought to promote indigenous citizens (*Bumiputera*) over Malaysians who are ethnically Indian or Chinese. Rasiah noted that Malaysia did not choose Loh Kin Wah, the managing director of the German company Qimonda, to head Silterra. The government also withheld grants from the most dynamic electronic firms if they were not led by *Bumiputera* and continued bestowing benefits on indigenous firms even if their performance was poor. Malaysia's emphasis on redistribution generated rent seeking activity and its semiconductor industry never progressed to higher value added activities such as design, R&D, and manufacturing.

China has become the largest consumer of semiconductors and uses these to produce final electronics goods. Bown (2020) noted that 90 percent of smartphones, 67 percent of smart televisions, and 65 percent of personal computers are made in China. Bown also reported that China's exports of semiconductors now comprise 20 percent of the world's total. These exports, however, are lower-end chips while its imports are cutting-edge devices. The Chinese government is using opaque subsidies to promote its domestic semiconductor industry and pursue self-sufficiency.

Bown (2020) recounted how these subsidies and national security concerns caused the Trump Administration to launch a trade war against the Chinese semiconductor industry. In 2017 the U.S. government initiated a Section 301 investigation into unfair trade practices. This resulted in 25 percent tariffs against Chinese chip imports. In 2019 the U.S. targeted the Chinese company Huawei. Huawei was a leading player in producing equipment for fifth generation (5G) telecommunications networks. The U.S. feared that Huawei might be required to provide sensitive military and civilian data that it obtained to the Chinese government. The Trump Administration then restricted sale of U.S. chips to Huawei. However, Huawei was able to obtain sufficient chips from Taiwan, South Korea, and other places. The U.S. then said that any foreign semiconductor manufacturer that supplied Huawei would no longer have access to U.S. tools and technology. The U.S. in 2020 also prohibited U.S. firms from selling to SMIC without explicit government approval. In the midst of this dislocation the coronavirus crisis hit the semiconductor sector.

3. Investigating How the Coronavirus Shock Impacted the Semiconductor Industry

To investigate how COVID-19 is affecting industries this paper examines how stock returns are affected. Finance theory teaches that stock prices equal the expected present value of future cash flows. Black (1987, p. 113) observed that, “The sector-by-sector behavior of stocks is useful in predicting sector-by-sector changes in output, profits, or investment. When stocks in a given sector go up, more often than not that sector will show a rise in sales, earnings, and out-lays for plant and equipment.” The response of stock prices should thus provide information about how sectors are being affected.

The coronavirus shock began causing stock prices around the world to fall on 19 February 2020. An equation is thus estimated explaining stock returns until 18 February 2020, and then actual out of sample values of the explanatory variables are used to predict stock prices during the crisis period. The difference between actual stock prices and predicted stock prices can shed light on how the crisis is affecting the sector.

The performance of the Taiwanese semiconductor sector is investigated, since Taiwan is the most technologically advanced semiconductor maker. The performance of two key downstream sectors, consumer electronics and automobiles, is also investigated. These are investigated for Korea since it is a major exporter of both consumer electronics and automobiles.

To explain sectoral stock returns, the returns on the countries’ aggregate stock markets, the return on the world stock market, the price of oil, the nominal exchange rate relative to the U.S. dollar, and a measure of interest rates are included. There is a long tradition in finance of using the return on a country’s aggregate stock market to capture the impact of economy-wide factors on individual firms or sectors (see, e.g., Brown and Warner 1980, 1985). The return on the world stock market then captures the impact of global factors on individual entities. The price of oil has been found by many to be helpful in explaining Asian stock returns (see Thorbecke, 2019). The exchange rate is included to capture sectors’ exposure to exchange rate changes. The interest rate is included to capture the influence of monetary policy on stock returns.

The following equation is estimated:

$$\Delta R_{i,t} = \alpha_0 + \alpha_1 \Delta R_{m,t} + \alpha_2 \Delta R_{m,World,t} + \alpha_3 \Delta P_{oil,t} + \alpha_4 \Delta er_t + \alpha_5 \Delta MP_t , + \quad (1)$$

where $\Delta R_{i,t}$ is the change in the log of the stock price index for sector *i*, $\Delta R_{m,t}$ is the change in the log of the price index for either the Taiwanese or the Korean aggregate stock market, $\Delta R_{m,World,t}$ is the change in the log of the price index for the world stock market, $\Delta P_{oil,t}$ is the change in the log of the spot price for Dubai crude oil, Δer_t is the change in the New Taiwan dollar/U.S. dollar exchange rate (for Taiwan) or the Korean won/U.S. dollar exchange rate (for Korea), and ΔMP_t represents the change in the Taiwan Central Bank discount rate (for Taiwan) or the Bank of Korea base rate (for Korea). The data are obtained from the Datastream Database and from the websites of the Central Bank of the Republic of China and the Bank of Korea.

Equation (1) is estimated using daily data over the 19 January 2001 to 18 February 2020 period. Actual values of the right-hand side variables over the 19 February 2020 to 19 January 2021 period are then used to forecast stock prices. Figure 1 presents results for the Korean consumer electronics sector. Actual returns fell more than 50 percent beginning on 19 February 2020. Although the forecasted values plummeted due to the deteriorating macroeconomic environment with the advent of the crisis, actual stock prices fell more than forecasted based on the macroeconomic variables and remained below forecasted values until July 2020. Stock prices then soared and by 19 January 2020 were more than 70 percent above pre-crisis values and more than 40 percent above forecasted values. As individuals were forced to work from home, their demand for consumer electronics and other ICT goods soared. This in turn generated the large stock price gains.

Figure 2 presents results for the Korean automobile sector. Actual returns fell almost 70 percent beginning on 19 February 2020. The forecasted values due to the deteriorating macroeconomic environment fell only half as much. Actual stock prices remained below forecasted stock prices until August 2020. They thereafter posted steady gains, and by 19 January 2020 were almost 70 percent above pre-crisis values and almost 40 percent above forecasted values. As many were shuttered at home, the outlook initially looked abysmal for the automobile industry. However, with the global recovery and peoples' desire to avoid public transportation, the prospects for the auto industry brightened.

Bown (2020) noted that 75 percent of semiconductor devices flow to electronics products and the other 25 percent go to automobiles and other applications. With the outlook for electronics and automobiles improving, one would expect the semiconductor industry to also benefit. Figure 3 indicates that this is true. Actual returns on the Taiwanese semiconductor sector fell about 30 percent with the advent of the crisis. Actual returns remained close to predicted returns until the beginning of July 2020. Actual returns then far outpaced predicted returns and by 19 January 2020 were almost 70 percent above pre-crisis values and almost 30 percent above forecasted values. The semiconductor industry is thus profiting during the pandemic.

4. Policy Lessons

Semiconductors are vital for the world economy. Though they were invented in the U.S., their manufacturing has migrated to South Korea, Taiwan, and other Asian countries. The U.S. and its Western allies now perceive the risks of having so much production centered so far away. Earthquakes, fires, or wars could cut off producers in the West from these vital inputs. The U.S. and Europe are thus seeking to nurture domestic semiconductor manufacturing (see, e.g., Fleming et al. 2021). As Eric Schmidt observed, they are unlikely to succeed only by throwing money at the problem (Tanaka, 2021).

The successes of Japanese, Korean, and Taiwanese firms offer some lessons. First, lucrative government contracts are less likely to produce a strong industry than competing in world markets. U.S. electronics firms after World War II developed transistors, CMOS semiconductors, LCD displays, and countless other technological breakthroughs. These firms were often coddled by defense contracts, however, and faced little pressure to convert these technologies into marketable products. Asian firms, on the other hand, focused on exporting and competing in consumer goods markets. This discipline forced them to choose technologies carefully and adapt them to make profitable products.

A second lesson is that entrepreneurs are essential. Tadashi Sasaki had the vision to use integrated circuits to miniaturize calculators. This led to hundreds of millions of calculators being sold. Byung-Chull Lee took risks to produce DRAM chips. His success in this area helped make Samsung a company in 2021 that has a market capitalization of almost $12 trillion.

A third lesson is that industrial policy is more likely to succeed when citizens view their national survival to be at risk and when they thus unite for the national good. This may have been the case for South Korea and Taiwan facing the threat of invasion from neighbors. Economic development was viewed as imperative, and workers, entrepreneurs, government officials, and outside advisors worked together to achieve it. When, as in the case of Malaysia, redistribution is a primary goal of government, industrial policy can lead to rent-seeking waste and not produce a competitive industry.

A fourth lesson is the importance of education and technology transfer. Tadashi Sasaki was well educated and quickly sensed the technologies that his firm should invest in. Engineers in Korea and Taiwan were relatively well educated and absorbed knowhow from their counterparts in America. This bridged the knowledge gap until they acquired the requisite manufacturing experience.

A fifth lesson is the necessity of providing firms with incentives. Malaysia often did not let *Bumiputera* firms fail even when their performance was poor. On the other hand, Hausmann and Rodrik (2003) showed that the Korean government stopped providing benefits to firms that did not succeed at exporting. Proper incentives can help industrial policy to achieve its target.

A sixth lesson is that protectionism can be counter-productive. Japan's refusal to let firms like Autonetics continue selling semiconductors to Japan and America's actions against chip firms in Japan ultimately weakened the semiconductor industries in both countries.

A seventh lesson is that cooperation between academia, industry, and government research institutes can be valuable. Not only did the TAC in Taiwan contain leading professors, but Taiwanese science parks enabled fertile interactions between universities, businesses, and the government.

Building a vibrant semiconductor manufacturing sector in the West will thus require careful thought and planning. Simply saying that the Korean and Taiwanese governments invested money in semiconductors and that Western governments should follow suit will prove insufficient.

Another lesson from the COVID-19 experience is that firms using semiconductors should move beyond just-in-time inventory management. Demand for automobiles whipsawed rapidly, and it was hard for automakers to foresee how their semiconductor needs would change. Keeping some inventories for precautionary reasons would be wise. Also, understanding their supply chains and their inherent vulnerabilities could save a lot of money. During the pandemic, difficulties at a fourth tier supplier sometimes reverted through the supply chain and cause delays. Firms need careful planning and adequate preparations to maintain resilience in the face of wars, natural disasters, pandemics, and other disruptions.

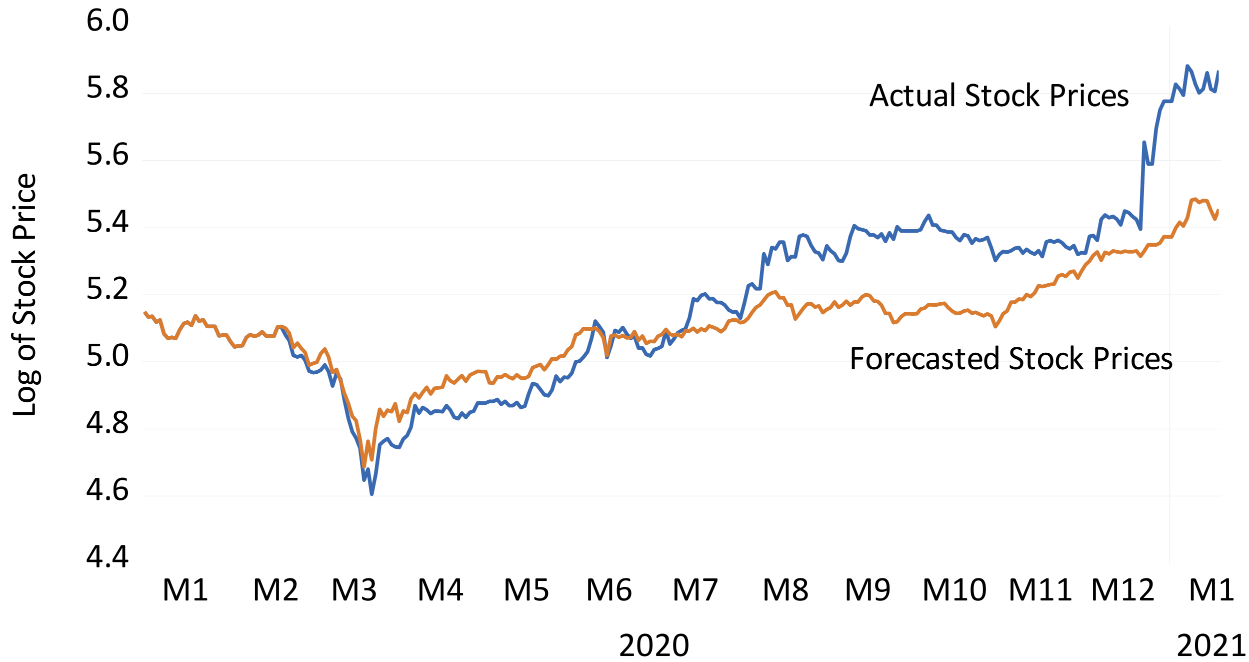

Figure 1. Actual and Forecasted Stock Prices for the Korean Consumer Electronics Sector
Source: Datastream Database and calculations by the author.

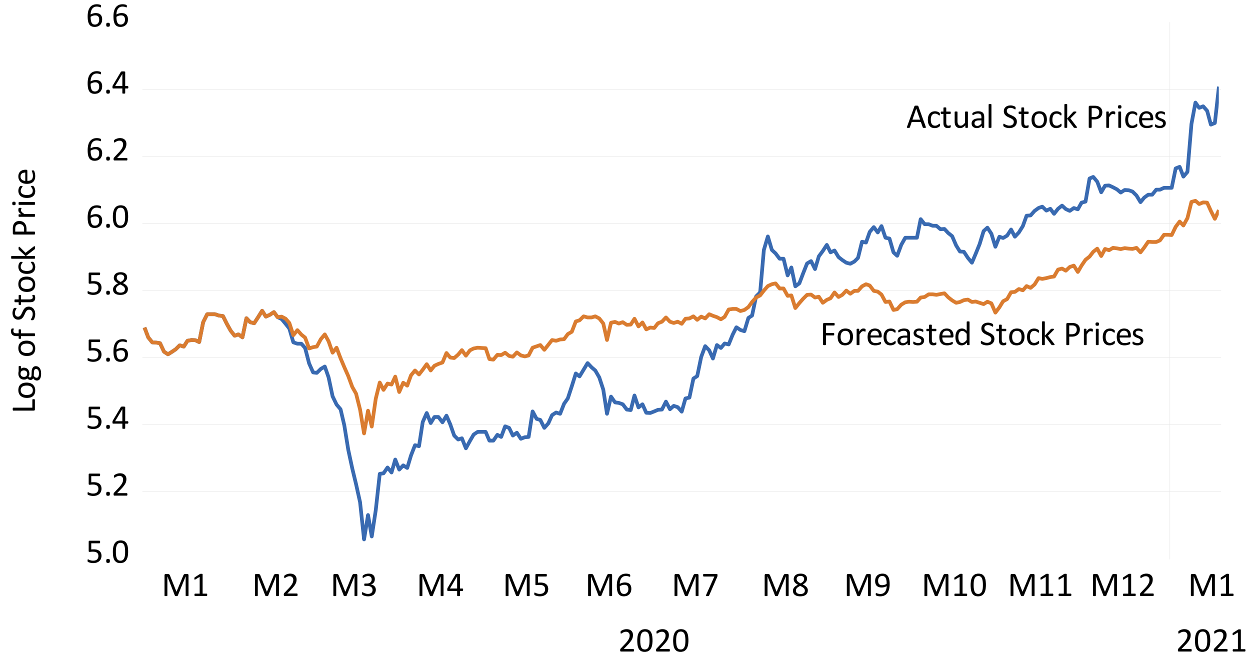

Figure 2. Actual and Forecasted Stock Prices for the Korean Automobile Sector
Source: Datastream Database and calculations by the author.

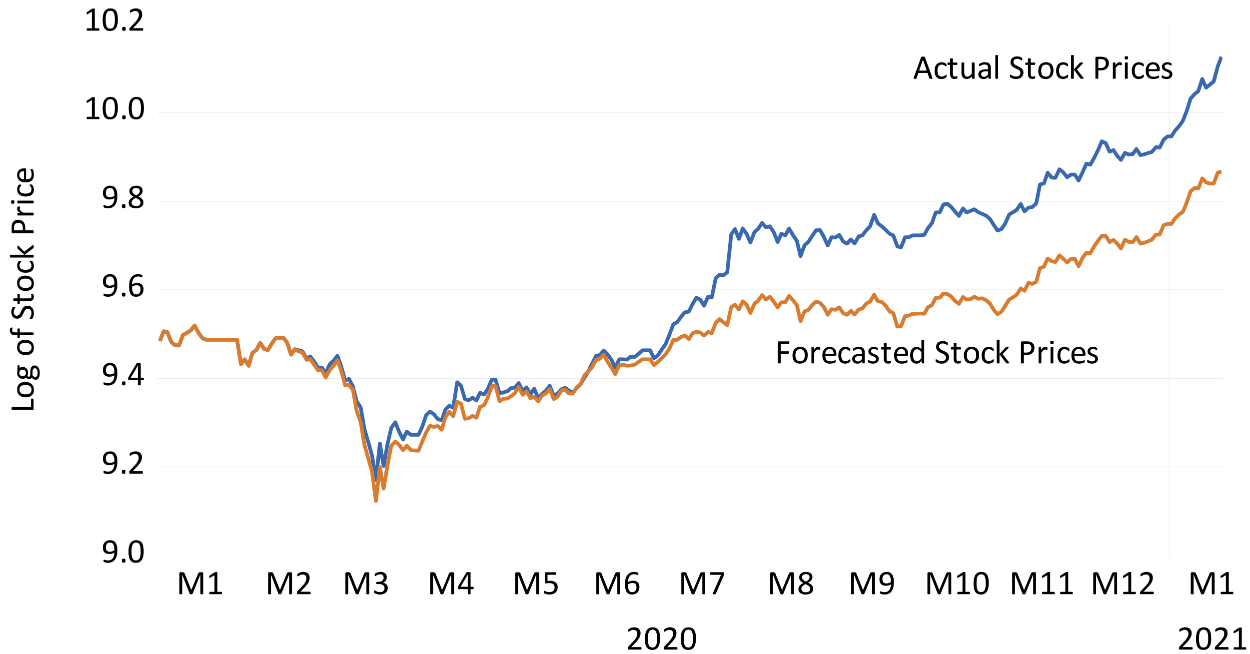

Figure 3. Actual and Forecasted Stock Prices for the Taiwanese Semiconductor Sector
Source: Datastream Database and calculations by the author.

References

Aspray, William 1994: Interview of Tadashi Sasaki, Piscataway, NJ, 25 May 1994, in: https://ethw.org/Oral-History:Tadashi_Sasaki [31 July 2021].

Black, Fischer 1987: Business Cycles and Equilibrium. New York.

Brown, Steven/Warner, Jerald 1985: Using Daily Stock Returns: The Case of Event Studies. Journal of Financial Economics 14, pp. 3-31.

Brown, Steven/Warner, Jerald 1980: Measuring Security Price Performance. Journal of Financial Economics 8, 205–58.

Bown, Chad 2020: How the United States Marched the Semiconductor Industry into Its Trade War with China. Peterson Institute for International Economics Working Paper No. 20-16, Washington.

Fleming, Sam/Hollinger,Peggy/Hall,Ben 2021: Semiconductors: Europe's Expensive Plan to Reach the Top Tier of Chipmakers, in Financial Times, 21 July 2021.

Hausmann, Ricardo/Rodrik Dani 2003: Economic Development As Self-Discovery. Journal of Development Economics, 72, pp. 603-633

Irwin, Douglas 1996: The U.S.–Japan Semiconductor Trade Conflict, in: Krueger, Anne O. (ed.): The Political Economy of Trade Protection, Chicago, pp. 5-14.

Johnstone, Bob 1999: We Were burning: Japanese Entrepreneurs and the Forging of the Electronic Age. New York.

Jung-a, Song 2021: Hyundai Faces Production Hit from April as Chip Shortage Bites, in: Financial Times, 24 March 2021.

Lin, Yeo/Rasiah, Rajah 2014: Human Capital Flows on Taiwan's Catch Up in Integrated Circuit Manufacturing. Journal of Contemporary Asia 44, pp. 64-83.

Pecht, M/Bernstein, J.B/Searls, D/Peckerar, M/Karulkar, P. 1997: The Korean Electronics Industry. Abingdon-on-Thames, U.K.

Rasiah, Rajah 2017: The Industrial Policy Experience of the Electronics Industry in Malaysia, in: Page, John/Tarp, Finn (eds.): The Practice of Industrial Policy: Government—Business Coordination in Africa and East Asia, Oxford, pp. 1-25.

Tanaka, Akito 2021: US needs Japan and Korea to counter China tech: ex-Google CEO, in: Nikkei Asia, 9 July 2021.

Thorbecke, Willem 2019: How Oil Prices Affect East and Southeast Asian Economies: Evidence from Financial Markets and Implications for Energy Security. Energy Policy 128, pp. 628-638.

Voinigescu, Sorin 2013: High-Frequency Integrated Circuits. Cambridge.

Yoshitomi, Masaru 2003: Post Crisis Development Paradigms for Asia. Tokyo.

Notes

[i] Voinigescu (2013) noted that by 2011 99 percent of chips are manufactured using CMOS.

[ii] Yoshitomi (2003) observed that Malaysia had overcome existential threats from rural unrest.