Quantifying Supply Chain Risk with Sales Data in the Smartphone Industry*

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Abstract

The recent trade war between the U.S. and China has led to sanctions on large Chinese firms with possible side effects on third countries. I analyze how sanctions, i.e. losing access to U.S. technology and supply, affect firm performance in the European smartphone market. Using detailed model-level data from 2010 to 2020, I first show that the sanctions negatively impacted both prices and sales of Huawei, the main Chinese target firm. Subsequently, I develop and estimate a differentiated products oligopoly model where consumers' demand depends on Google Mobile Service and mobile chipset generation among the relevant product attributes. I find that consumers highly value Google and the chipset generation. I finally perform policy counterfactuals where Huawei gains Google's Android operating system or further runs out of 5G chipset, I find that Samsung, Apple, and Xiaomi mainly capture Huawei's lost market share. Furthermore, I also find that the trade war between the U.S. and China reduces both consumer welfare and total welfare in the European smartphone market.

Keywords: trade shock, smartphone industry, demand estimation

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1 Introduction

Geopolitical risk management has long been a key issue for multinational companies. Business risks arising from international political conflict can present multinational firms with intractable problems. For example, in 2003, the U.S. and France had disputes over the Iraq War, and the market share of French-sounding, U.S. supermarket brands declined (Pandya and Venkatesan, 2016). Due to territorial disputes and historical hostility, there was a widespread civilian boycott of Japanese goods in China in 2012. This decreased the market share of Japanese brands and benefitted Chinese and non-Japanese foreign businesses in China (Sun et al., 2021; Barwick et al., 2019). Geopolitical risks are arguably one of the most important concerns for international entrepreneurs and firms.

This research studies the impact of geopolitical conflicts in the context of the European smartphone market. The smartphone industry has been one of the fastest-growing industries in the world, with billions of dollars at stake. From 20.7 million units in 2004 to 1.37 billion units in 2019, global smartphone sales increased, generating nearly $458.4 billion in revenue.[1]

In order to put pressure on China to stop its long-standing unfair trade practices and intellectual property theft, US President Donald Trump began putting tariffs and other trade restrictions on it in January 2018. Telecommunication indutry is one of the main target industries in the conflict. In May 2019, as the trade war heated up, the Chinese telecommunications corporation Huawei and its 68 affiliated organizations in 26 countries were added to this forbidden party list. This means Huawei is unable to do business with any organization that operates in the United States without permission. Due to this external geopolitical shock, Huawei's newly released phones are no longer able to pre-install Google Mobile Services and are denied access to 5G chipsets which highly rely on U.S. technology and material.

This study first analyses the negative impacts of trade shock from reduced form evidence. We then focus on how trade supply chain risk, particularly the disruption caused by "Google" software, affects market share and profit in the smartphone business and predicts the change in market structure brought by 5G chipset supply disruption.

To analyze the effects of supply chain disruption, I use Europe as the "Third Market" of Huawei rather than the Chinese and American markets. I focus on the effects of the trade war between the United States and China on the European market for two reasons.

First, the European market is Huawei's second-largest market. Figure 1 shows the proportions of Huawei's annual sales in Europe between 2010 and 2020. During the period of the sample, a growing part of Huawei's sales come from the European market. Therefore, the European market is crucial for Huawei's smartphone business. Huawei is also becoming increasingly important for European consumers. The top 5 mobile phone

[1] Data comes from IDC's Worldwide Quarterly Mobile Phone Tracker.

manufacturers' market share change in Europe between 2010 and 2020 are depicted in Figure 2. Apple and Samsung are the market leaders in Europe from 2010 to 2020. Huawei's market share has increased since 2015, with 5% in 2015 and peaks with 23.2% market share in 2019.

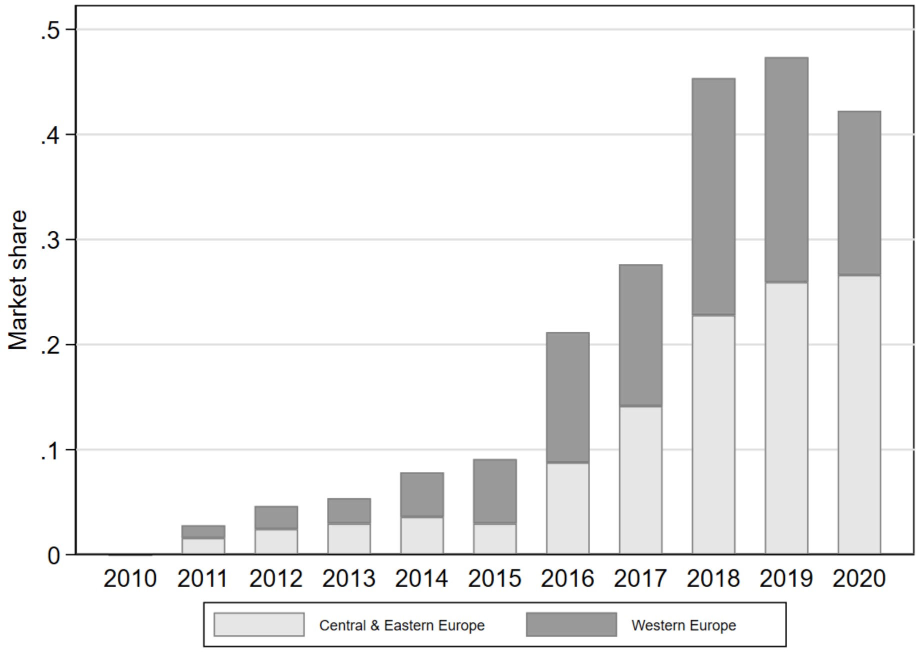


Figure 1: Percentage of Huawei's annual quantity sold in the European market

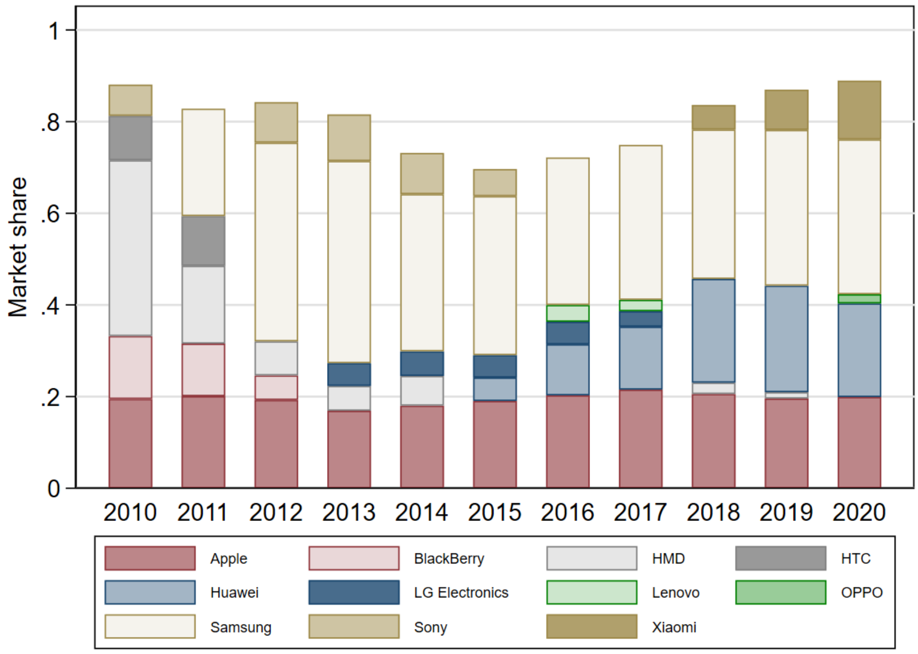


Figure 2: Top 5 brands market share in Europe over 2010-2020

Second, although China is one of Huawei's focal markets, Google search is partially blocked in mainland of China. Losing access to Google Mobile Service, therefore, does not significantly affect consumer demand in the Chinese market. In addition, the tech war is between China and the U.S., but the market share of Huawei is relatively small in the U.S. market. According to our dataset, Huawei's average annual market share in the U.S. market from 2010 to 2020 is around 1.2%.[2]

The main findings of this research can be summarized as follows. First, I find that the trade shock substantially reduced the target firm's price and market share. Huawei's sales and price reduced by 53.2% and 11.2%, respectively, when compared with other Chinese firms in the market, i.e. OPPO, vivo, Xiaomi, OnePlus, and Realme. The evidence suggests that this could be driven by the lost access to Google's Android operating system, but also an anticipation of chipsets out-of-stock necessary for 5G.

Second, I evaluate the effects of losing access to Google service and 5G chipset using BLP demand model. It turns out that consumers have significant valuations for GMS and 5G chipsets, the average consumer's willingness-to-pay (WTP) for Google service is equivalent to a price of \$111.6 and \$358.2 for 5G compatibility. Under both scenarios, Huawei's market share becomes lower. Of those unaffected firms, Samsung gains the most from the lost share of Huawei, Apple, and Xiaomi come the next. In terms of total welfare, both losing access to GMS and supply disruptions of the 5G chipset reduce the total welfare and suppliers' profits. This shows that trade wars imply important side effects to consumers, target firms, and other competing firms.

By evaluating the impact of trade sanctions on smartphone companies in the European market, this paper contributes to three related strands of literature: trade conflicts, product characteristic evaluation, and the smartphone industry.

This paper contributes to the literature of quantifying the risk of international conflict in the context of the China–United States trade war. Pandya and Venkatesan (2016) show that during the 2003 U.S.–France dispute over the Iraq War, the market share of French-sounding, U.S. supermarket brands declined. Sun et al. (2021) study the impact of anti-Japanese effects in the automobile market in China. This decreased the market share of Japanese brands and helped Chinese and non-Japanese foreign businesses in China. Hiller and Savage (2021) use tablet computer market-level data to estimate the pass-through of tariffs on firms assembling in China, it turns out that the tariff reduces profits and welfare, while firms assembling elsewhere benefit from the reduction in rivals' competitiveness.

In this paper, I quantify the value of "Google Mobile Service" and 5G capability in the smartphone industry. Chu (2013) studies the nation equity in the PC industry. Kong and Rao (2021) evaluate the value of "Made in the USA" on product sales by conducting

[2]For comparison, the average annual market shares of Apple and Samsung from 2010-2020 are around 37.6% and 23.3%, respectively

a field experiment on eBay over 900 auctions. Chu et al. (2021) use a structural approach to study the impact of Lenovo's acquisition of IBM's PC division in China's PC market on brand equity. Bachmann et al. (2023) also use the Volkswagen emissions scandal as a natural experiment to provide evidence that collective reputation externalities. Duch-Brown et al. (2023) evaluate the impact of market integration, accounting for spillovers between multiple distribution channels in the PC industry.

By exploring the impact of trade conflicts on market structure, this paper is also related to the strand of research that studies the smartphone industry. For example, Sun (2012) explores how mobile applications changed the value of mobile phone branding. Sinkinson (2014) studies the motivations for and implications of exclusive contracts, with an application to smartphones in the U.S. Hiller et al. (2018) use aggregate market data to estimate patent value in the United States smartphone industry. Björkegren (2019) estimates consumers' dynamic demand for mobile phones using transaction-level data. Fan and Yang (2020) study whether oligopolistic competition leads to too few or too many products, and how a change in competition affects the number and the composition of product offerings. Yang (2020) finds that vertical integration in the smartphone industries boosts innovation and wellbeing, mostly due to the merged companies' coordinated investments. Fan and Zhang (2022) study the welfare effect of a consumer subsidy with price ceilings in the Chinese smartphone industry. Wang (2023) uses the market-level data in the smartphone industry to study firms' product portfolio choices when faced with a policy-induced increase in competition.

This paper is organized as follows. The background of policy is covered in Section 2, where I also discuss supply and demand side policy shocks. Section 3 describes the dataset and reduced form evidence. I develop the structural frameworks for demand estimation in Section 4. I present the counterfactual simulation results and discussions in Section 5 and Section 6 concludes.

2 Institutional Background

2.1 Background

Donald Trump spoke out against a number of current trade agreements throughout the 2016 presidential campaign. He committed to bringing back to the United States manufacturing jobs that had been outsourced to nations like China and India. Beginning in January 2018, President Trump intensified his efforts, notably those aimed at China, by issuing stern threats about enforcing huge fines for alleged intellectual property (IP) theft and imposing substantial tariffs. In retaliation, China levied a 25% tax on more than 100 American goods.

The Bureau of Industry and Security (BIS) made several changes in May 2019 to the Export Administration Regulations (EAR) to better control Huawei and its 68 listed non-U.S. affiliates across 26 countries. This was done to further address the ongoing threat Huawei and its non-U.S. affiliates pose to U.S. national security and foreign policy interests.

BIS updated the Entity List to include Huawei and its 68 non-American affiliates. A temporary general license for Huawei and its non-U.S. affiliates was also removed by BIS in favor of a more constrained permission that will better protect American national security and foreign policy objectives. For the export, reexport, or transfer (within the country) of any item subject to the EAR to any of these listed Huawei businesses, these acts endured a license requirement.

The U.S. government no longer grants American companies export licenses to Huawei for the majority of their products. Huawei is unable to conduct business with any US-based companies as a result. Honor, a subbrand of Huawei, had some autonomy, but it was still considered to be a member of the Huawei family. This meant that it was still affected by the Huawei prohibition.[3] Being on the "Entity List" hindered Huawei from working with many of its major suppliers, including Google, Qualcomm, and Intel.

I divide these external hazards into demand shocks and supply shocks, as shown in Figure A.1. We discuss these shocks from the core component of a smartphone in the next two subsections.

2.2 Supply shock

Huawei's chip supply has been sanctioned at several supply chain nodes. The supply shocks mainly include the disruption in SoC (System on Chip)[4] supplies from both Huawei's upstream suppliers and manufacturers. Appendix Figure A.1 presents the impact of the trade war on the semiconductor companies in the smartphone industry.

In terms of the upstream supplier, the main semiconductor companies which include Qualcomm and other U.S. chip producers cannot supply their SoCs to Huawei. In the short run, Huawei needs to utilize its existing 5G inventory for production, but once the inventory is depleted, production may come to a halt. From September 2020 to April 2021, about 69% export licenses to Huawei were permitted. Qualcomm was permitted to sell 4G mobile phone chips to Huawei. Intel, AMD, and Nvidia are also allowed to sell PC chips to Huawei. However, 5G-related microchips are still forbidden.

Taiwan Semiconductor Manufacturing Corporation (TSMC), the world's biggest con-

[3] Huawei sold Honor in November 2020 to Shenzhen Zhixin New Information Technology Co. in China. There won't be any direct ties between Honor and Huawei. This will release it from any restrictions imposed by the U.S. sanctions and allow it to operate as its own company. Huawei and Honor, however, were both listed as entities within the time period of our sample.

[4] SoC is a crucial smartphone component that combines a mobile application processor (basically a CPU), GPU, modem, and other chips, in addition to the standard hardware components like the screen, battery, camera, and microphone.

tract chipmaker and a key Huawei contract manufacturer, has to stop new orders from Huawei following the ban. The largest contract chip maker in mainland China, Semiconductor Manufacturing International Corporation (SMIC), cannot produce chips for Huawei, because these firms' productions heavily rely on U.S. equipment and raw materials.

2.3 Demand shock

The basic software component of a mobile phone is the operating system and applications, as shown in the upper left of Figure A.1. A mobile OS provides an interface between the device's hardware components and its software functions. Android users download applications from Google Play and iOS users download applications from App Store.

The first demand shock for Huawei is losing access to Google service. The U.S. government added Huawei to its Entity List on May 16, 2019. Due to this government action, none of the US companies—including Google—are permitted to work with Huawei. Google is prohibited from collaborating with Huawei on new device models or providing its apps, such as Gmail, Maps, YouTube, Play Store, and others, available for preloading or downloading on Huawei's devices. Huawei phones certified by Google and launched before May 15, 2019, would continue to operate as normal.

Google Mobile Services (GMS) is at the heart of every Android smartphone. It includes a collection of APIs and all Google apps, including Google Maps, Google Drive, YouTube, Google Photos, Google Play Store, Google Chrome, and so on. To compensate for the unavailability of GMS, Huawei created its rival mobile ecosystem—Huawei Mobile Services, or HMS. However, most Android apps that need support from Google still can not run on the HMS core platform.

The U.S. Department of Commerce only licenses 4G chips, and Huawei can only produce 4G phones. It's the only way to bypass the sanctions placed on Huawei by the U.S. government. The most recent Huawei models, such as the Huawei Mate 50 series (released in September 2022), Huawei Nova 10 series (released in July 2022), and the recently introduced P60 series (released in March 2023), are not capable of connecting to 5G networks, though it has not yet occurred in our data sample (2010Q1-2020Q2).[5]

To sum up, the trade shock has a potential negative impact on the demand for Huawei phones. The likely mechanism is the anticipation of a decline in the demand, mostly as a result of the threat of losing access to Google's Android operating system, but also due to the device's deficient 4G capabilities when compared to those of its rivals.

[5] https://consumer.huawei.com/be/phones/

3 Data and Preliminary Evidence

In this section, I first describe the dataset on the market for smartphones. Next, I consider the price and quantity effect of the tech war to see how the price and quantity of Huawei's phones evolve after the trade shock compared with other competing brands.

3.1 Data

The dataset is from IDC (International Data Corporation), a global market intelligence firm. It contains details on quarterly mobile phone sales on the national level from 2004Q1 to 2020Q2 at the manufacturer-brand-model level, along with product attributes such as processor vendor, processor cores, processor speed, screen size, storage, and other form factors.

In this research, the data set is on 27 European countries over 42 quarters from 2010Q1 to 2020Q2.[6] The initial data set includes 169,356 observations on the quarter-country-brand-model level, which is about 169 products on the country/quarter level. We exclude observations in countries of "Rest of CEE" and the corresponding model names are "Others". We construct our measure of smartphone price with IDC data on the average sales price in US dollars. I use the CPI data to deflate the prices into 2015 USD.[7] We also exclude extremely high- and low-priced handsets, we keep models of which the average price is between 100 and 2000 US dollars. The final data set consists of 133,591 observations on products, countries, and quarters. The number of unique products across products, countries, and quarters in the entire sample is 6,935.

The core variable which indicates whether a smartphone can use Google or not is collected from comparing the Google support devices list[8] with the model's name in the IDC data. From May 2019, there is a total of 29 models of Huawei and Honor that cannot pre-install Google service.[9] Consistent with the trade policy, all of them are released after the time of being on the "Entity List".

Table 2 presents the summary statistics on the quantity, price, and product characteristics on the quarter-country-brand-model level. For the dummy variable *GMS* which is 1 if the model of Huawei and Honor is on the forbidden list, 0 otherwise. *ScreenSize* is the diagonal measure of the smartphone's display area in inches, *Megapixels* is the cam-

[6] Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Kazakhstan, Netherlands, Norway, Poland, Portugal, Rest of CEE, Romania, Russia, Serbia, Slovakia, Spain, Sweden, Switzerland, Ukraine, United Kingdom.

[7] https://fred.stlouisfed.org/series/USACPIALLMINMEI

[8] https://storage.googleapis.com/play_public/supported_devices.html

[9] Huawei: Mate 30, Mate 30 Pro, Mate Xs, P40, P40 Lite, P40 Lite E, P40 Pro, P40 Pro Plus, Y5p, Y6p, Y7p (2020), Y8p, nova 5, nova 7i.

Honor: 30, 30 Pro Plus, 30s, 7A Prime, 8A 2020, 8A Prime, 8S (2020), 8S Prime, 9A, 9C, 9S, 9X Pro, V30, View 30 Pro.

ZTE: Axon 9 Pro, Blade 10, Blade 20 Smart, Blade A7, Blade A7 Vita, Blade V2020.

Table 1: Summary statistics

	N	Mean	Std. Dev.	min	max
units	133,591	11,783	35,727	1	1,265,977
price	133,591	358.68	244.79	91.78	1,964.80
GMS	133,591	0.997	0.05	0	1
ScreenSize	133,591	5.04	0.98	2	7.2
Megapixels	133,591	13.83	12.10	0	108
Storage	133,591	48.10	75.60	8	1024
age	133,591	4.36	2.81	1	29
cores	133,591	5.05	2.73	1	10
G2	133,591	0.01	0.08	0	1
G3	133,591	0.25	0.43	0	1
G4	133,591	0.73	0.44	0	1
G5	133,591	0.01	0.08	0	1

[1] There are 11 products in the data that do not have a camera: BlackBerry 7130e, BlackBerry 7280, BlackBerry 8800, BlackBerry 8820, Nokia 9300, Nokia E60, Nokia E61, Nokia E62, Sony Ericsson M600, and others. We obtained these data directly from third-party phone-comparison website www.GSMArena.com.

era's megapixel (MP), and *Storage* is the storage capacity of the smartphone in gigabytes (GB). *Age* is the number of quarters since the product's first sale on the market. *Cores* is the number of processor cores. I also observe the chipset generations used by each product, which are generation 2.5, generation 3, generation 4, or generation 5.

The average quarterly sales are around 11,783 units. The price is $358.7 per handset on average, with a standard deviation of 244.8. Smartphones are two form factors, regular smartphones, and phablets.[10] Phablets represent 34.36% of the market share and 27.07% of the revenue. The regular smartphone makes up 65.64% of the market share and 72.93% of the revenue. On average, the screen size was 5.0 inches, the camera megapixels were 13.8 MP, and the storage capacity was 48 GB. The average number of quarters since the release date for phones in my data sample was 4.36. The average number of processors in the CPU is 5 in a smartphone. About 70% of phones have 4G capability, 30% of the phones are 3G phones, and the 2.5G and 5G phones only take up 0.9% and 0.6% in the sample data.

There is substantial variation in prices and characteristics across products. For example, screen size ranges from 2 to 7.2 inches, camera megapixels range from 0 to 108 MP, and storage capacity ranges from 8GB to 1,024GB. This variance shows that different mobile phones aren't produced the same and that manufacturers differentiate their products to appeal to customers who don't perceive smartphones as perfect substitutes.

[10] A regular smartphone typically has a screen size between 4 to 5.5 inches, while a phablet has a larger screen size, usually between 5.5 to 7 inches.

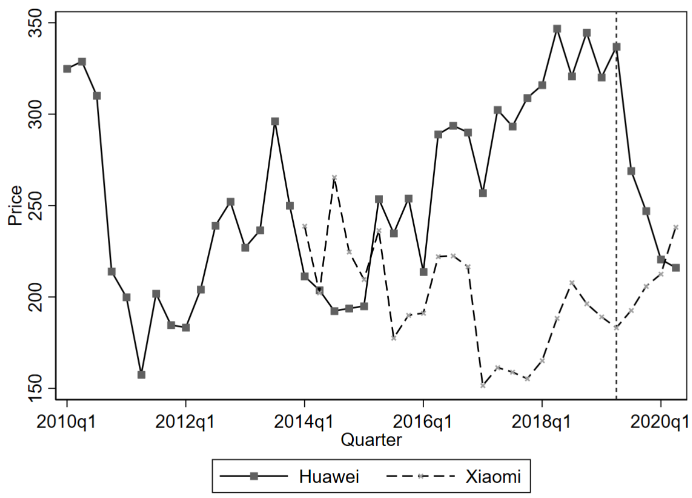


Figure 3: Huawei and Xiaomi's quarterly averaged price in Europe (USD)

3.2 Reduced Form Evidence

I aggregate the data to the brand-country level.[11] Xiaomi is the second biggest Chinese mobile phone brand in the European market, so we take Xiaomi as the control company in the graphical evidence. Figure 3 shows the price (in US dollars) evolution of Huawei and Xiaomi, and Figure 4 shows the quarterly quantity (in millions) sold in Europe by Huawei and Xiaomi before and after the tech war.[12] I can see Huawei's average price sharply decreases from \$337 in 2019Q2 to \$216 in 2020Q2 immediately after the tech war, and quarterly sales quantity drop from 10.5 billion in 2019Q2 to 9.4 billion in 2020Q2. On the contrary, the average price and quarterly sales of Xiaomi keep steadily increasing trends. This suggests that the trade shock generates a cost and/or demand shock to the target firm, which leads to a sharp price and quantity decrease.

To gain further insights, we use the following regression specification:

$$y_{ict} = \beta_0 + \beta_1 * \mathbb{1}(H_i * W_t) + \delta_{ic} + \delta_t + \varepsilon_{ict} \tag{1}$$

y_{it} is log of price or log of quantity of brand i at country c of quarter t. $\mathbb{1}(H_i * W_t)$ is the interaction term. W_t is a dummy variable which is 1 if t is after Trade War, 0 otherwise. H_i is a dummy variable which is 1 if i is Huawei or Honor, 0 otherwise. β_1 identifies how the trade war affects Huawei's price or quantities. I also control the brand-country, and time fixed effect. Quarter fixed effects are also included to control for the seasonal change in demand and price.

To address the potential problem that the control group might also be contaminated by

[11] The quantity is the sum of all models' quarterly units by brand. The average price is calculated by dividing the total quarterly sales value by the total quarterly quantity by brand.

[12] Here we plot the company level quantity, of which Huawei includes the brand sales of Huawei and Honor.

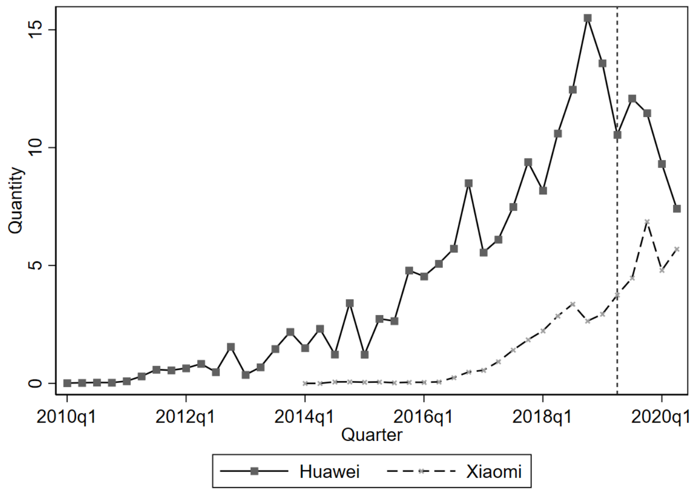


Figure 4: Huawei and Xiaomi's quarterly sales in Europe (million units)

Note: Vertical line refers to the quarter of tech war (2019Q2).

the trade shock, in the difference-in-difference model setting, I only include the unaffected Chinese firms, which are OPPO, vivo, Xiaomi, OnePlus, and Realme as the control group. Finally, the data contains the brand-country level averaged price and quantity, which covers 25 European countries from 2010Q1 to 2020Q2.[13]

Table 2 shows the regression results. The trade shock led to a large quantity and price decrease for the targeted firm. From the empirical results shown in Table 2, the price and quantity of the target firm, Huawei, decreased by 11.2% and 53.2% after the trade sanction, respectively. In equilibrium, the demand shocks consumers perceive, which include losing access to GMS and 5G, and also the anticipation in brand reputation, have more negative effects than the supply shock that Huawei has experienced. Therefore, I can conclude that the trade sanction represents more of a demand shock than a supply shock.

In the DiD model setting, I assume the trade shock did not affect the prices of Huawei's competitors. Therefore, I estimate an event study to provide further evidence for the parallel trends assumption. Treatment occurs in 2019Q2, following Miller et al. (2021), I then create 9 leads (which are the quarters prior to treatment) and 5 lags (the quarters post-treatment) in model specification shown in Eq. (2). The omitted category is the quarter of being on the "Entity List", so all coefficients are with respect to 2019Q2.

$$y_{ict} = \beta_0 + \sum_{\tau=-9}^{-1} \lambda_\tau \mathbb{1}_{i\tau} + \sum_{\tau=1}^{5} \gamma_\tau \mathbb{1}_{i\tau} + \delta_{ic} + \delta_t + \varepsilon_{ict} \tag{2}$$

[13] Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Kazakhstan, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Spain, Sweden, Switzerland, Ukraine, United Kingdom.

Table 2: Price and quantity effects in percentage

	price (percent change)		units (percent change)	
$\mathbb{1}(H_i * W_t)$	-21.2***	-11.1***	-77.9***	-53.2***
	(0.028)	(0.019)	(0.028)	(0.032)
Brand/Country	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
Quarter	No	Yes	No	Yes
N	2,367	2,321	2,367	2,321
R^2	0.716	0.877	0.844	0.950

[1] Notes: * p <.1, ** p <.05, *** p <.01. Robust standard errors are reported. Standard errors are clustered at the country level. The percentage of quantity and price effects from a transformation of the parameter β_1 using $exp(\beta_1) - 1$ (and a corresponding adjustment of the standard errors using the delta method.)

Figure 5: Coefficients and s.e. for price

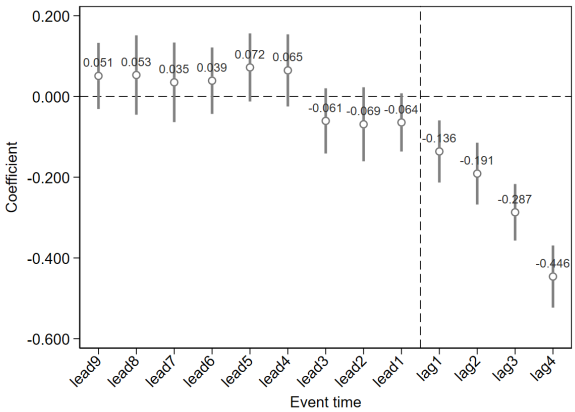
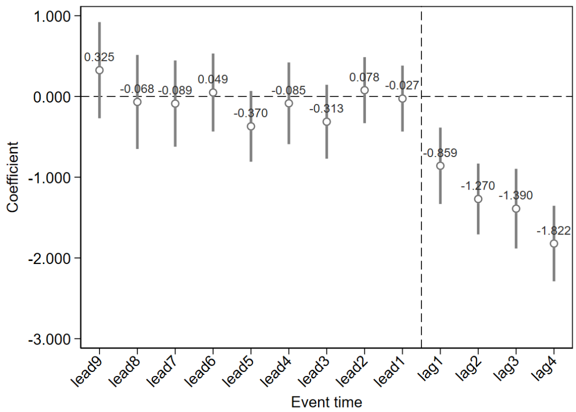


Figure 6: Coefficients and s.e. for quantity



The event studies of the price effect and quantity effect are presented in Figure 5 and Figure 6. In terms of the coefficients on the leads, they are not statistically different from zero prior to treatment. There was no difference in price and sales quantity between the trending tendencies of Huawei and the control group prior to treatment. The risen coefficients post-treatment were caused by the increasing number of models that cannot pre-install GMS, chipset stock issues, and lowering consumer expectations.

In the next sections, I focus on the risk of losing access to Google service and 5G chipset. The likely mechanism is the consumers' anticipation of a decline in demand is the threat of losing access to Google's Android operating system and also the 5G incapability, which is a huge decline in product quality.

4 Structural Framework

The reduced form evidence identifies the general shock of both losing access to Google service and anticipation of losing access to U.S.-made hardware. To separately see the impact of the two sanctions, I use a discrete choice random coefficient demand model, which values various product characteristics and incorporates unobserved consumer heterogeneity which generates rich substitution patterns.

We then present the model of oligopolistic price-setting behavior, used to uncover pre-shock marginal costs and to predict post-shock prices. By applying the structural demand model, I can distinguish between the effects of demand and supply shock and also enable us to perform counterfactual and examine welfare change related to demand shocks.

4.1 Consumer demand

I use a random-coefficient discrete choice model to describe smartphone demand. I assume that the utility that consumer i gets from purchasing j at quarter t is

Assume the utility of consumer i buys product j is:

$$u_{ijt} = X_{jt}\beta_i - \alpha_i p_{jt} + \lambda_{mt} + \kappa_c + \gamma_t + \xi_{jt} + \epsilon_{ijt} \tag{3}$$

where X_{jt} is the observed product characteristics and the random coefficient β_i captures consumers' heterogeneous tastes and is assumed to follow a normal distribution with mean β and variance σ^2. I denote the price of j in quarter t by p_{jt}. To capture consumers' average taste for a brand m in period t as well as a general time trend in consumers' taste for smartphones, we include a brand/year fixed effect, λ_{mt}. To capture regional and seasonal differences in demand, I also include a country (κ_c) and a quarter fixed effect (γ_t). The term ξ_{jt} represents a demand shock, and the error term ϵ_{ijt} captures consumers' idiosyncratic taste, which is assumed to be i.i.d. and follows a type-I extreme value distribution. I normalize the mean utility of the outside option to be 0. Thus, the utility of the outside option is $u_{i0t} = \epsilon_{i0t}$.

$$s_{jt} = \int \frac{exp(X_{jt}\beta_i - \alpha_i p_{jt} + \lambda_{mt} + \kappa_c + \gamma_t + \xi_{jt})}{1 + \sum_{k=1}^{j} exp(X_{kt}\beta_i - \alpha_i p_{kt} + \lambda_{mt} + \kappa_c + \gamma_t + \xi_{kt})} dF(\alpha, \beta) \tag{4}$$

$F(\alpha, \beta)$represents the distribution function of the random coefficient α_i and β_i. I define the mean utility of j in t as

$$\delta_{jt} = X_{jt}\beta - \alpha p_{jt} + \lambda_{mt} + \kappa_c + \gamma_t + \xi_{jt} \tag{5}$$

and invert it out on (4) following Berry et al. (1995).

Following Fan and Yang (2020) using monthly sales data and 10% of the U.S. population as the market size, the market size used in the estimation is about 30 percent of the European countries' population during the sample period.[14] I include GMS, screen size, camera megapixels, storage, NFC, age, number of processor cores, and chipset generation in X_j. ξ_j may be correlated with price and market shares, so instrumental variables should be used. Following Berry et al. (1995), I use sums of the other products' characteristics (over the brand and the entire market), which is the sum of characteristics of the other products produced by the same firm, and the sum of characteristics of products produced by the other firms. I include counts of the number of other products (overall, by firm) in the instruments. I also include the four-month lagged exchange rates of the Chinese, Japanese, and Korean currencies to US$ as a cost shifter in the instruments (Fan and Yang, 2020).

4.2 Oligopoly model

I use a multi-product price-setting oligopoly model to uncover the marginal costs when combined with demand parameters, similar to Hiller et al. (2018), Fan and Yang (2020), Yang (2020) and Duch-Brown et al. (2023). By backing out marginal cost, it can predict the market share and price effects resulting from the trade war. This approach can be justified under a competitive retail sector, or more generally under an imperfectly competitive retail sector with efficient contracting between producers and retailers (no double marginalization effects). As a result, the markup can be interpreted as a combination of market power between manufacturers and retailers. Marginal cost is the sum of the production cost and also the local distribution cost that occurs to local retailers. I do not model the retailing relationship in our model setting because I only have aggregate sales data on the model level rather than the wholesale price.

Each brand f has a portfolio of products F_f. The total variable profit function is shown in (6), each brand is maximizing the sum of profits for each product $k \in F_f$:

$$\Pi_f(\mathbf{p}) = \sum_{k \in F_f} (p_k - c_k) q_k(\mathbf{p}) \tag{6}$$

where c_k is the constant marginal cost for product k and $q_k(\mathbf{p})$ is demand as a function of the price vector. The first-order condition of the profit maximizing price of each product $j = 1, \ldots, J$ is given by (7):

$$q_j(\mathbf{p}) + \sum_{k \in F_f} (p_k - c_k) \frac{\partial q_k(\mathbf{p})}{\partial p_j} = 0 \tag{7}$$

[14] The European national-level population data is collected from the World Bank of 2020.

A multiproduct Bertrand-Nash equilibrium obtains if the FOC (7) holds for all products $j = 1, \ldots, J$. To write the system of J first-order conditions in vector notation, define the $J \times J$ matrix $\boldsymbol{\theta}$ as the brands' product ownership matrix, a block-diagonal matrix with a typical element $\theta(j,k)$ equal to 1 if products j and k belong to the same brand, and 0 otherwise. Let $\mathbf{q}(\mathbf{p})$ be the $J \times 1$ demand vector, and $\boldsymbol{\Delta}(\mathbf{p}) \equiv \partial \mathbf{q}(\mathbf{p})/\partial \mathbf{p}'$ be the corresponding $J \times J$ Jacobian matrix of first derivatives. Let c be the $J \times 1$ marginal cost vector. Using the operator $\odot$ to denote element-by-element multiplication of two matrices of the same dimension, I have:

$$\mathbf{q}(\mathbf{p})(\boldsymbol{\theta} \odot \boldsymbol{\Delta}(\mathbf{p}))(\mathbf{p} - \mathbf{c}) = 0 \tag{8}$$

This can be inverted to give (9), which decomposes the price into two terms: marginal cost and markup, which depends on the own- and cross-price elasticities of demand.

$$\mathbf{p} = \mathbf{c} - (\boldsymbol{\theta} \odot \boldsymbol{\Delta}(\mathbf{p}))^{-1}\mathbf{q}(\mathbf{p}) \tag{9}$$

Equation (9) can be rewritten to uncover the marginal cost vector c based on the actual prices and estimated price elasticities of demand, i.e., $\mathbf{c} = \mathbf{p} + (\boldsymbol{\theta} \odot \boldsymbol{\Delta}(\mathbf{p})^{-1}\mathbf{q}(\mathbf{p})$. Equation (9) can also be used to predict the counterfactual equilibrium when there is a change in the product characteristics, which Huawei can obtain the access to Google Mobile Service and 5G supply. The counterfactual involves two possible changes, a change in the marginal cost and a change in product characteristics. To simulate the new price equilibrium, I used fixed point iteration on (9).

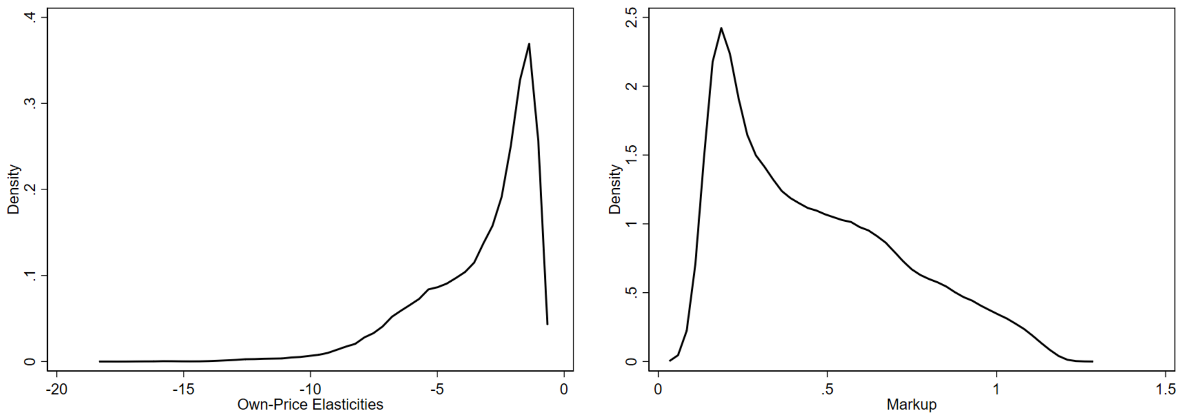
5 Empirical Analysis

5.1 Parameter estimates

Table 3 presents the estimated demand parameters for the demand models, column (1) and column (2) show the OLS and 2SLS regression results from the logit demand model. The empirical results of the random coefficient logit demand model are shown in column (3). From our preferred 2SLS empirical results of the RCL demand model, the size and magnitude of the price coefficients are similar to Hiller et al. (2018) and Fan and Yang (2020).

Unsurprisingly, consumers have a significantly positive valuation for Google service, we find that an average consumer's willingness-to-pay (WTP) for Google service is equivalent to a price of \$111.6. Consumers have a significantly higher valuation for products with larger screen sizes, higher camera resolution, and higher storage. We find that a one-inch increase in screen size is equivalent to a price decrease of \$95.6. All other things held constant, the representative consumer is willing to pay \$2.1 for an additional megapixel

Figure 7: Distribution of Own-Price Elasticities and Markups



of camera resolution, \$0.8 for an additional GB of storage, \$160.2 for 3G compatibility, \$237.2 for 4G and \$358.2 for 5G. Fan and Yang (2020) obtain a lower WTP for 3G compatibility of \$102 and \$150 for 4G compatibility. Hiller et al. (2018) estimate a much lower WTP for 4G compatibility (\$7.93).

From the estimates we obtain in the preferred specification of RCL-BLP model in Table 3, we can back out the marginal cost of each model. We then project the implied marginal costs at equilibrium onto smartphone characteristics. I assume marginal cost is linear in handset characteristics:

$$mc_{jct} = \sum_{k=1}^{7} \beta_k x_j^k + \lambda_j + \lambda_c + \lambda_t + \epsilon_{jct} \tag{10}$$

where x_j includes GMS, screen size, camera resolution, storage, and chipset generation. Additionally, marginal costs are allowed to have different intercepts for different models, countries, and over time. ϵ_{jct} is an i.i.d. normal cost shock. Table 3 also reports the estimation results on marginal cost. GMS, screen size, camera resolution, storage, and chipset generation have a positive effect on marginal costs.

The left panel of Figure 7 shows the implied price elasticities and markups from the BLP demand parameter estimates. Price elasticities are on average -3.30. Together, these elasticities imply an average markup of 46%, ranging from 5.5% BlackBerry Porsche Design P9982 to 126% Samsung Galaxy Pocket Neo. The right panel of Figure 7 plots the markup distributions.

5.2 Quantifying the effects

I now quantify how the trade sanction shifted smartphone demand and market structure in Europe. Removing trade sanctions essentially increases the product quality of the targeted firm in all European countries. This, in turn, leads to a new market equilibrium.

Table 3: Estimation Results

	Logit-OLS	Logit-GMM	RCL-BLP mean	RCL-BLP std. dev.	Marginal Cost
prices	-0.001	-0.008	-0.009	0.002	
	(0.000)	(0.001)	(0.002)	(0.001)	
GMS	1.093	1.002	1.004	0.063	51.763
	(0.119)	(0.134)	(0.487)	(11.315)	(62.761)
ScreenSize	-0.104	0.879	0.860		152.110
	(0.012)	(0.121)	(0.166)		(2.292)
Megapixels	0.009	0.016	0.019		0.447
	(0.001)	(0.001)	(0.002)		(0.092)
Storage	-0.002	0.009	0.007		0.718
	(0.000)	(0.001)	(0.002)		(0.004)
age	-0.169	-0.186	-0.171		
	(0.002)	(0.003)	(0.009)		
cores	0.023	0.168	0.177		
	(0.003)	(0.018)	(0.019)		
G3	0.579	1.439	1.442		67.151
	(0.069)	(0.125)	(0.146)		(10.515)
G4	0.717	2.108	2.136		98.976
	(0.071)	(0.184)	(0.207)		(10.707)
G5	0.409	3.441	3.224	0.099	217.149
	(0.094)	(0.387)	(9.005)	(85.436)	(11.310)

[1] Notes: Based on 133,591 observations. Standard errors are shown in parentheses. 200 modified latin hypercube sampling (MLHS) draws were used for market share integral during the estimation.

Although I would ideally perform our analysis on all European countries, my analysis is already quite comprehensive because the 26 included countries covered the majority percent of GDP in Europe.

To assess the effects, I make use of the demand estimates and the backed-out marginal costs from the estimates from Table 3. Table 4 summarizes the design of the two main simulations I use to quantify the effects of supply disruptions. First, I conduct a counterfactual analysis to see how the market structure changes when Huawei has access to GMS. Then, to make further predictions, although Huawei still has 5G SoC inventory in the data sample, I perform a counterfactual analysis in the last period to simulate a new market equilibrium when Huawei can only produce products with 4G SoC.

Table 4: Simulation designs

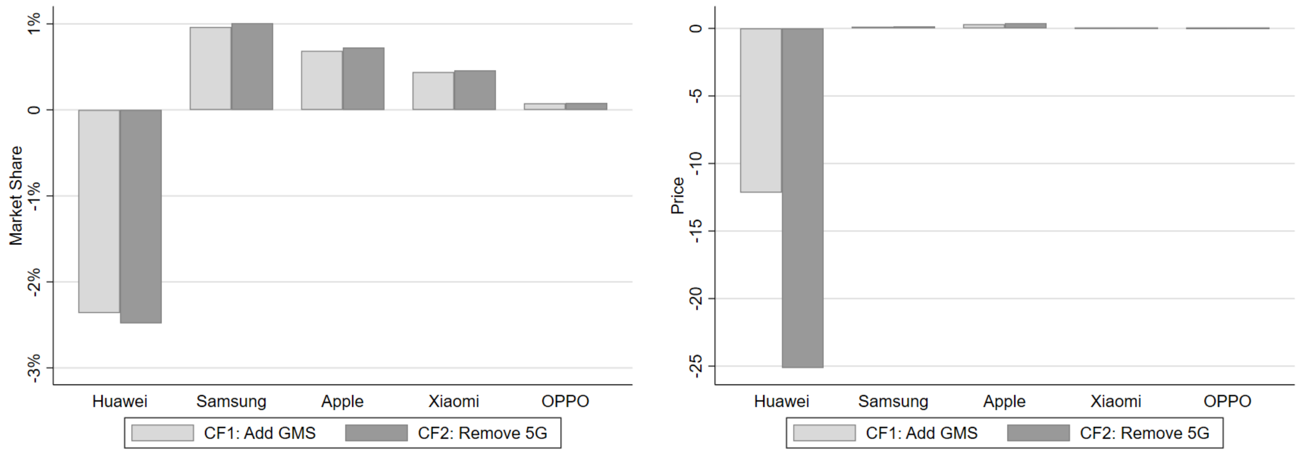
	Counterfactual I	Counterfactual II	Data
GMS	Yes	No	No
G5	Yes	No	Yes

For comparison convenience, I summarize the main findings in the last period of the dataset in Figure 8 and Table 5. Figure 8 shows the market share change under two counterfactual scenarios, and Table 5 presents the demand and welfare losses across firms. By taking the difference between data and results from counterfactual I, I can obtain the losses from losing access to GMS. Similarly, the difference between counterfactual II and counterfactual I further predicts the demand and market welfare change when Huawei runs out of 5G chipset inventory.

Distribution of Losses across Firms. In terms of sanction effectiveness, although the affected products only take up less than 1% (smartphones without GMS and Huawei's 5G smartphones) of the market share, I can see that the sanction significantly reduces Huawei's market share. Under both scenarios, Huawei's market share becomes lower. I also find a significant increase in the sales of the major competing firms (Samsung, Apple, and Xiaomi). Specifically, Samsung gains the most from the lost share of Huawei, Apple, and Xiaomi come the next. In contrast, the sales of smartphones produced by fringe manufacturers would have changed little. There is little substitution from the leading brands to fringe brands. The impact of the trade sanctions is thus primarily on the intensive margin.

The simulation results across firms are shown in Table 5. In counterfactual I, the sanction reduces the sales of Huawei by 0.91 million units (17% lower) and reduces its revenue by $379.49 million. Moreover, in counterfactual I, Samsung benefits the most from the trade war (gain 52,106 units), Apple comes next (gain 38,425 units), and Xiaomi ranks third (gain 28,591 units). Similarly, when I further removed 5G capability from

Figure 8: Counterfactual Market Share and Price Changes



all 5G Huawei smartphones in 2020Q2, its sales units dropped by 0.95 million units and revenue decreased by 431.83 million dollars. We can also see from Figure 8, that the 5G chipset supply disruption made Huawei and Honor's total market share drop from 19.0% to 16.5% in the second quarter of 2020. At the same time, Samsung gains 1.0% Xiaomi gains 0.46% from Huawei, and Apple gains 0.72%. The new equilibrium price barely changes for all brands.

The reason for the small price effects is that these scenarios purely capture the price convergence effect. The changes in unit sales and revenue are ascribed to the changes in product quality. Because the quality and marginal costs move in opposite directions, the price effects when removing GMS and 5G are quantitatively negligible. As a result, the price effect is substantially smaller than the market share effect. The detailed counterfactual results on the model level can be found in the appendix. We present the simulation results of the flagship products of Huawei, Apple, Samsung, and the other three Chinese firms, Xiaomi, OPPO, and Vivo. The potential profits Huawei and other companies may gain and lose are also shown in the table.

The structural form simulation effects are also smaller than that of the reduced form evidence. There are several possible reasons for this. First, besides losing GMS and losing 5G capability perceived by consumers, there might also be a decline in the brand reputation of Huawei, which is not reflected in our model. Another reason is that I do not have enough variation of the core variables "GMS" and "5G" in the data sample, which may lead to underestimating consumers' preference for these product characteristics. In the long run, more and more models of Huawei cannot pre-install GMS and are incapable of 5G, one can get a more precise estimate of consumers' valuation for Google service and chipset generation.

Table 5: Counterfactual results

Panel A: Demand Response (in million units)		
	Losing GMS	Losing GMS and 5G
Huawei	-0.91	-0.95
Samsung	0.052	0.057
Apple	0.038	0.044
Xiaomi	0.029	0.030
Total	-0.79	-0.82

Panel B: Welfare Distribution (in million US $)		
	Losing GMS	Losing GMS and 5G
ΔCS	-107.94	-113.56
ΔHuawei	-379.49	-431.83
ΔSamsung	18.01	20.29
ΔApple	33.32	39.07
ΔXiaomi	7.25	7.97
Total	-427.43	-475.56

[1] Based on BLP demand estimates from Table 4. changes in consumer surplus and changes in profits are measured in Millions of dollars per quarter.
[2] The profit is calculated using the real sales data and the backed-out marginal cost.

Side Effects. In this subsection, I discuss how the trade shock between the U.S. and China affects the "Third Market", which includes the total effects across the European countries of removing GMS and 5G from Huawei. To that end, it is crucial to note that the conflicts between the main countries could have significant negative impacts on the third market. Consumers in uninvolved countries will also be hurt during international conflicts.

Table 5 presents consumers' welfare loss and suppliers' profits change. Removing GMS from new-released Huawei phones is equivalent to \$107.94 billion consumer welfare loss, and removing 5G will reduce consumer welfare by \$113.56. At the same time, the manufacturers also have a significant decrease in their total profits which mainly comes from the shrinkage in consumers' demand, removing GMS will lead to 0.79 million consumers switching to the outside option and more than 0.82 million consumers will not choose the inside products when Huawei lose access to 5G SoC.

Compared with the total profits in 2020Q2 (12,347 million dollars), the welfare effects of removing GMS and 5G are much smaller. However, I should note that phones without GMS and with 5G of Huawei only account for a very small amount of market share in our data period. For similar reasons, the estimated impacts from the trade sanctions are much smaller compared with the reduced form results. There are several main reasons behind this: first, the share of Huawei's 5G phones in 2020Q2 is 2.87%, and the share of phones with GMS from 2019Q2 to 2020Q2 is 4.58%. This led to a relatively small change in mean utilities when conducting counterfactual simulations. Putting things together, I find that external geopolitical policies do have a significant negative impact on multinational companies.

6 Conclusions

This research uses an exogenous shock to assess the effect of trade shock between the U.S. and China on firm performance in the third market, Europe. Specifically, I focus on the smartphone industry of which Huawei is restricted from using GMS and 5G chipset supply. I first examine that the trade restriction on Huawei and Honor resulted in significant price and quantity decreases of 10% and 50%, respectively. This enables me to assess counterfactual predictions at the level of the individual firms using a structural econometric model where I model both the demand- and supply-side effects.

I apply random coefficient logit demand, which creates potentially more flexible substitution patterns. Moreover, BLP is more suitable for markets with a large number of products because of consumer heterogeneity. The demand estimates show that GMS has a significant positive impact on consumers' utility which allows me to perform further counterfactual analysis. The counterfactual results show that

1) the sanctions are effective in terms of reducing Huawei's market share. In the

counterfactual results, Huawei's market share has a significant drop and its lost share is mainly obtained by its main competing firms, which Samsung gains the most, Apple and Xiaomi come next.

2) the trade sanctions have significant side impacts on the "Third Market". In the welfare analysis, these sanctions reduce consumer welfare in Europe. Therefore, I want to note that the geopolitical risks will not only have negative impacts on the main countries but also will hurt consumers in the uninvolved countries.

I caution that the model is a partial equilibrium description of the short-run effects of trade sanctions on welfare in the European consumer market for smartphones. Firms and retailers are assumed to maximize profits from all of their product models under Bertrand competition. The number of firms and products in the market, and where they are produced, do not change when the trade restriction is imposed in the simulated market. Demand is also static so individual consumers do not consider future changes in prices in their current choice decisions. Future research should explore the welfare effects of sanctions when one or more of these standard assumptions are relaxed.

Appendices

A Additional Industry Background

Figure A.1 presents the impact of the trade war on the semiconductor companies in the smartphone industry. The companies or businesses in red are directly impacted by the trade policy; they lack the necessary permits to conduct business with U.S. companies like Qualcomm and TSMC.

SoC is a crucial smartphone component that combines a mobile application processor (basically a CPU), GPU, modem, and other chips (Yang, 2020), in addition to the standard hardware components like the screen, battery, camera, and microphone. Most OEMs (original equipment manufacturers) buy SoCs from Qualcomm and MediaTek. In 2014, Huawei developed Kirin and applied it to Huawei's flagship smartphones later on. Samsung developed its own SoCs (Exynos) and supplied Samsung and Meizu phones. Apple is unusual among handset OEMs because it uses thin modems (from Qualcomm), in conjunction with its own proprietary application processor.

In terms of chip manufacturing companies, Taiwan Semiconductor Manufacturing Corporation (TSMC), the world's biggest contract chipmaker and a key Huawei supplier, has to stop new orders from Huawei following the ban. The largest contract chip maker in mainland China, Semiconductor Manufacturing International Corporation (SMIC), cannot produce chips for Huawei, because these firms' productions are heavily relied on U.S. equipment and raw material.

In 2019, the Trump administration pressed Dutch officials to cancel the sale of an Extreme ultraviolet lithography (EUVL) machine to SMIC. At that time, Advanced Semiconductor Materials Lithography (ASML) had to stop renewing the license needed to ship the tool. SMIC, as Huawei's alternative manufacturer, its manufacturing activities have also been severely impacted by the trade conflict.[15]

Table A.1: Huawei's annual R&D investment

	2016	2017	2018	2019	2020	2021	2022
R&D investment	76.4	89.7	101.5	131.7	141.9	142.7	161.5
Percentage of revenue	14.6%	14.9%	14.1%	15.3%	15.9%	22.4%	25.1%
R&D personnel	45%	45%	45%	49%	53.4%	54.8%	55.4%

[1] R&D investment is in CNY billion.

[2] Data is collected from Huawei's 2016-2022 Annual Report.

[15] ASML is the only company in the world that owns the technology and makes the machinery to make physical chips out of silicon wafers. Chipmakers like TSMC, NVIDIA, and Intel won't be able to make the chips without ASML's EUV technology.

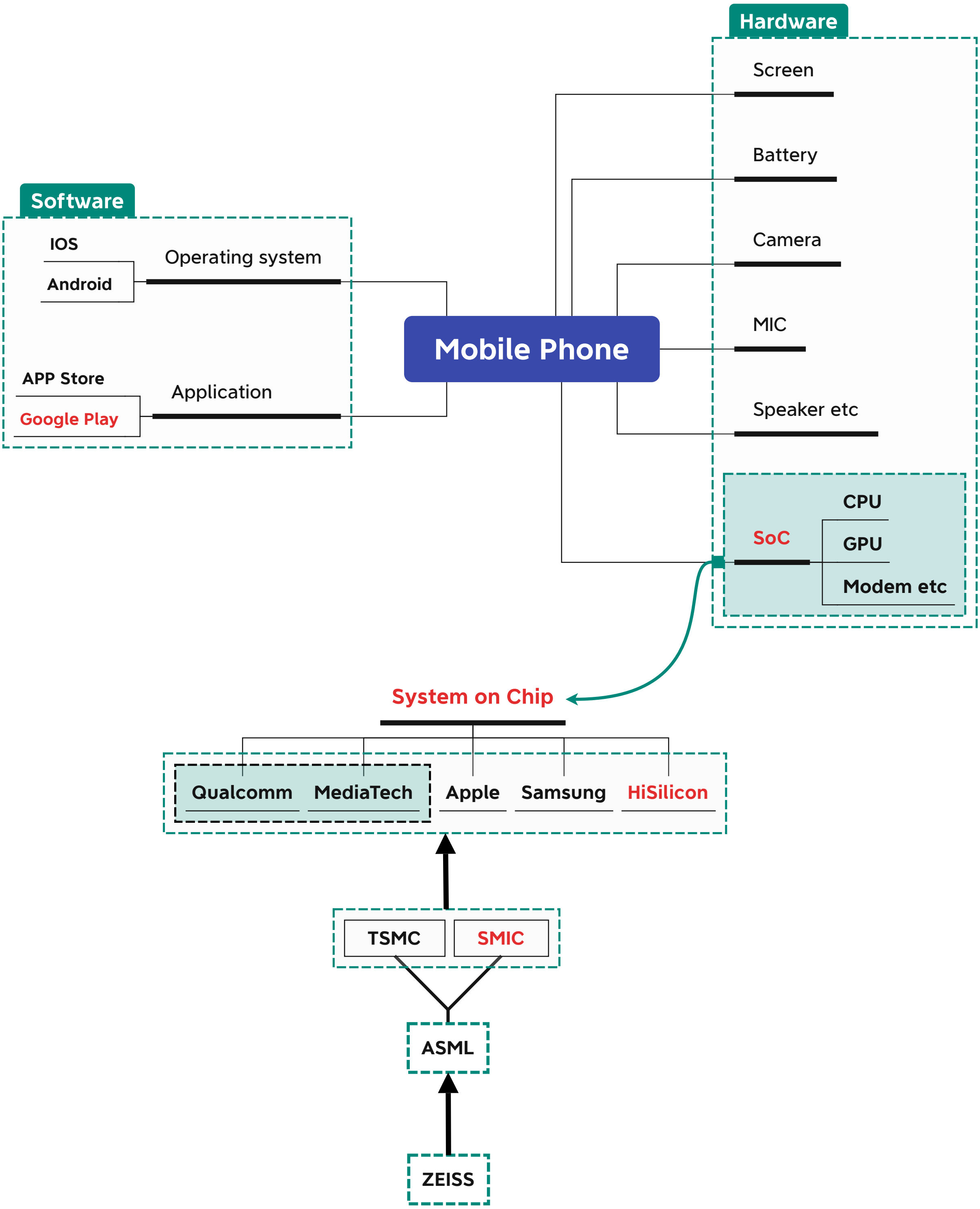


Figure A.1: Components of a mobile phone and policy background

B Additional Tables and Figures

Table A.2: Counterfactual I results by model of 2020Q2

Brand	Model Name	Units	Units_hat	Price	ΔUnits	ΔRevenue
Huawei	**P40 Pro**	101,356	175,939	920.3	74,583	68.64
	P40 Lite	287,514	544,971	240.9	257,457	62.02
	P40	85,824	158,704	692.8	72,880	50.49
	Mate Xs	14,136	26,403	2,288.3	12,267	28.07
	P40 Lite E	167,244	309,327	161.3	142,083	22.92
	P30 Lite	823,599	778,871	237.8	-44,728	-10.63
	P30 Pro	285,316	274,465	634.8	-10,851	-6.89
Honor	**9S**	231,075	364,320	81.0	133,245	10.79
	9C	131,813	215,650	139.0	83,836	11.65
	8A Prime	181,311	299,676	105.0	118,365	12.43
	9A	225,601	369,754	116.0	144,153	16.72
Samsung	Galaxy S20+	236,454	226,949	929.0	-9,505	-8.83
	Galaxy S20	442,731	433,944	806.0	-8,787	-7.08
Apple	iPhone 11	2,532,260	2,514,180	775.1	-18,081	-14.01
	iPhone SE (2020)	1,789,570	1,779,165	494.0	-10,405	-5.14
Xiaomi	Redmi Note 8T	863,231	824,263	161.7	-38,968	-6.30
	Redmi Note 9	451,232	422,076	182.3	-29,156	-5.31
	MI 10	190,963	184,097	760.3	-6,866	-5.22
OPPO	Find X2 Pro	35,477	32,492	1,047.0	-2,985	-3.13
	Find X2	68,079	65,728	824.3	-2,351	-1.94
vivo	Y30	22,039	19,469	196.5	-2,570	-0.51
	Y19	30,875	28,231	189.1	-2,644	-0.50

[1] Revenue change is in million U.S. dollars.

Table A.3: Counterfactual II results by model of 2020Q2

Brand	Model Name	Units	Units_hat	Price	ΔUnits	ΔRevenue
Huawei	**P40 Pro**	101,356	6,934	920.3	-94,422	-86.90
	Mate Xs	14,136	26	2,288.3	-14,110	-32.29
	Mate 20 X	15,785	5,578	730.4	-10,207	-7.45
	P40 Pro+	5,490	10	1,265.2	-5,480	-6.93
	P40 Pro Plus	346	1	1,238.8	-345	-0.43
	Mate 30	3,389	3,296	1,190.8	-93	-0.11
	P30	127,481	128,156	440.6	675	0.30
	Mate 20 Pro	35,512	35,928	574.6	416	0.24
Honor	**30**	25,933	49	426.4	-25,884	-11.04
	30 Pro Plus	5,476	10	637.0	-5,466	-3.48
	30s	4,097	7	325.0	-4,090	-1.33
	V30	22	0	721.3	-22	-0.02
	20 Pro	42,361	42,769	371.4	408	0.15
	20 Lite	158,605	159,239	202.0	634	0.13
Samsung	**Galaxy S20+**	236,454	247,115	929.0	10661	9.90
	Galaxy S20 Ultra	154,024	160,092	1225.5	6,068	7.44
	Galaxy S20	442,731	451,384	806.0	8,653	6.97
	Galaxy S10	464,076	472,238	698.0	8,162	5.70
	Galaxy S10+	150,720	156,716	812.7	5,996	4.87
Apple	iPhone 11	2,532,260	2,545,331	775.1	13,071	10.13
	iPhone SE (2020)	1,789,570	1,794,015	494.0	4,445	2.20
	iPhone XR	754,123	756,502	646.9	2,379	1.54
Xiaomi	**MI 10**	190,963	197,881	760.3	6,918	5.26
	Mi 10 Pro	57,314	60,734	915.4	3,420	3.13
OPPO	**Find X2 Pro**	35,477	39,839	1,047.0	4,362	4.57
	Find X2	68,079	70,618	824.3	2,539	2.09

[1] Revenue change is in million U.S. dollars.

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