ABSTRACT

Title of dissertation: THE INCIDENCE OF TRADE WARS:
EVIDENCE FROM THE US SOLAR INDUSTRY

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Trade wars between countries in the renewable energy sector have proliferated in recent years, potentially hindering the growth of the industry. This dissertation investigates the welfare effect of anti-dumping policies initiated by the US government against Chinese manufacturers. It focuses on the US solar industry, which has grown more than thirtyfold over the past ten years.

Chapter 1 describes the policy background leading to the trade war, together with institutional details of the industry. Furthermore, it proposes a two-country theoretical model to formalize how anti-dumping policies affect the market in equilibrium.

Chapter 2 estimates a structural econometric model with a differentiated demand system and marginal cost for solar manufacturing that incorporates the vertical structure between upstream solar manufacturers and downstream solar installers. The estimation results suggest large markups among solar manufacturers and installers.

Chapter 3 conducts policy simulations and shows the impact of trade war on the US solar market. In particular, it considers different changes in anti-dumping duty and subsidy rates, and evaluates the welfare effect among different market participants. The results show the anti-dumping policy has decreased producer surplus and consumer surplus by around $874 million (in 2015 US dollars) and has increased the greenhouse gas emissions by 5.98 million tons for the period 2010 - 2015. The installation capacity of US solar market would have increased by 36.4% if there had been no anti-dumping policies. Compared with the large decrease in profits for Chinese solar manufacturers, US manufacturers benefit only slightly from the US anti-dumping policy.

Chapter 4 further investigates the welfare effects of trade policies on the population of consumers, by using a random coefficient discrete choice model which captures the heterogeneity in consumer tastes for differentiated products. It then explores the welfare change among different groups of consumers. The results show that consumers who are relatively less sensitive to solar panel price (i.e., consumers who reside in areas with higher median income, a lower percentage of households with children and a higher proportion of democratic supporters) would benefit the most if there had been no anti-dumping duties.

Chapter 5 concludes and discusses the issue of trade protectionism occurred in other industries.

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by

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Dedication

To my beloved parents for giving me invaluable educational opportunities

To the memory of my brother, Wenliang

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List of Abbreviations

ARRA	American Reinvestment and Recovery Act of 2009
BLP	Berry Levinsohn Pakes
BOS	Balance of System
CDB	China Development Bank
EU	European Union
FOC	First Order Condition
GATT	General Agreement on Tariffs and Trade
GMM	Generalized Methods of Moments
IV	Instrumental Variable
LBNL	Lawrence Berkeley National Laboratory
MSA	Metropolitan Statistical Area
PV	photovoltaics
SREC	Solar Renewable Energy Certificates
US	United States
WTO	World Trade Organization

Chapter 1: Introduction of Solar Trade War

1.1 Motivation

The solar power sector has grown rapidly over the past 10 years. The capacity of photovoltaic (PV) systems has soared 3300%, from 6,660 MW in 2006 to 229,300 MW in 2015 worldwide. Meanwhile, the average solar module price has plummeted by 82.5% from $4/Watt in 2006 to around $0.7/Watt in 2015, a decrease believed to be driven by improvement in technology and economies of scale (Barbose and Darghouth, 2016). While the solar manufacturing sector has been historically dominated by companies located in United States, Japan and Germany, Chinese firms have gradually gained market share since 2010. For the period 2010 - 2015, six Chinese companies have been listed in the top ten cell producers. Several factors explain the market dominance of Chinese firms: cost advantage, generous subsidies from the government, and preferential loans from banks.

In October 2011, several American manufacturers sued Chinese solar manufacturers for violating anti-dumping rules set by World Trade Organization (WTO). Chinese solar manufacturers were accused to sell heavily subsidized solar panels on the US market. In May 2012, the US Department of Commerce announced that anti-dumping duties were set at 31% for Chinese solar manufacturers that chose to participate in the investigation; companies that chose not to participate were subject to a 250% tariff. In retaliation, China imposed tariffs on exports of polysilicon products from United States. Although this trade war affected companies in both countries, Chinese solar companies appeared to be particularly negatively impacted. For example, Suntech Power, a Chinese firm that was once the largest solar manufacturer in the world, became insolvent after the US anti-dumping policy came into effect, and it went bankrupt in February 2014.

The trade war in the solar industry has been widely discussed, but little is know about its total economic cost. In this dissertation, I fill this gap and estimate the incidence of US anti-dumping policy among different market participants. In particular, I answer five related questions: (1) How much did US and Chinese firms benefit or lose from this policy? (2) How much did US consumers lose? (3) Were there heterogeneous welfare effects among different groups of consumers. (4) Did US installers benefit or lose from this policy? (5) To what extent has this policy impacted the expansion of the solar market in the US?

I first use a two-country theoretical model, and show three results regarding the impact of anti-dumping policy on equilibrium prices, quantities, and producer surplus. First, an anti-dumping policy will increase the price of the foreign firm; the price of the domestic firm will increase or remain the same; and increase for the latter firm will always be less than the former. Second, the demand for the foreign solar panels will fall, and the demand for the domestic solar panels will increase provided that it is elastic. Third, the foreign solar firm will lose profits, and the domestic solar firm will gain positive profits provided that its solar panel is elastic.

I then use a structural model to empirically test these predictions and quantify the welfare effect of anti-dumping policies on different market participants. My data come from the Lawrence Berkeley National Laboratory (LBNL)'s *Tracking the Sun* report series. This dataset provides household-level information on almost all of the solar PV installations in the US market for the period 2010 - 2015. I observe when and where the household installed its residential solar PV system, the size, the price, the brand of the solar panels used, and the name of the installer, among other things. In addition, I observe key characteristics of each product, such as energy conversion efficiency, technology type, and color of the frame. The estimation results are intuitive: on the demand side, the households prefer solar panels with high energy conversion efficiency, panels made of monocrystalline cells and panels with silver frames. On the supply side, I model the vertical structure of the industry and explicitly account for the strategic behaviors of domestic and foreign manufacturers, and domestic installers. The solar manufacturers are assumed to set their prices first and the installers follow. The margin calculated corresponds to pure double-marginalization price-cost margin with linear oligopoly pricing at the manufacturer and retail levels (Berto Villas-Boas, 2007). The estimation results on the supply side suggest that marginal cost increases with manufacturing wage, lending interest rate, energy conversion efficiency and labor cost in installation.

I simulate the estimated demand and supply models for six counterfactual scenarios to explore how the anti-dumping duty and manufacturing subsidy rates impact the US solar industry: In simulation I, I set the anti-dumping duty rates to zero while the US and China's subsidy rates remain unchanged; In simulation II, I set the anti-dumping duty rates to zero, while setting China's subsidy rates to be equal to that of US; In simulation III, I set the anti-dumping duty rates to zero, while setting the US subsidy rates to be equal to that of China; In simulation IV, I set the anti-dumping duty and China's subsidy rates to zero, while US subsidy rates remain unchanged; In simulation V, I set the anti-dumping duty and US subsidy rates to zero, while China's subsidy rates remain unchanged; In simulation VI, I set the anti-dumping duty, US and China's subsidy rates to zero.

The simulation results suggest that the anti-dumping duty has decreased producer surplus and consumer surplus by \$874 million (in 2015 US dollars) and has increased the greenhouse gas emissions by 5.98 million tons for the period 2010 - 2015. The installation capacity of US solar market would have increased by 36.4% if there had been no anti-dumping policies. Compared with the large decrease in profits for Chinese solar manufacturers, US manufacturers benefit only slightly from the US anti-dumping policy. A domestic country can attempt to mitigate the effect of dumping from foreign firms by subsidizing domestic manufacturers. The simulation results suggest that this approach might produce better outcome in terms of promoting the development of the solar industry, but it is costly.

To capture the incidence of trade restrictions on different types of consumers, I extend the model and use a random coefficient discrete choice model with heterogeneity in consumer tastes for solar panel prices, and explore the distribution of welfare changes among different groups of consumers. I revisit the six counterfactual simulations and the results suggest that consumers who are relatively less sensitive to solar panel price (i.e., consumers residing in areas with higher median income, a lower percentage of households with children, and a higher proportion of democratic supporters) would benefit the most if there had been no anti-dumping duties. In other words, these groups of consumers have lost the most in welfare from the US anti-dumping policy.

1.2 Literature Review

This dissertation contributes to the literature on trade wars, solar markets and vertical relationship in industrial organization. I will mainly discuss the research on trade wars and briefly go through the other two streams of literature hereinafter.

This dissertation contributes to the empirical understanding of the impacts of trade wars, which have become increasingly common in recent years. Anti-dumping duties are popular instruments of the trade policy which aims at protecting domestic market. Before 1980 anti-dumping tariffs were primarily used by five major developed countries (Australia, Canada, EU, New Zealand and the US), but since 1980, developing countries (i.e. India, Mexico, China) have started to retaliate and have also adopted anti-dumping tariffs. This trend proliferated after the World Trade Organization (WTO) has been established (Vandenbussche and Zanardi, 2008). For example, in the 1980s, the US took anti-dumping action against Japan on the imports of semiconductors. Back then, Japanese firms were very successful in the semiconductor industry and captured a large share in the US market (Irwin, 1996). Also, in the late 1990s, the US steel industry initiated a new round of anti-dumping action aimed at imported steel from Asian countries (Mastel, 1999). India and

China have initiated hundreds of anti-dumping investigations since they adopted the anti-dumping law in 1985 and 1997, respectively.

Regarding to the economic effect of anti-dumping policies, Gallaway et al. (1999) use a computable general equilibrium model to estimate that the overall welfare cost of hundreds of active US anti-dumping and countervailing duty orders in 1993 was $4 billion. Prusa (2001) documents two key costs of anti-dumping protection: first, once an anti-dumping policy has been adopted, countries often have a difficult time restraining its use; second, on average, anti-dumping duties cause the value of imports to fall by 30 - 50 percent. Egger and Nelson (2011) employ a trade model to evaluate the effect of anti-dumping policy on the trade volume and social welfare over the period 1960 - 2001, and find that the impacts have been negative, but quite modest.

The impact of the anti-dumping policy on the domestic industry may not be uniform across all producers within an industry (Feinberg, 2013), and often differs across different industries.

Cohen-Meidan (2013) reviews the effect of imposing anti-dumping duties on Mexican and Japanese imports of gray Portland cement. The reaction to the duties in the US Portland cement industry ranges from incomplete substitution with alternative imports to no substitution and no change in the market shares of affected foreign producers. He concludes that the impact of a trade policy can differ considerably across regions, even within the same country and industry, as a result of within country market segmentation.

Blonigen et al. (2013a) evaluate the role of anti-dumping protection in preventing exit. They find little evidence that anti-dumping policy has decreased exit in the steel industry. The lack of evidence with regard to the impact of anti-dumping and countervailing duties on exit may seem surprising, but is consistent with the result in Feinberg and Hartigan (2007) and Blonigen et al. (2013b). The wave of bankruptcies in the US steel industry in the early 2000s occurred despite relatively high levels of anti-dumping protection.

Reynolds (2013) tests whether the anti-dumping petition process itself can help domestic firms raise prices and analyze the impact of anti-dumping petitions on competition levels in two industries, US semiconductor and tapered roller bearing industries. He finds little evidence that either of these industries increases their market power following the filing of petitions for trade relief, suggesting that the widespread belief that anti-dumping leads to more market power may not always hold.

Levinsohn (1995) studies the trade friction in the 1990s between United States and Japan in the automobile parts market. In order to address the growing bilateral trade deficit in auto parts, the US threatened tariffs on thirteen Japanese luxury cars, but agreed to drop the threatened tariff later. By simulating the threatened tariffs, he concludes that the tariffs would have resulted in drastically reduced sales of the thirteen models, and Japanese profits in total would have fallen around 12.5 percent, while the European firms would have captured many of the lost Japanese sales. The US firms would have been pretty much unaffected by the tariffs.

My dissertation extends the literature on trade wars by studying a fast-growing green industry and focuses on the trade issues between United States and China, which are nowadays the world's two largest economies.

Second, my dissertation contributes to the growing literature on the solar power market. One stream of this literature has focused on evaluating the factors leading to the adoption of residential solar power. Chernyakhovskiy (2015), Bollinger and Gillingham (2012), Burr (2012), and Gillingham and Tsvetanov (2014) all examine the adoption of residential solar photovoltaic (PV) systems in the United States. They show that the financial incentives, solar-specific mandates, and peer effect as important drivers of solar capacity growth. The uncertainty of the future government subsidy can also affect the household adoption of solar PV when they consider the option value of their investment decision (Bauner and Crago, 2015). A second stream of the literature focuses on the cost reduction of solar prices (Bollinger and Gillingham, 2014; Reichelstein and Sahoo, 2015; Gillingham et al., 2015). They find that learning-by-doing among the installers lowers the solar prices, primarily the non-hardware costs of the solar PV installations. More recent work have shown rising interests on the structural estimation of demand and supply in the solar PV market. Gerarden (2017) finds that consumer subsidies can encourage firms to innovate to reduce their costs over time and he quantifies these impacts by estimating a dynamic structural model of competition among solar panel manufacturers. Dorsey (2017) provides evidence that using online bidding platforms to increase seller's competition and expand buyers choice set can serve as an effective way to increase adoption. My dissertation is different in that it uses a structural model of demand and supply with vertical contracting to evaluate the anti-dumping policies in the solar industry.

Third, my dissertation contributes to the empirical literature on vertical relationships. In the vertical contracting between manufacturers and retailers, the wholesale price data is typically unavailable, which makes the retailers' and manufacturers' marginal cost difficult to measure separately. Berto Villas-Boas (2007) uses a linear pricing model and derives conditions under which data on the retail price and quantities are sufficient to identify the vertical model of upstream manufacturer and downstream retailer oligopoly-pricing behavior. This type of model has been widely used to examine the vertical structure in different industries, such as the contract between smartphone firms and carriers in the smartphone market (Fan and Yang, 2016), the codeshare contract between ticketing and operating carriers in the airline market (Gayle, 2013), and the vertical relationship between manufacturers and retailers in the bottled water market (Bonnet and Dubois, 2010). My dissertation is the first to study vertical contracting between upstream manufacturers and downstream installers in the solar sector.

1.3 The Solar Industry

This section describes the growth of the US solar market, the US and China's subsidy policies on the solar power and the anti-dumping policy initiated by the US against Chinese manufacturers.

1.3.1 The US Solar Market

Solar power has become an important source of renewable energy in the US. According to the Solar Energy Industries Association, the total size of solar PV installation across the US has reached 14.6 gigawatts in 2016. Solar power has overtaken wind, hydro and natural gas to become the largest source of new electricity capacity on US grid in 2016, based on estimates from US Energy Information Administration [1]. The National Solar Jobs Census reports that more people are working in solar now than at oil rigs and in gas fields, and one of every 50 new jobs in the US in 2016 is added by the solar industry [2]. Solar has become one of the fastest-growing sectors of the US economy.

California is the state with the most solar energy in the US and its installed capacity in 2016 was 3.9 gigawatts, which is enough to provide electricity to millions of homes. California benefits from high insolation, but has also enacted policies to support solar, such as the Renewable Portfolio Standard which requires that 33% of California's electricity come from renewable resources by 2020. New Jersey is second in the country in terms of solar usage. It has 1.5 gigawatts capacity of solar power installed. Though not the sunniest place in United States, the Garden State's solar market has benefited by one of the most favorable net metering standards, allowing customers of any size array to use net metering. The rest of the top 10 states in solar installation capacity are Arizona, Massachusetts, New York, Nevada, Texas,

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[1] Source: Ars Technica, `https://arstechnica.com/science/2016/12/solar-is-top-source-of-new-capacity-on-the-us-grid-in-2016/`

[2] Source: National Solar Jobs Census 2016, The Solar Foundation, available at:SolarJobsCensus.org

Pennsylvania, Minnesota and Colorado (see Figure 1).

To make readers better understand the solar industry, I provide some technical information about the photovoltaic (PV) systems. A solar PV system comprises the solar array and the balance of system (BOS), which includes wiring, switches, a mounting system, inverters, a battery bank and battery charger. The solar PV system can be classified into three types: residential rooftop, commercial rooftop, and ground-mount utility-scale systems. A typical residential system has a capacity of 10 kilowatts, on average, and is mounted on a sloped roof, while a commercial system may reach a megawatt-scale and a utility-scale system is usually equal to or greater than 5 megawatts in size. There are mainly two types of solar panels, which are the most important part of a PV system. Monocrystalline solar panels are made from a single crystal and their color is dark black, while polycrystalline solar panels are made of multiple crystals and their color is dark blue (see Figure 2). Monocrystalline solar panels takes longer to be produced and they typically perform better than polycrystalline solar panels.

One important feature about the solar industry is the continued decline of solar panel prices. The price has dropped 82.5% during the period 2006 - 2015, from \$4/W to \$0.7/W, and both the total installed price and non-module cost have fallen to different extent (see Figure 3). The total installed price includes everything needed to get a solar PV system: the modules (panels), the power electronics, the mounting hardware, and the labor cost involved in the installation itself. The total installed price keeps falling while the module (panel) cost has remained relatively flat since 2012. This pattern is believed to be driven by the decline in the cost of inverters which convert DC to AC power, and also the decline in labor cost resulting from learning-by-doing in the installation workers (Barbose and Darghouth, 2016).

1.3.2 Government Incentives in the US

The growth of the US solar sector has been helped with various subsidy programs offered by the state and federal governments.

The federal government's first push for solar energy took place in the 1970s in order to cope with the oil crisis. The Congress passed the Energy Tax Act of 1978, as a result of which commercial investment tax credit and the residential energy credit were created to provide financial incentives (with a maximum of $2000 or $2500[3]) to those who purchased solar properties.

The federal government's second push for solar energy began in the early 2000s as a part of the energy strategy for the 21st century launched by the Bush administration. The Energy Policy Act of 2005 created a 30% investment tax credit (ITC) for solar PV installations, with a $2,000 limit for residential installations. Subsequently the Energy Improvement and Extension Act of 2008 removed the $2,000 limit and the American Recovery and Reinvestment Act of 2009 temporarily converted the 30% tax to a cash grant (Bollinger and Gillingham, 2014).

The federal subsidy is believed to be an important factor leading to the recent growth of the solar sector. In 2006, when the 30% tax credit was introduced, the annual installation of residential solar PV system in the US was 2,573 units. Nine

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[3] The residential energy credit is calculated at 30 percent of the first $2,000 spent on purchasing solar products and 20 percent of the next $8,000 spent on purchasing solar products with a maximum of $2,500.

years later, the annual installation has grown hundredfold, to about 246,554 units (see Figure 4). Cumulative installation of solar PV system has reached to nearly 700,000 units with 4.36 gigawatts capacity in total by the end of 2015.

The financial subsidy for residential solar PV installations at the state level varies considerably from place to place and the incentive generally falls into four categories: cash rebate, state tax credit, Solar Renewable Energy Certificates (SREC) and Performance-based Incentives (PBI) [4].

Cash Rebate. The homeowner can receive a cash rebate from the state for promoting the use of solar energy. This one-time rebate is provided on a $/kW basis at the time the system is installed and only lasts for a limited time in the state, and will end once a certain amount of installation is reached. For example, in California, it is a one-time, lump-sum upfront payment, nominally $0 - $2.5 per watt [5]. In Maryland, its Residential Clean Energy Grant Program pays $1000/project for customers who install a residential solar PV system smaller than 20 kW[6].

State Tax Credit. Some states offer additional tax credits for installing the solar PV system, thus dropping the upfront cost of the installation, which is similar to the federal ITCs.

SREC. Solar Renewable Energy Certificates are credits that the homeowner can obtain by selling the solar electricity to the grid. Usually, the homeowner will be paid several hundreds of dollars by the utility companies. SREC is slightly different

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[4] See energysage.com for more details, `https://www.energysage.com/solar/cost-benefit/solar-incentives-and-rebates/`

[5] Source: Go Solar California, `http://www.gosolarcalifornia.ca.gov/csi/`

[6] Source: Maryland Energy Administration, `http://energy.maryland.gov/residential/Pages/incentives/CleanEnergyGrants.aspx`

from net metering polices. The meter simply runs backwards when the solar PV system produces more than what is needed and the homeowner can receive a credit for the extra electricity sold back to the grid.

PBI. Performance-based incentives are per kilowatt-hour credits that are paid based on the actual total energy produced by the solar system during a certain period of time. Unlike SREC, PBI don't have to be sold through a market, and incentive rates are determined when the system is installed. PBI policy is effective in stimulating the solar installers and homeowners to focus on appropriate installation and maintenance of their systems, since the payment is solely based on the energy production. One example of PBI program is California Solar Initiative, where incentives are paid monthly for five years based on the actual energy produced by the household's solar PV system.

In addition to subsidizing consumers in the solar PV installations, the US government also subsidizes its solar manufacturers to promote the development of its solar sector. There are generally three types of subsidies offered to the US solar manufacturers.

(1) **Advanced Energy Manufacturing Tax Credit**. As a part of the American Reinvestment and Recovery Act of 2009 (ARRA), the Department of Energy and Department of Treasury jointly launched the Advanced Energy Manufacturing Tax Credit program in January 2010 for the manufacturers of clean energy equipment, including solar cells, wind turbines, electric cars, and geothermal heat pumps. Solar manufacturers who build factories or upgrade equipment are eligible for these tax credits which equal to 30% of the investment cost in their manufacturing facili-

ties. Phase I of this program was awarded funds of $2.3 billion and phase II provided $150 million of additional credits. In January 2010, President Obama announced the list of one hundred eighty-three clean energy manufacturing projects in 43 states that received the credits and four polysilicon manufacturing enterprises were on this list [7].

(2) **Business and Property Tax Credit**. Some states provide heavy subsidies in the form of business tax credit or property tax credit to attract investment from solar manufacturers and expand local employment. For example, qualified high-technology businesses (including solar manufacturing firms) in Michigan are eligible for business tax credit "for a period of time not to exceed 7 years as determined by the Michigan economic growth authority, an amount not to exceed 200% of the sum of the payroll and health care benefits of the qualified high-technology business attributable to employees who perform qualified new jobs"[8]. In addition, solar manufacturing firms which build their plants or facilities located in renaissance zone [9] of Michigan state are exempt from property tax once approved by the state and local governments.

(3) **Subsidized Land**. State may provide subsidized land and infrastructure improvement to attract business to their areas. For example, in March 2007, the city of Pocatello in the State of Idaho purchased 67.3 acres for $942,975 and leased the property to polysilicon manufacturer Hoku, for building plants at an incredible low

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[7] Source: U.S. Department of the Treasury, `https://www.treasury.gov/press-center/press-releases/Pages/tg1848.aspx`

[8] Source: MICHIGAN BUSINESS TAX ACT (EXCERPT) Act 36 of 2007, section 208.1431.

[9] Michigan Renaissance Zones are regions of the state designated as virtually tax free for any business or resident presently in or moving into a zone for a period of up to 15 years

price of \$1 per year for 99 years [10]. In 2008, the Montgomery County in the state of Tennessee built a new four-lane county road specially for Hemlock Semiconductor, a polysilicon manufacturer, in order to make more convenient access for vehicles travelling between the Hemlock Semiconductor site and the interstate highway [11].

1.3.3 Government Incentives in China

China has been one of the world's largest manufacturers of solar panels since 2008 and became the largest producer of photovoltaic power in 2015 when it surpassed Germany. In 2017, China became the first country to exceed 100 gigawatts of cumulative installed PV capacity. The extremely rapid development of its solar industry coincides with the government subsidies and support. China first launched the solar strategy in 2001 when formulating its Tenth Five-Year Plan (2001 - 2005). Back then, there was no domestic solar industry in China and the global solar market was tiny. Later on, China implemented a series of policies to encourage the development of renewable energy and its solar subsidies initially focused on the manufacturing side, offering tax breaks, subsidized land, cash grants and preferential lending (Ball et al., 2017).

Tax Breaks. Qualified Chinese solar producers are eligible for a credit of 50% of the value-added tax. These tax breaks were first implemented in 2013 for two years, and then extended through 2018. Besides tax incentives on the central-

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[10] Source: Idaho State Journa, `https://idahostatejournal.com/news/india-investors-purchase-hoku-plant-in-pocatello/article_9c96530a-888b-5edb-a301-8ff2169fdca9.html`

[11] Source: Hemlock Semiconductor Group, `http://www.hscpoly.com/content/hsc_comp/four-lane-road.aspx`

government level, local governments provide various reduction in both value-added tax and income tax. For example, the municipal government of Wuxi, hometown to Suntech Power, offers local tax reductions for solar manufacturers with large revenue (Ball et al., 2017).

Subsidized Land. Some Chinese solar manufacturers have received free or discounted land from local governments for their solar-manufacturing hubs, primarily for the purpose of building factories. For example, LDK, a solar manufacturer which built its factory in the city of Xinyu in the Jiangsu Province in 2015, reportedly benefited from the provision of subsidized land from the municipal government [12].

Cash Grants. Chinese solar manufacturers have received cash grants from their municipal and provincial governments as an incentive for the local development of solar industry. For example, as reported by LDK in its financial filings, these incentive in 2007 included \$3.1 million in electric bill reduction and \$3.5 million cash grant from local government authority [13]. In addition, some solar manufacturers may receive a cash injection from their local governments when they experience financial distress. The rationale behind these government rescue is that these companies are large employers and taxpayers, thus important contributors to the local economy (Ball et al., 2017). One of the prominent examples is Suntech Power. Suntech Power, which was once the pioneer of Chinese solar manufacturers, defaulted on payment of \$541 million worth of bonds in March 2013. Suntech Power filed for bankruptcy

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[12] Source: NBD article, `http://www.nbd.com.cn/articles/2012-06-22/662422.html`

[13] Source: Form 20-F for LDK, `https://www.sec.gov/Archives/edgar/data/1385424/000114554908000623/h02002e20vf.htm`

subsequently and was restructured in Apirl 2014. The Wuxi municipal government supported Suntech Power in two ways: it provided a $150 million cash injection in Suntech Power's holding company and offered Suntech Power a five-year exemption from revenue taxes after the restructuring [14].

Preferential Lending. Government-affiliated banks in China have provided preferential lending to finance solar manufacturers. China Development Bank (CDB), controlled by the Chinese government, is the primary lender in financing China-based solar companies. In 2010 alone, the CDB authorized an unprecedented $30.41 billion line of credit to five top Chinese solar manufacturers: LDK Solar, Suntech Power, Yingli, JA Solar, and Trina (Ball et al., 2017). Several loans offered to solar manufacturers were very generous and may not have been offered by private banks. A good example is the case of Yingli, one of China's largest solar suppliers. It has received $1.16 billion in new loans from CDB in the Spring of 2016 when it was on the verge of insolvency [15]. This debt helped Yingli repay its existing loans thus avoiding a potential default, and supported Yingli to expand its production capacity. The Export-Import Bank of China, one of the three Chinese policy banks, also provides low-interest loans to foreign buyers of Chinese solar companies' products. The preferential rates offered by the banks act as implicit government subsidies.

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[14] Source: Bloomberg New Energy Finance, `https://www.bnef.com/Insight/8856`

[15] Source: Bloomberg, `http://www.bloomberg.com/news/articles/2016-04-08/china-said-to-push-for-1-16-billion-in-loans-for-yingli-imri0khz`

1.3.4 Anti-dumping Policies

In the context of international trade, dumping occurs when manufacturers export products to another country at a price below the price charged in its home market or below its cost of production (definition in the GATT/WTO). In October 2011, a coalition of solar manufacturers, led by SolarWorld, a German company with considerable manufacturing in the United States, filed an anti-dumping petition against solar products from China. They claimed that Chinese solar manufacturers collected heavy subsidies from their government and dumped the solar cells and panels into the American market. In November 2011, US Department of Commerce initiated anti-dumping and countervailing duties [16] investigations of imports of solar cells from China. The merchandise covered by these investigations consisted of "crystalline silicon photovoltaic cells, and modules, laminates, and panels, consisting of crystalline silicon photovoltaic cells, whether or not partially or fully assembled into other products, including, but not limited to, modules, laminates, panels and building integrated materials."[17]

In October 2012, the Department of Commerce issued its affirmative final determination and concluded that Chinese solar producers were benefiting from unfair government subsidies and were selling solar cells in United States by dumping margins ranging from 18.32% to 249.96%. The rates of anti-dumping duties faced

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[16] Countervailing duties, also known as anti-subsidy duties, are trade import duties imposed under World Trade Organization (WTO) rules to neutralize the negative effects of subsidies.

[17] See the detail in the fact sheet released by the International Trade Administration of the US Department of Commerce: `http://enforcement.trade.gov/download/factsheets/factsheet_prc-solar-cells-ad-cvd-init.pdf`

by Chinese solar makers fell into four categories: 1) 31.73%, received by Suntech Power, one of the largest solar manufacturers; 2) 18.32%, received by Trina Solar; 3) 25.96%, received by fifty-nine other exporters; 4) 249.96%, received by all remaining Chinese exporters. In the countervailing duties investigation, Suntech Power and Trina Solar received countervailing rates of 14.78% and 15.97%, respectively, while all other Chinese producers received a rate of 15.24%.

However, this ruling only applied to panels made from Chinese solar cells. A few Chinese companies were able to evade the duties by assembling panels from cells produced elsewhere, for example in Taiwan Region, even though the production materials (such as ingots and wafers) for those cells came from China.

To close this loophole, in January 2014, SolarWorld filed new anti-dumping and anti-subsidy cases against China and Taiwan Region with the US Department of Commerce and the US International Trade Commission. In December 2014, the Department of Commerce announced the investigation result and imposed steep tariffs on imports from China and Taiwan Region. Trina Solar and Renesola/Jinko received anti-dumping duty rates of 26.71% and 78.42%, respectively and forty-three other exporters qualified for a separate rate of 52.13%. All remaining Chinese producers received an anti-dumping rate of 165.04%. In the countervailing duties investigation, Trina Solar and Suntech Power received countervailing rate of 49.79%and 27.64%, respectively. All other producers in China have been assigned a countervailing rate of 38.72%.

In July 2012, in retaliation to the US policies, the Ministry of Commerce of the People's Republic of China began the anti-dumping and countervailing investigation on the solar-grade polysilicon exports from United States. In January 2014, the Ministry of Commerce announced the final investigation result and imposed tariffs on imported US polysilicon products. On average, the US polysilicon manufacturers received anti-dumping and countervailing duty rates of 57% and 2.1%, respectively. [18]

1.4 Two-country Theoretical Model

In this section, I propose a two-country theoretical model to explore how the prices, quantities and producer surplus will change in response to an anti-dumping duty. Consider an economy with a duopolistic solar industry: a domestic firm and a foreign firm. There are three types of players in this market: the upstream solar manufacturers (domestic and foreign), the downstream domestic solar installers and the consumers. The solar manufacturer produces solar panels and sells by wholesale to the solar installers. The solar installers sell the panels to the consumers while providing installation services. The home country imposes an anti-dumping duty rate of τ on the imports.

I model this problem as a two-stage game. In the first stage, the foreign and domestic solar manufacturer compete in a Bertrand game, and choose their wholesale price P_f and P_d, respectively. In the second stage, the solar installers choose the final price π^f for an installed foreign solar panel and the final price π^d for an installed domestic solar panel.

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[18] See the fact sheet released by the Ministry of Commerce of the People's Republic of China: http://www.mofcom.gov.cn/article/b/e/201401/20140100466573.shtml

1.4.1 Solar Manufacturers' Subgame

The first stage profit function for the foreign and domestic solar manufacturers are, respectively,

$$\Pi^f = \max_{P_f} (P_f - \tau P_f - C_f) D^f(P_f, P_d) - G_f \tag{1.1}$$

$$\Pi^d = \max_{P_d} (P_d - C_d) D^d(P_f, P_d) - G_d \tag{1.2}$$

Where C_f and G_f represent the marginal and fixed cost for the foreign solar manufacturer, respectively; C_d and G_d represent the marginal and fixed cost for the domestic solar manufacturer, respectively. P_f and P_d are the wholesale prices for the foreign and domestic solar panels, respectively; $D^f(P_f, P_d)$ and $D^d(P_f, P_d)$ represent the installers' inverse demand for foreign and domestic solar panels, respectively.

The first order condition with respect to price for the domestic and foreign solar manufacturer is given by, respectively

$$\Pi^f_1 = (1 - \tau) D^f(P_f, P_d) + (P_f - \tau P_f - C_f) D^f_1(P_f, P_d) = 0 \tag{1.3}$$

$$\Pi^d_2 = D^d(P_f, P_d) + (P_d - C_d) D^d_2(P_f, P_d) = 0 \tag{1.4}$$

For the second order condition to hold, we must have

$$\Pi^f_{11} = (1 - \tau) D^f_1(P_f, P_d) + (P_f - \tau P_f - C_f) D^f_{11}(P_f, P_d) \leq 0 \tag{1.5}$$

$$\Pi_{22}^{d} = D_2^d(P_f, P_d) + (P_d - C_d)D_{22}^d(P_f, P_d) \leq 0 \tag{1.6}$$

In a Bertrand competition, the slope of the firms' response function is upward. An increase in the product price of one firm will not reduce the marginal profitability of the other firm, and vice versa. Hence, the cross-partial derivative is non-negative and it yields

$$\Pi_{12}^{f} = (1-\tau)D_2^f(P_f, P_d) + (P_f - \tau P_f - C_f)D_{12}^f(P_f, P_d) \geq 0 \tag{1.7}$$

$$\Pi_{21}^{d} = D_1^d(P_f, P_d) + (P_d - C_d)D_{21}^d(P_f, P_d) \geq 0 \tag{1.8}$$

Totally differentiating equation (1.4) and rearranging the terms gives

$$[D_1^d + (P_d - C_d)D_{21}^d]dP_f + [2D_2^d + (P_d - C_d)D_{22}^d]dP_d = D_2^d dC_d \tag{1.9}$$

Totally differentiating equation (1.3) and rearranging the terms gives

$$\begin{aligned}&[2(1-\tau)D_1^f + ((1-\tau)P_f - C_f)D_{11}^f]dP_f + [(1-\tau)D_2^f + ((1-\tau)P_f - C_f)D_{12}^f]dP_d \\ &= D^f d\tau + D_1^f P_f d\tau + D_1^f dC_f\end{aligned} \tag{1.10}$$

Applying Cramer's rule yields

$$\begin{bmatrix} dP_f \\ dP_d \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} \alpha_{22} & -\alpha_{12} \\ -\alpha_{21} & \alpha_{11} \end{bmatrix}\begin{bmatrix} D_2^d dC_d \\ D^f d\tau + D_1^f P_f d\tau + D_1^f dC_f \end{bmatrix} \tag{1.11}$$

Where $\Delta = \alpha_{11}\alpha_{22} - \alpha_{12}\alpha_{21}, \alpha_{11} = D_1^d + (P_d - C_d)D_{21}^d, \alpha_{12} = 2D_2^d + (P_d -$

$C_d)D^d_{22}, \alpha_{21} = 2(1-\tau)D^f_1 + (P_f - \tau P_f - C_f)D^f_{11}, \alpha_{22} = (1-\tau)D^f_2 + (P_f - \tau P_f - C_f)D^f_{12}$

1.4.2 Solar Installers' Subgame

The installers sell the solar panels to the consumers and provide installation service for them. Let π^f be the final price of an installed foreign solar panel and π^d be the final price of an installed domestic solar panel. Suppose installers have a common per unit installation cost c, so the full marginal cost of installing a foreign solar panel is $c + P_f$ and the full marginal cost of installing a domestic solar panel is $c + P_d$. Assuming perfect competition among the installers for the foreign panels [19], we have $\pi^f = c + P_f$. Similarly, assuming perfect competition among the installers for the domestic panels, we have $\pi^d = c + P_d$. Let $F^f(\pi^f, \pi^d)$ be the exogenous final demand function for the foreign panels and $F^d(\pi^f, \pi^d)$ be the exogenous final demand function for domestic panels. These demand functions reflect the fact that the buyers regard them as imperfect substitutes. In order to install one unit of panel, an installer must purchase one unit of panel from the manufacturer. Therefore, we have the following four equations.

$$\pi^f = c + P_f \tag{1.12}$$

$$\pi^d = c + P_d \tag{1.13}$$

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[19] My empirical part (Chapter 2) predicts positive profits for solar installers, which is not consistent with my theory here. I will make two assumptions in my empirical part: installers cannot install more than a fixed number of panels per day and differ in their constant cost of installation per panel, then the marginal installer will make zero profits but those with lower costs will make inframarginal rents.

$$D^f = F^f(\pi^f, \pi^d) \tag{1.14}$$

$$D^d = F^d(\pi^f, \pi^d) \tag{1.15}$$

Totally differentiating equations (1.14) and (1.15) yields

$$dD^f = F_1^f d\pi^f + F_2^f d\pi^d = F_1^f dP_f + F_2^f dP_d \tag{1.16}$$

$$dD^d = F_1^d d\pi^f + F_2^d d\pi^d = F_1^d dP_f + F_2^d dP_d \tag{1.17}$$

1.4.3 Comparative Analysis

In this section, I derive how the prices, quantities and welfare change with the anti-dumping duty rate τ. I propose three corollaries regarding the anti-dumping policy: (1) In response to the anti-dumping duties, foreign solar panel price will increase, and domestic solar panel price will increase or remain the same. However, the magnitude of price increase of foreign solar panels is always greater; (2) In response to the anti-dumping duties, the demand for the foreign solar panels will fall; on the other hand, the demand for the domestic solar panels will increase, provided that domestic solar panel is elastic; (3) As a result of the anti-dumping duties, the foreign solar producers will lose profits; by contrast, the domestic solar producers will gain positive profits, provided that the domestic solar panel is elastic. In the following, I give the proofs for each corollary.

Corollary I: In response to the anti-dumping duties, foreign solar panel price will increase, and domestic solar panel price will increase or remain the same. The magnitude of price increase for foreign solar panels is greater.

Proof:

In equation (1.11), assuming G_f and G_d are constants, we have $dG_f = 0$ and $dC_d = 0$. The change of wholesale prices with respect to the anti-dumping duty τ is given by

$$\frac{dP_f}{d\tau} = -\frac{\alpha_{12}}{\Delta}[D^f + D_1^f P_f] \tag{1.18}$$

$$\frac{dP_d}{d\tau} = \frac{\alpha_{11}}{\Delta}[D^f + D_1^f P_f] \tag{1.19}$$

Where $\Delta = \alpha_{11}\alpha_{22} - \alpha_{12}\alpha_{21}, \alpha_{11} = D_1^d + (P_d - C_d)D_{21}^d, \alpha_{12} = 2D_2^d + (P_d - C_d)D_{22}^d, \alpha_{21} = 2(1-\tau)D_1^f + (P_f - \tau P_f - C_f)D_{11}^f, \alpha_{22} = (1-\tau)D_2^f + (P_f - \tau P_f - C_f)D_{12}^f$

The second order condition, i.e., inequalities (1.5) and (1.6), and cross-partial condition, i.e., inequalities (1.7) and (1.8), indicate that, $\alpha_{21} \leq 0$, $\alpha_{12} < 0$, $\alpha_{22} \geq 0$ and $\alpha_{11} \geq 0$. The assumption in the uniqueness condition (or stability condition) states that $\left|\Pi_{22}^d\right| > \Pi_{21}^d$ and $\left|\Pi_{11}^f\right| > \Pi_{12}^f$. Thus, we can derive that $|\alpha_{12}| > \alpha_{11}$ and $|\alpha_{21}| > \alpha_{22}$ and finally $\Delta < 0$. Here, the uniqueness condition ensures that the Bertrand reaction functions are well behaved and have slope less than one in absolute value, therefore there exists unique Bertrand equilibria (Friedman (1977), Singh and Vives (1984)). Equation (1.3) gives that $D^f + P_f D_1^f = G_f D_1^f/(1-\tau) < 0$.

With the signs of α_{12}, α_{11}, Δ and $D^f + P_f D_1^f$ determined, we can easily get

$$\frac{dP_f}{d\tau} > 0, \; \frac{dP_d}{d\tau} \geq 0 \tag{1.20}$$

Furthermore, we can get

$$\frac{dP_f}{d\tau} - \frac{dP_d}{d\tau} = -\frac{\alpha_{11} + \alpha_{12}}{\Delta}[D^f + D_1^f P_f] > 0 \tag{1.21}$$

Expression (1.20) indicates that in response to the anti-dumping duties τ, the foreign solar panel price will increase, while the domestic solar panel price will increase or stay the same. Expression (1.21) indicates that the percentage increase is greater for the foreign solar panel. Consider a special case in which the installer's demand for domestic solar panels, denoted by $D^d(P_f, P_d)$, has the form

$$D^d(P_f, P_d) = P_f^\delta P_d^\theta \tag{1.22}$$

where δ measures the substitution effect from foreign solar products and θ is the price elasticity of demand for domestic solar products. We have $D_1^d = \delta P_f^{\delta-1} P_d^\theta$, $D_{21}^d = \theta\delta P_f^{\delta-1} P_d^{\theta-1}$, and it yields

$$\begin{aligned}
\alpha_{11} &= D_1^d - \frac{D^d}{D_2^d} D_{21}^d && (1.23)\\
&= \delta P_f^{\delta-1} P_d^\theta - \delta P_f^{\delta-1} P_d^\theta && (1.24)\\
&= 0 && (1.25)
\end{aligned}$$

thus in this special case

$$\frac{dP_d}{d\tau} = 0 \tag{1.26}$$

Corollary II: In response to the anti-dumping duties, the demand for the foreign solar panels will fall; on the other hand, the demand for the domestic solar panels will increase, provided that domestic solar panel is elastic.

Proof:

The change of foreign solar panel sales (denoted by D^1) with respect to the anti-dumping duty τ is given by

$$\frac{dD^f}{d\tau} = F_1^f \frac{dP_f}{d\tau} + F_2^f \frac{dP_d}{d\tau} \tag{1.27}$$

From the demand function $F^f(\pi^f, \pi^d)$ and $F^d(\pi^f, \pi^d)$, we have

$$F_1^f < 0,\ F_2^f > 0,\ F_1^d > 0,\ F_2^d < 0 \tag{1.28}$$

The properties of function F determine the properties of function D, thus we have

$$D_1^f < 0,\ D_2^f > 0,\ D_1^d > 0,\ D_2^d < 0 \tag{1.29}$$

Given own effect is larger than cross effect, we have

$$-F_1^f > F_2^f,\ -F_2^d > F_1^d \tag{1.30}$$

Inequalities (1.21), (1.28) and (1.30) give

$$\frac{dD^f}{d\tau} = F_1^f \frac{dP_f}{d\tau} + F_2^f \frac{dP_d}{d\tau} < 0 \tag{1.31}$$

The above result indicates that the anti-dumping duty will decrease the demand for the foreign solar panels. This is very intuitive, since the anti-dumping policy increases the price in foreign solar panels sold in the domestic market. In the following, I will analyze how the demand for domestic solar panels will change.

The change of demand for domestic solar panels (denoted by D^d) with respect to the anti-dumping duty τ is given by

$$\begin{aligned} \frac{dD^d}{d\tau} &= F_1^d \frac{dP_f}{d\tau} + F_2^d \frac{dP_d}{d\tau} \\ &= D_1^d \frac{dP_f}{d\tau} + D_2^d \frac{dP_d}{d\tau} \\ &= \frac{D^f + D_1^f P_f}{\Delta} [(P_f - C_d)(D_{21}^d D_2^d - D_{22}^d D_1^d) - D_1^d D_2^d] \\ &= \frac{D^f + D_1^f P_f}{\Delta} [-D^d D_{21}^d - D_1^d D_2^2 + \frac{D^d D_{22}^d D_1^d}{D_2^d}] \end{aligned} \tag{1.32}$$

However, the sign of $-D^d D_{21}^d - D_1^d D_2^d + \frac{D^d D_{22}^d D_1^d}{D_2^d}$ is ambiguous and depends on the function form of D^d. Assuming the installer's demand for domestic solar panels, denoted by $D^d(P_f, P_d)$, has the form

$$D^d(P_f, P_d) = P_f^\delta P_d^\theta \tag{1.33}$$

where δ measures the substitution effect from foreign solar products and θ is the price elasticity of demand for domestic solar products. We have $D_1^d = \delta P_f^{\delta-1} P_d^\theta$,

$D_2^d = \theta P_f^\delta P_d^{\theta-1}$, $D_{21}^d = \theta\delta P_f^{\delta-1} P_d^{\theta-1}$, and $D_{22}^d = \theta(\theta-1) P_f^\delta P_d^{\theta-2}$, and it yields

$$-D^d D_{21}^d - D_1^d D_2^d + \frac{D^d D_{22}^d D_1^d}{D_2^d} = -\theta\delta P_f^{2\delta-1} P_d^{2\theta-1} + (\theta-1)\delta P_f^{2\delta-1} P_d^{2\theta-1} - \theta\delta P_f^{2\delta-1} P_d^{2\theta-1} \tag{1.34}$$

$$= (-\theta-1)\delta P_f^{2\delta-1} P_d^{2\theta-1} \tag{1.35}$$

From equation (1.29), we have $D_1^d > 0$, therefore the substitution coefficient $\delta > 0$. From equation (1.20), we have $\frac{D^f + D_1^f P_f}{\Delta} > 0$, hence when $\theta < -1$, we will have $\frac{dD^d}{d\tau} > 0$. It indicates that if the domestic solar panel is elastic, then the anti-dumping duty (imposed on foreign solar panels) will increase the sales of domestic solar panels. The more substitution between domestic and foreign solar panels, the more sales domestic producers will gain from the anti-dumping policy.

Corollary III: As a result of the anti-dumping duties, the foreign solar producers will lose profits; by contrast, the domestic solar producers will gain positive profits, provided that the domestic solar panel is elastic.

Proof:

The change of foreign solar producer's profit with respect to the anti-dumping duty rate τ is given by

$$\frac{d\Pi_f}{d\tau} = (\frac{dP_f}{d\tau} - 1)D^f + (P_f - \tau P_f - C_f)\frac{dD^f}{d\tau} \tag{1.36}$$

Once the tariff is imposed on the imported foreign solar panels, the foreign solar producer will increase its sale price and it will share the tariff burden with the consumers provided that solar panel is not perfectly inelastic or elastic. In other words, the price of foreign solar products will not increase more than τ, so we have $\frac{dP_f}{d\tau} < 1$. From (1.31), we know $\frac{dD^f}{d\tau} < 0$. With $\frac{dP_f}{d\tau} < 1$ and $\frac{dD^f}{d\tau} < 0$, we have $\frac{d\Pi^f}{d\tau} < 0$. The result implies the foreign solar producer will lose profit if it faces an anti-dumping duty rate τ.

In the following, I will analyze that how the anti-dumping policy will affect domestic solar producers. The change of domestic solar producer's profit with respect to the anti-dumping duty rate τ is given by

$$\frac{d\Pi^d}{d\tau} = \frac{dP_d}{d\tau} D^d + (P_d - C_d)\frac{dD^d}{d\tau} \tag{1.37}$$

$$= \frac{dP_d}{d\tau} D^d + (P_d - C_d)\Big[\frac{\partial D^d}{\partial P_f}\frac{dP_f}{d\tau} + \frac{\partial D^d}{\partial P_d}\frac{dP_d}{d\tau}\Big] \tag{1.38}$$

$$= \big[D^d + (P_d - C_d)\frac{\partial D^d}{\partial P_d}\big]\frac{dP_d}{d\tau} + (P_d - C_d)\frac{\partial D^d}{\partial P_f}\frac{dP_f}{d\tau} \tag{1.39}$$

Plug equations (1.18) and (1.19) into equation (1.39) and we have

$$\frac{d\Pi^d}{d\tau} = \frac{D^f + D_1^f P_f}{\Delta}\Big\{[D^d + (P_d - C_d)D_2^d][D_1^d + (P_d - C_d)D_{21}^d] - [(P_d - C_d)D_1^d][2D_2^d + (P_d - C_d)D_{22}^d \tag{1.40}$$

$$= \frac{D^f + D_1^f P_f}{\Delta}\Big\{D^d D_1^d + (P_d - C_d)[D_{21}^d D^d - D_1^d D_2^d] + (P_d - C_d)^2[D_2^d D_{21}^d - D_1^d D_{22}^d]\Big\} \tag{1.41}$$

From equation (1.4), we have

$$P_d - C_d = -\frac{D^d}{D_2^d} \tag{1.42}$$

Plug equation (1.42) into the right hand side of equation (1.41) and we have

$$D^d D^d_1 + (P_d - C_d)[D^d_{21} D^d - D^d_1 D^d_2] + (P_d - C_d)^2 [D^d_2 D^d_{21} - D^d_1 D^d_{22}] \tag{1.43}$$

$$= D^d D^d_1 - \frac{D^d}{D^d_2}[D^d_{21} D^d - D^d_1 D^d_2] + (\frac{D^d}{D^d_2})^2 [D^2_2 D^d_{21} - D^d_1 D^d_{22}] \tag{1.44}$$

$$= D^d D^d_1 - \frac{D^d D^d D^d_{21}}{D^d_2} + D^d D^d_1 + \frac{D^d D^d D^d_{21}}{D^d_2} - \frac{D^d D^d D^d_1 D^d_{22}}{D^d_2 D^d_2} \tag{1.45}$$

$$= \frac{D^d D^d_1 [2 D^d_2 D^d_2 - D^d D^d_{22}]}{D^d_2 D^d_2} \tag{1.46}$$

Equations (1.41) and (1.46) yield

$$\frac{d\Pi^d}{d\tau} = \frac{D^f + D^f_1 P_f}{\Delta} \Big[\frac{D^d D^d_1 [2 D^d_2 D^d_2 - D^d D^d_{22}]}{D^d_2 D^d_2} \Big] \tag{1.47}$$

Assuming the installer's demand for domestic solar panels, denoted by $D^d(P_f, P_d)$, has the form

$$D^d(P_f, P_d) = P^\delta_f P^\theta_d \tag{1.48}$$

Where δ measures the substitution effect between foreign and domestic solar products, and θ is the price elasticity of demand for domestic solar products. We have $D^d_1 = \delta P_f^{\delta-1} P^\theta_d$, $D^d_2 = \theta P^\delta_f P^{\theta-1}_d$, $D^d_{22} = \theta(\theta-1) P^\delta_f P^{\theta-2}_d$, and it yields

$$\frac{d\Pi^d}{d\tau} = \Big(\frac{D^f + D^f_1 P_f}{\Delta} \Big) \Big(\frac{\theta+1}{\theta} \Big) P_d^{2(\delta+\theta)-1} \delta \tag{1.49}$$

From equation (1.29), we have $D^d_1 > 0$, therefore the substitution coefficient $\delta > 0$. From equation (1.20), we have $\frac{D^f + D^f_1 P_f}{\Delta} > 0$, hence when $\theta < -1$, we will have $\frac{d\Pi^d}{d\tau} > 0$. It implies that if the domestic solar panel is elastic, then the profit for domestic solar producer will increase from the anti-dumping duty that is imposed on foreign solar products. The parameter δ suggests that the higher substitution effect between domestic and foreign solar panels, the more profit domestic producer will make from the anti-dumping policy. From inequality (1.30), we have $-\theta > \delta$, therefore $2(\delta + \theta) - 1 < 0$, suggesting that the magnitude of profit increase in domestic solar producer will decrease with the domestic solar prices. Overall, the magnitude of profit change for domestic solar producer will depend on quantity effect ($P_d^{2(\delta+\theta)-1}$) and substitution effect (δ).

Since solar panel is not a necessity good, its price elasticity of demand should be smaller than -1 (i.e., elastic demand). In summary, as shown by the comparative analysis, in response to the anti-dumping duties, foreign solar producer will lose profits as a result of increased price and decreased demand, while domestic solar producer will gain profits as a result of increased (or unchanged) price and increased demand. In the following chapter, I will proceed to the empirical analysis.

Chapter 2: Econometric Model

I now outline a model of the solar industry where demand and supply are represented. The demand side is modeled within a discrete choice framework. Specifically, I use a mixed logit demand model, where for simplicity I ignore the timing of the purchase decision. The supply side captures the vertical structure, in which the upstream manufacturers determine the wholesale prices for the solar panels and the downstream installers determine the retail price while providing installation service for the consumers.

2.1 Consumer Demand for Solar Panels

The main purpose of the demand model is to capture the behavioral responses to solar panel prices. A consumer can choose the solar installer as well as different types of solar panel to install. I assume that a consumer's choice is a solar panel/installer combination, indexed by j. Since there are many solar installers in my sample, to simplify the empirical process, I classify the installers into ten groups, in which the first nine groups represent the top nine installers who have significant market share across the sample and the tenth group represents the rest of the installers (see Table 5).

I use a mixed logit model to analyze consumer purchase decision. The mixed logit model obviates the three limitations of standard logit by allowing for random taste variation, unrestricted substitution patterns, and correlation in unobserved factors over time (Train, 2009). The conditional indirect utility of consumer i in MSA w from purchasing and installing j during year t is given by

$$U_{ijwt} = X_j\beta_i + \alpha p_{jwt} + \lambda_{mr} + \eta_t + \zeta_{jt} + \epsilon_{ijt} \tag{2.1}$$

where X_j is a vector of observed nonprice product characteristics (energy conversion efficiency, a zero-one indicator that takes one if the panel is made of polycrystalline cells, a zero-one indicator that takes one if the solar panel(module) has a black frame); β_i is a vector of consumer-specific marginal utilities (assumed random) associated with the different nonprice product characteristics in X_{jt}; p_{jwt} is the consumer purchase price for product j, which is calculated by subtracting government subsidies from total installed price and divide by the size of the solar PV system; α represents marginal disutility of price (assumed fixed across consumers); λ_{mr} is the solar manufacturer and installer fixed effect, where m represents the solar manufacturer and r represents the solar installer; η_t is the year fixed effect; ζ_{jt} is the product characteristics unobserved by the econometrician but observed by the consumers and firms; error ϵ_{ijt} is i.i.d and follows the type I extreme value distribution.

The consumer taste parameter for nonprice product characteristics is modeled as

$$\beta_i = \beta + \Sigma v_i \tag{2.2}$$

where v_i is a random draw from a multivariate standard normal distribution (i.e., $v_i \sim N(0, \mathbf{1})$), Σ is a diagonal scaling matrix. This specification allows the individual taste parameter for nonprice characteristics varies across consumers. The predicted market share of product j is given by

$$s_{jwt}(X_{jt}, p_{jwt}; \alpha, \beta, \Sigma) = \int \frac{exp(\delta_{jwt} + \mu_{ijwt})}{1 + \sum_{l=1}^{J} exp(\delta_{lwt} + \mu_{ilwt})} dF(\nu) \tag{2.3}$$

where $\delta_{jwt} = X_{jt}\beta + \alpha p_{jwt} + \lambda_{mr} + \eta_t + \zeta_{jt}$ is the mean utility across consumers obtaining from purchasing and installing product j; μ_{ilwt} is a consumer-specific deviation from the mean utility level which associates with the consumer tastes for different product characteristics. $F(\cdot)$ is the standard normal distribution function.

The trans-log version of the predicted market share of solar panel/installer pair j in MSA w during year t is

$$\ln s_{jwt} - \ln s_{0wt} = X_j\beta_i + \alpha p_{jwt} + \lambda_{mr} + \eta_t + \zeta_{jt} \tag{2.4}$$

where s_{jwt} is the market share of the inside goods and s_{0wt} is the market share of the outside goods. The market share for the outside goods is usually defined as one minus the shares of inside goods. I select 42 solar panel models which have significant sales in United States as the inside goods. These 42 popular models are manufactured by eight publicly listed solar companies, including five Chinese manufacturers (Trina Solar, Suntech Power, Canadian Solar, Renesola and Yingli Green Energy), two US manufacturers (SunPower and REC Solar), and one South

Korean manufacturer (Hanwha Q CELLS). The names of the brands and the models are listed in Table 3.

To include the no-purchase option into the choice set of the outside goods, I need to define the market size on each MSA-year level accordingly. Assume the number of single family homes in MSA w is M_w, then the observed market share of product j is given by $s_{jwt} = \frac{q_{jwt}}{M_w \times V}$, where q_{jwt} is the actual demand for product j and V is the percentage of buildings which are solar-viable in that MSA area. The parameter V reflects the fact that not all buildings are suitable for installing solar PV systems.

The demand model has two potential limitations. First, I assume that the model is static and the consumers are not forward looking. In the case of solar panel whose price falls over time, a forward-looking consumer may anticipate the price reduction and delay her purchase decision. Therefore, the static demand specification may underestimate the true price elasticity (Aguirregabiria and Nevo, 2013). Second, the specification of static model also assumes that the consumers are off the market after their initial purchase and installation of solar modules. This will again underestimate the price elasticity by phasing out the change in the distribution of consumers (Gowrisankaran and Rysman, 2012). However, as argued by Gerarden (2017), there is a feature of the solar market that ameliorates the first concern brought by the static model specification: continued price reductions in the solar market were not fully anticipated, even by the government and industry practitioners, hence the consumers may not anticipate the decline of solar prices.

2.2 Supply Side

In this section, I derive a supply equation that approximates the solar manufacturer' optimizing behavior in the vertical contracting with the solar installer. The structural econometric model is inspired by Fan and Yang (2016) and Gayle (2013), and the price-cost margins are derived in the spirit of Berto Villas-Boas (2007).

The supply side of the model can be described as a three-stage game. In the first stage, the solar manufacturer chooses its products. In the second stage, it sets the upstream price charged to the solar installers given the demand shock. In the third stage, the solar installers choose the final price charged to the consumers.

To solve for this subgame perfect Nash equilibrium it is standard to use backward induction, i.e., by solving the final subgame first. In the final stage of the model, the solar installer chooses total installed price p_{jt} after observing the set of products available (denoted by F_{rt}), the price paid to the solar manufacturers for getting the solar panels (denoted by p^m_{jt}), and the given demand. The total installed price p_{jt} is a package price charged to the consumer, which includes the solar module(panel) price and the price on the installation. Suppose the marginal cost for the solar installer to complete an installation of product j is c^r_{jt} per consumer. Then the installer r's profit for each unit of a product sold is $p_{jt} - p^m_{jt} - c^r_{jt}$.

The derivation for the price-cost margin follows the procedure in Berto Villas-Boas (2007). Each installer r's profit function in period t is given by

$$\max \pi_{rt} = \sum_{j \in F_{rt}} \left[p_{jt} - p_{jt}^{m} - c_{jt}^{r} \right] M s_{jt}(p) \tag{2.5}$$

where M is the market size. Then the first order condition is given by

$$p_t - p_t^m - c_t^r = -(T_r * \Delta_{rt})^{-1} s_t(p) \tag{2.6}$$

where T_r is the installer's ownership matrix with the general element $T_r(k, j)$ equal to one when both products k and j are sold by the same installer and zero otherwise; Δ_{rt} is the installer's response matrix, with element $(k, j) = \frac{\partial s_{jt}}{\partial p_{kt}}$.

In the second stage, the solar manufacturer sets the upstream price that it charges the installer given the observed demand. The solar manufacturer m's profit-maximizing problem is therefore

$$\max \pi_{mt} = \sum_{j \in F_{mt}} \left[p_{jt}^{m} - c_{jt}^{m} \right] M s_{jt}(p) \tag{2.7}$$

where c_{jt}^m is the marginal cost of the solar manufacturer that produces the product j. The first order condition is given by

$$p_t^m - c_t^m = -(T_m * \Delta_{mt})^{-1} s_t(p) \tag{2.8}$$

where T_m is the ownership matrix for the solar manufacturer, analogously defined as the matrix T_r above. Δ_{mt} is the solar maker's response matrix, with element $(k, j) = \frac{\partial s_{jt}}{\partial p_{kt}^m}$, which represents the first order differentiation of the market share of all products with respect to all upstream prices. In Appendix A, I discuss how Δ_{mt} is computed.

Combining equations (2.6) and (2.8) yields the solar manufacturer and installer's joint marginal cost mc_t,

$$mc_t = c_t^m + c_t^r = p_t + (T_r * \Delta_{rt})^{-1} s_t(p) + (T_m * \Delta_{mt})^{-1} s_t(p) \tag{2.9}$$

Specifically, I assume the solar manufacturer's marginal cost depends on a vector of variables X_t and the solar installer's marginal cost depends on a vector of variables Y_t. Then the joint marginal cost is

$$mc_t = \gamma_1 X_t + \gamma_2 Y_t + \kappa + \varepsilon_t \tag{2.10}$$

where X_t includes wage rate in manufacturing, lending interest rate and the panel's energy conversion efficiency; Y_t includes the wage rate in roofing; κ is installer-year fixed effect. In my specification, I assume the manufacturer's marginal cost is determined by the labor cost, capital cost and the panel's key product attributes (i.e., energy conversion efficiency), and the installer's marginal cost is determined by the labor cost in installation. The fixed effect captures the time effect and installer-level heterogeneity.

Combining equations (2.9) and (2.10) yields

$$p_t + (T_r * \Delta_{rt})^{-1} s_t(p) + (T_m * \Delta_{mt})^{-1} s_t(p) = \gamma_1 X_t + \gamma_2 Y_t + \kappa + \varepsilon_t \tag{2.11}$$

which I bring to the data for estimation.

However, some of the solar manufacturers have received government subsidies in their production, thus lowering their products' marginal cost. In this way, the unadjusted marginal cost derived in equation (2.9) is overestimated. To address the bias, I need to subtract the subsidy from the unadjusted marginal cost. Denote the adjusted marginal cost by $mc_t^{'}$, I have

$$mc_t^{'} = c_t^m(1 - sub_t) + c_t^r \tag{2.12}$$

where sub_t is the subsidy rate on the solar manufacturers. Replace mc_t with $mc_t^{'}$ and rerun equation (2.10), the parameters on the supply side will be estimated.

The estimation procedure is summarized as follows: 1. run regression (2.11) and get the estimated coefficients $\hat{\gamma}_1$, $\hat{\gamma}_2$, and $\hat{\kappa}$; 2. calculate the fitted value of the solar manufacturer's marginal cost c_t^m; 3. calculate the adjusted marginal cost $mc_t^{'}$ according to equation (2.12); 4. replace mc_t with $mc_t^{'}$ and rerun regression (2.10).

2.3 Data and Identification

2.3.1 Data and Descriptive Statistics

For this study, I have compiled a new dataset on US solar market between 2010 and 2015 from various sources. The main dataset comes from Lawrence Berkeley National Laboratory (LBNL)'s *Tracking the Sun* report series, which provide the information on prices and quantities of solar PV installation. LBNL collects project-level data on residential and commercial solar PV installations. The original sources of the data are from state agencies and utility companies that manage solar PV incentive programs and solar energy credit registration systems. The dataset is accessible publicly and can be downloaded from the National Renewable Energy Laboratory's Open PV Project data portal. This data file includes residential and commercial solar PV systems, excluding utility-scale projects. As of the end of 2015, the data file includes over 0.8 million observations of the solar PV installations and has a rich set of observables. For each solar PV system recorded by this data file, we can observe various information about this installation, including installation date, system size, total installed price, sales tax cost, rebate or grant, zip code or city, insolation rate, reported annaul PV generation, installer name, module manufacturer name, module model, module technology, module efficiency, etc.

The other sources of data used in this dissertation are: (1) US Census Bureau, which provides MSA-level demographic variables on the education, median income and age across the US; (2) US Energy Information Administration, which provides the state-level electricity prices information; (3) US Bureau of Labor Statistics, which provides hourly wage in manufacturing across different counties and hourly wage rate in roofing in the US; (4) World Bank, which provides information on the lending interest rates across different countries; (5) Google Project Sunroof, which estimates the technical solar potential of all buildings in a region based on sunlight, installation size and space, and reports the percentage of buildings that are solar-viable in the region.

The sample used in this dissertation is confined to the residential PV installation, which has a total number of 645,269 installations nationwide and nearly half of them happening in the state of California. Among different solar makers, Chinese companies (including Suntech Power, Trina Solar, ET Solar and Yingli Green Energy, etc) accounted for 25% of the market share in 2011 and accounted for 14% of the market share in 2015 (see Table 1). More than 1,000 models of solar panels produced by over 150 firms are observed in the dataset (see Table 2). The inside goods I select consist of 42 models produced by eight solar manufacturers (see Section 2.1 for more details), and the MSA markets selected in my sample accounts for nearly 31% of the total markets in the US.

Table 4 reports the summary statistics for the key variables in my dissertation. The average of the total installed price for one solar PV system is \$5.12/W, with a standard deviation of \$1.65/W. The average government subsidy received by the consumers is \$0.82/W, which is nearly 16% of the total cost for a solar PV system. The average energy conversion efficiency for solar panels is 0.17 with a standard deviation of 0.02. Nearly 46% of the solar modules are made of polycrystalline panels, and 20% of the solar modules have black frames. The average electricity price on the state level is 16.11 cents/kWh with a standard deviation of 3.01 cents/kWh. Across the MSA markets in my sample, on average, 30.23% people have a bachelor's degree or higher, and the average of the median income and median age are \$78,280 and 38.78 years old, respectively. The average number of single family homes on the MSA level is 868,000, and on average, for each MSA, nearly 72% of the buildings are solar-viable. The average manufacturing wage and lending interest rate are \$18.84/hour and 4.67%, respectively. The average wage rate in roofing across different states in the US is \$23.82/hour.

2.3.2 Identification

In the demand side estimation, the purchase price p_{jwt} is expected to be correlated with unobserved product characteristics, leading to an endogeneity problem. The other product characteristics are however assumed to be exogenous. The coefficient on the price is identified using variation from instrumental variables (Berry, 1994). There are three candidates for the instruments that are plausibly uncorrelated with unobserved product characteristics: government subsidies, the so-called BLP instruments, and the Hausman instrument.

Government Subsidies. Li (2016) uses government subsidies as instrumental variables for vehicle price to identify the demand parameter in the US electric vehicle market, as they are uncorrelated with demand shocks. In my dissertation, government subsidies offered to the households for solar PV installations vary by state, year and panel model. A larger subsidy indicates lower purchase price faced by the consumer. The government subsidies can be regarded as cost-shifters, as they only affect the consumer demand for the solar panels through the purchase prices, and they are uncorrelated with unobserved product characteristics.

BLP Instruments. A natural instrument for the price is to use a cost side instrument, however, the cost variable is often not available (Berry et al., 1995). The BLP instruments provide an alternative approach for variation in prices in differentiated product settings that is based on a first order approximation of the equilibrium pricing function (Gandhi and Houde, 2016). They are one series of differentiation in attribute space and are constructed by adding up the values of

(i) characteristics of other products made by the same manufacturer, and (ii) the characteristics of products made by other manufacturers. They are uncorrelated with the demand shock given the assumption that the other product characteristics arrive as part of an exogenous development process (Li, 2016). I construct BLP instruments based on all three product characteristics, namely energy conversion efficiency, technology type and frame color, and denote them by $BLP\_efficiency$, $BLP\_technology$ and BLP_black, respectively.

Hausman Instrument. A particular type of proxy for cost-shifter is Hausman instrument (Hausman, 1996): the prices of product j in other market M' can be used a a proxy for marginal cost of good j in market M. In my dissertation, the Hausman instrument is the average installed price for the same type of solar panel sold in other MSAs in the same year, denoted by $Hausman_{jwt}$. The identifying assumption for the Hausman instrument is that demand for a given type of solar panel in MSA A is independent from the demand for the same type in MSA B. The advantage of Hausman instrument stems from the fact that all the instruments are contained in the price data. However, the underlying assumption associated with Hausman instrument is sometimes too restrictive. Successful applications of Hausman instrument rely on the validity of two assumptions: (i) the unobserved shocks to product costs affect all geographic markets, and (ii) there are only geography-specific unobservable demand shocks and not nationwide demand shocks (Megerdichian, 2010). The first assumption captures the relevance of the instrument, and the second assumption validates the exogeneity of the Hausman instrument. If there is a general shock throughout the nation, then the prices in areas other than C would be correlated with the error term in the demand function for area C, and so the Hausman instrument would not satisfy the exclusion restriction. Criticisms of the Hausman instrument mainly focus on its exogeneity assumption (Bresnahan and Gordon (1997), Nevo (2000) and Nevo (2001)). For a nationally-branded differentiated product, including solar panels, national advertising campaigns can affect both demand and price, thus rendering Hausman instrument invalid.

In order to select the appropriate instrumental variables from the three candidate sets described above, I use the two-stage least square (2SLS) method to estimate a standard logit model which is more restrictive than the mixed logit model. The specification for the standard logit model is in Appendix B. Table 6 reports the results for the first-stage regression, in which price is regressed on different instruments. Models 1 - 3 use each set of the instruments (subsidy, BLP instruments and Hausman instrument), models 4 - 6 employ pairs of them, and model 7 applies all three of them. The F-tests of the joint significance of the instruments in models 1 - 7 all yield values greater than 10. Model 1 has the largest (F-statistic = 383) and Model 3 the smallest (F-statistic = 12.49). The results suggest that the instruments do have explanatory power of variations in price. Then I move forward to the second-stage estimates, in which Berry-type market shares (i.e., $\ln s_{jwt} - \ln s_{0wt}$) are regressed on the instrumented price. The results in Table 7 suggest that, BLP instruments lead to significant price coefficient (Model 2, 4, 5 and 7), while subsidy and Hausman IVs result in smaller and insignificant price coefficient (Model 1, 3 and 6). This may be explained by the following reasons: state subsidies and nation-wide demand shock (such as national advertising campaigns) vary across years, thus they don't have much variation left once year-fixed effect has been controlled. Overall, the BLP instruments perform well and are generally accepted in the literature. I will use BLP instruments as instrumental variables in my model, and will also do two robustness checks, each of which adds one more instrument (subsidy or Hausman IV) to my main specification.

On the supply side, ψ_t captures the unobserved component of the marginal cost, which influences the equilibrium price. Therefore, the cost vector X_t and Y_t are likely to be correlated with ψ_t in the supply equation. The instruments used in the demand side are also valid for the supply side, because they will influence the size of the markup of a solar manufacturer on each of its products, as well as the markup of a solar installer. The BLP instruments are measures of the degree to which an solar manufacturer's product is close to its competitor's product. Economic theory suggests it will shift the equilibrium markup.

2.4 Estimation Result for Main Specification

The demand and supply parameters are estimated jointly by using Generalized Methods of Moments (GMM). The details on the estimation are provided in Appendix C.

2.4.1 Demand Parameters

Table 8 reports the estimation results for the demand side in my main specification. The upper panel of demand side estimation reports the mean marginal utility for each product characteristics (α and β), and the panel immediately below this upper panel reports the variation in taste for nonprice characteristics (Σ). The price coefficient is negative and statistically significant at the 1% level. The coefficient on "Efficiency" is positive and statistically significant at 1% level, suggesting that consumers on average favor panels with higher energy conversion efficiency. Energy conversion efficiency quantifies a solar panel's ability to convert sunlight into electricity. High efficiency indicates the panel can convert solar energy at a low cost. The coefficient on "Technology" is negative and statistically significant at the 1% level, suggesting that consumers tend to choose panels made of monocrystalline cells. Compared with polycrystalline panels, monocrystalline solar panels generally have higher efficiency rates, and they are also more space-efficient and have a longer lifespan. The coefficient on "Black" is negative and statistically significant at the 1% level, suggesting that consumers prefers solar panels with silver frames rather than those with black frames. The taste variation parameters on "Efficiency", "Technology", and "Black" are all statistically significant at the 1% level, suggesting that consumers are heterogeneous, with respect to their tastes, for the nonprice characteristics of the solar panels.

The demand parameter in Table 8 yields a mean own-price elasticity of demand of -4.199, which is higher than the estimates (-1.76) in Gillingham and Tsvetanov

(2014). This may be due to the fact that the choice sets defined in my model are panel/installer combinations which provide more flexibility for the consumers' choices. Table 13 reports the price elasticity of demand for the most popular models within each brand: Sunpower's SPR-327, REC Solar's REC260, Trina Solar's TSM-250PA, Canadian Solar's CS6P-250P, Suntech Power's STP185S, Hanwha Q CELLS's Q.PRO, Yingli Green's YL250P, and Renesola's JC250M. The own-price elasticity of demand for models produced by Suntech Power is the highest(-4.724) and the own-price elasticity for models produced by Hanwha Q CELLS is the lowest(-2.932).

Table 9 and 10 present the results of the robustness checks for the demand side estimation, in which the former uses the BLP instruments and government subsidies as IVs and the latter uses the BLP instruments and Hausman instruments as IVs. In Table 9, the estimated price coefficient is -0.626 and is statistically significant at the 5% level. The signs of the estimated coefficients on the nonprice characteristics are consistent with those in my main specification, but two of them (coefficients on energy conversion efficiency and black dummy) are not statistically significant. For the taste variation parameters, only parameter for technology dummy is statistically significant at the 1% level. In Table 10, the estimated price coefficient is -0.777 and is statistically significant at the 5% level. The estimated coefficients on nonprice characteristics are all statistically significant at conventional levels of significance and their signs are consistent with those in my main specification. The taste variation parameters are all statistically significant at the 1% level.

2.4.2 Supply Parameters

Table 11 reports the firms' markups and marginal cost. With vertical relationships between the upstream and downstream firms, the average markup for the solar manufacturer and the solar installer is \$1.038/W and \$1.033/W, respectively. The average margin for the solar manufacturer and the solar installer is 20.27% and 20.17%, respectively. Considering the government subsidy accounts for around 30% of the total installed price for each residential solar PV installation, the price charged by the solar manufacturers and installers seems reasonable. The joint marginal cost amounts to \$3.079/W on average.

Table 8 also reports the estimation result on the supply side in my main specification. The coefficients on manufacturing wage and interest rate are both positive and statistically significant at the 5% level, suggesting that joint marginal cost increases with labor cost in manufacturing and capital cost, which are proxied by hourly compensation cost in manufacturing and lending interest rate, respectively. The significantly positive coefficients on energy conversion efficiency and installing wage suggest that, joint marginal cost increases with the product's energy conversion efficiency and the labor cost in installation, in which the latter is proxied by the hourly wage rate for the roofing. Table 9 and 10 provide robustness checks for the supply side estimation. The coefficients on the cost variables have the same signs as those in my main specification and are all statistically significant at conventional levels of significance.

The above joint marginal cost is overestimated since it doesn't subtract the subsidy the solar manufacturers have obtained from their governments. I use the procedure described in Section 2.2 to calculate the adjusted marginal cost and present the estimation result for the cost parameters in Table 12. In the calculation process, I assume only the US and China have offered subsidies to their solar manufacturers. China offers various forms of subsidies to its solar manufacturers (see Section 1.3.3), but the accurate calculation of the overall subsidy rate is a potential problem. Fortunately, in the announcement issued by US Department of Commerce regarding to the anti-dumping investigation against China in 2012, it listed the determined subsidy rates received by all Chinese solar producers/exporters. For the brands in my inside goods, the subsidy rates received by Suntech, Trina Solar and Renesola were assessed to be 14.78%, 15.97% and 38.72% [1], respectively, and the subsidy rates received by Canadian Solar and Yingli Green Energy were assessed to be 15.24%. In the announcement issued by the Ministry of Commerce of the People's Republic of China in 2014, it determined that the average subsidy rates received by the US solar manufacturers were 2.1%, according to its results on anti-dumping and countervailing investigation on imported US solar products.

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[1] The subsidy rate received by Renesola was first determined in the announcement issued by US Department of Commerce in 2014.

Chapter 3: Policy Analysis of Trade Restrictions

In this chapter, I use the estimated structural model to study the market outcome of trade-related policies. As shown in Chapter 1, subsidy policy on the solar manufacturing and anti-dumping policy are the two important factors that may have influenced the development of the solar industry. Moreover, countries may respond in subsidy rates when facing dumping from foreign companies by increasing the subsidy rates for their domestic firms. This motivates the various counterfactual scenarios that I consider.

I conduct six counterfactual simulations based on different anti-dumping duty and subsidy rates : In simulation I, I set the anti-dumping duty rates to zero while the US and China's subsidy rates remain unchanged; In simulation II, I set the anti-dumping duty rates to zero, while setting China's subsidy rates to be equal to that of US; In simulation III, I set the anti-dumping duty rates to zero, while setting the US subsidy rates to be equal to that of China; In simulation IV, I set the anti-dumping duty and China's subsidy rates to zero, while US subsidy rates remain unchanged; In simulation V, I set the anti-dumping duty and US subsidy rates to zero, while China's subsidy rates remain unchanged; In simulation VI, I set the anti-dumping duty, US and China's subsidy rates to zero.

In each counterfactual scenario, I compute the simulated equilibrium price and demand, and then compare the outcome with the simulated outcome in the baseline scenario. The baseline scenario refers to the situation when there is an anti-dumping policy. Figure 5 reports the comparison of the simulated equilibrium price between counterfactual and baseline scenarios. For example, in simulation I, on average, the prices for Chinese solar products will decrease by around 10% and the prices for US solar products will not change much, when I set the anti-dumping duty rates to zero.

Following Small and Rosen (1981), I use the compensating variation to calculate the change in consumer surplus in any counterfactual scenario, given by

$$\Delta CS = -\frac{1}{\alpha}\left[\ln\left(\sum_{j=1}^{J}\exp(W_j^1)\right) - \ln\left(\sum_{j=1}^{J}\exp(W_j^0)\right)\right] \tag{3.1}$$

where α is the consumer marginal disutility of price, W_j^0 and W_j^1 are the expected maximum utility for the consumers in baseline and simulated scenario, respectively.

Before proceeding further, I discuss three important components in performing the welfare calculation. First, the anti-dumping and countervailing duty rates imposed on Chinese solar products. Table 14 reports the anti-dumping and countervailing duty rates imposed on the imported Chinese solar products. As I mentioned in Section 2.4, different Chinese manufacturers may face different anti-dumping and countervailing duty rates, and these duty rates that have been implemented since 2014 are higher than that in 2012. As shown in Table 14, Chinese solar manufacturer Renesola was not subject to the anti-dumping and countervailing duty rates in 2012. This was because the anti-dumping policy which came out in 2012 only applied to China-made cells and modules assembled with such cells, but it didn't apply to the firms (such as Renesola) whose solar products were assembled from cells manufactured elsewhere. To close the loophole that let the Chinese solar manufacturers sidestep the duties, the US Department of Commerce amended its ruling in 2014 and set steeper tariff since then.

Second, the proportion of module price and non-module cost in a typical residential solar panel installation in the US. The anti-dumping and countervailing duty rates are imposed on the solar panels(modules), however, in my dataset, the price for the solar panel is not observable and only the total installed price is available. To resolve this problem, I obtain the price for solar module from total installed price. The total installed price includes module price and non-module cost, with the latter involving labor, overhead and marketing costs (Bollinger and Gillingham, 2014). Table 15 reports the breakdown of total installed price. In 2010, the module price accounted for nearly 30% of the total cost, and in 2015 this ratio decreased to around 20%. Based on the proportion of module price in the total installed price as listed in Table 15, I can approximate the panel(module) price from the total installed price.

Lastly, the environmental benefits that arise from solar PV installation. There are two categories of avoided pollution from installing solar PV systems: carbon dioxide emission and local air pollutants. The amount of pollution that can be avoided is dependent on the type of electric power generation displaced by solar

PV systems 25 years from now on. Following Gillingham and Tsvetanov (2014)'s approach, I set 25 years as the time limit for estimating environmental benefit and employ damage estimates of air pollutants from natural gas fired generation. These are based on the fact that most manufacturers provide a 25-year warranty on their solar panels and natural gas accounts for a significantly large fraction of the electricity generation in the US. Other parameters involved include the average carbon dioxide emission rate across the US, the toal external costs from natural gas-fired generation in the US, and social cost of carbon. The average carbon dioxide emission rate across all regions and hours of the day is estimated to be 1.21 pounds of CO2 per kilowatt hour, i.e., 0.000605 tCO2/kWh. (Zivin et al., 2014). The total external cost from natural gas-fired generation is estimated to be 0.021/kWh (Muller et al., 2011). For the social cost of carbon, I apply the result $37/tCO2 from IAWG (2013) which is widely used by the US government.

Based on the parameters estimated by the main specification of my structural model, I calculate the simulated results for the six counterfactual scenarios and report them below. I also conduct simulations based on alternative models using two other sets of IVs(i.e., BLP instruments and government subsidies, BLP instruments and Hausman instrument), and put their results in Appendix D.

3.1 Simulation I: Removing Anti-dumping Duties

In this section, I evaluate the effect of removing the anti-dumping duties while keeping the US and China's subsidy rates on their solar manufacturing unchanged.

As shown by the two-country model, removing the anti-dumping policy will drive down the price of imported Chinese products and stimulate their sales.

Table 17 presents the change in demand for solar panels in the simulated scenario I, when the anti-dumping duty rates levied on imported Chinese solar products are set to be zero but US and China's subsidy rates remain unchanged. Simulating the purchase price, the percentage increase in product sales from Chinese solar manufacturers (Canadian Solar, Renesola, Suntech Power, Trina Solar and Yingli Green Energy) would range from 22.7% to 107.3% for the period 2010 - 2015, while the percentage decrease in sales from US solar manufacturers (REC Solar and SunPower) would range from -0.04% to -0.4%. The overall sales of solar panels in the MSA markets of my sample would increase by 83,951 kW, or 36.4% compared with the baseline scenario when the anti-dumping policy is in place. This simulated result is consistent with my comparative static analysis in Chapter 1, in which I show that a fall in the anti-dumping duty rate will increase the demand for imported solar product and decrease the demand for domestic solar products. Since the MSA markets selected in my sample account for 31% of the total markets in the US, the simulated sales across the US would increase by 270,810 kW.

The anti-dumping policy initiated by the US changes the competition among Chinese and US solar manufacturers. Removing the anti-dumping duties would decrease the imported Chinese solar panel prices and may make more consumers switch to US solar products. The simulation results in Table 18 show the social welfare change incurred for different market participants and the environmental benefit implied if the anti-dumping policy had been removed. Over the period 2010 - 2015, for MSA markets in my sample, the net gain for US consumers, US manufacturers, Chinese manufacturers and US installers would be 84.56, -0.22, 94.17 and 92.49 million dollars, respectively. If I scale the results to all MSA markets across the US, the net gain for US consumers, US manufacturers, Chinese manufacturers and US installers would be 272.77, -0.72, 303.77 and 298.37 million dollars, respectively.

The anti-dumping duties seem to have a relatively small effect on the domestic manufacturers' profits. This can be explained by the fact that the substitution effect between US and Chinese solar products is quite small. From equation (1.49), in response to the anti-dumping duties, the domestic producer's profit will depend on the quantity effect and the substitution effect. In my simulation on the equilibrium price, the solar panel price for domestic producers have not changed much. This is possible in theory, referring to the special case in Corollary I when the demand function for domestic solar panel is in the form of Cobb-Douglas. Therefore, the domestic producer's profit will mainly depend on the substitution effect. The small impact of the anti-dumping duties on the US manufacturers' profit may be attributable to the small substitution between US and Chinese solar products. If the anti-dumping policy is in place, the consumers may switch to solar products produced by other countries, for example, the European and Japanese solar products. These products may have captured many of the lost Chinese sales.

Without anti-dumping duties, the US solar market would expand by 36.4%, and the increase in solar PV installations would result in greater environmental benefit in terms of reducing greenhouse gas emissions and local air pollutants. The simulation results in Table 18 suggest that, the greenhouse gas emission would be reduced by 1.85 million tons and the economic cost of air pollution resulted from natural gas-fired generation would be reduced by 30.73 million dollars, together amounting to total environmental benefit of 63.49 million dollars. If I scale the results to all MSA markets across the US, the reduced greenhouse gas emission would reach 5.98 million tons and the total environmental benefit would be worth 204.82 million dollars.

3.2 Simulation II: Reducing Subsidy Rates

In this section, I examine the market outcome when the anti-dumping duty rates are set to zero and China matches its subsidy rates on solar manufacturing with that of United States. Subsidy policy provides an alternative tool to anti-dumping issues. A country which has been sued for dumping can respond by reducing subsidy rates on domestic firms as a settlement with the dumping allegation, thus avoiding anti-dumping duties.

Table 19 presents the change in demand for solar panels in the simulated scenario II. Assume the countervailing duty rates (see Table 14) calculated by the US Department of Commerce are reasonable, and I use the averages (28.31%) as a proxy for China's average subsidy rates on its domestic solar manufacturers. As described in Section 1.3.4 and Section 2.4.2, the average subsidy rates of United States on its domestic solar manufacturers is 2.1%. If China's subsidy rates were set to be equal to that of US, then the average price of imported Chinese solar products would be presumably higher.

Simulating the consumer purchase price, I find that the percentage increase in sales from Chinese manufacturers (Canadian Solar, Renesola, Suntech Power, Trina Solar, Yingli Green Energy) would range from 5.5% to 58.7%. The percentage decrease in sales from US manufacturers (REC Solar and SunPower) would range from -0.02% to -0.1%. The overall sales of solar panels in the MSA markets of my sample would increase by 39,355 kW, or 17.1% compared with the baseline scenario when the anti-dumping policy is in place. Since the MSA markets selected in my sample account for 31% of the total markets in the US, the simulated sales across the US would increase by 126,950 kW.

The relative decrease in subsidy rates from China will change the competition among Chinese and US solar manufacturers. The resulted price increase in the imported Chinese solar products may make more consumers switch to US products. The simulation results in Table 20 show the social welfare change incurred for different market participants and the environmental benefit implied in this counterfactual simulation. Over the period 2010 - 2015, for MSA markets in my sample, the welfare change for US consumers, US manufacturers, Chinese manufacturers and US installer would be 40.18, -0.09, 43.39 and 42.70 million dollars, respectively. If I scale the results to all MSA markets across the US, the net gain/loss for US consumers, US manufacturers, Chinese manufacturers and US installers would be 129.62, -0.29, 139.96 and 137.75 million dollars, respectively.

Generous government subsidy is believed to be the key factor that has enabled Chinese solar manufacturers to rapidly gain market shares in the US. If China were to respond by reducing its subsidy rates offered to solar manufacturers and setting it equal to the rate offered in the US, the solar market in United States would expand by 17.1%. This result can be separated into two parts: first, China would avoid the anti-dumping policy by matching the subsidy rates, thus the US market would achieve a 36.4% growth in the installed solar capacity, compared with the baseline scenario (as shown in Simulation I); second, reducing subsidy rates on Chinese firms would drive up the price of Chinese solar products, thus slowing down the expansion of US solar market by 19.3% (36.4% - 17.1%).

The environmental benefit from reducing greenhouse gas emissions and local air pollutants also seems quite significant. The simulation results in Table 20 suggest that, the greenhouse gas emissions would be reduced by 0.87 million tons and the economic cost of air pollution resulted from natural gas-fired generation would be reduced by 14.41 million dollars, together amounting to total environmental benefit of 29.76 million dollars. If I scale the results to all MSA markets across the US, the reduced greenhouse gas emissions would reach 2.80 million tons and the total environmental benefit would be worth 96.01 million dollars.

3.3 Simulation III: Increasing Subsidy Rates

In this section, I explore the simulated market outcome when the anti-dumping duty rates are set to zero and US matches its subsidy rates on solar manufacturing with that of China. The logic behind this counterfactual scenario is that import country may respond by increasing subsidy rates on domestic firms when facing dumping from foreign firms.

Table 21 presents the change in demand for solar panels in the simulated scenario III. The US subsidy rates on solar manufacturing are assumed to be 2.1% on average and the average subsidy rates received by Chinese solar manufacturers are 28.31%. If the US matches its subsidy rates with that of China, the domestic solar panel prices are expected to fall significantly. Simulating the consumer purchase price, the percentage increase in sales from Chinese solar manufacturers (Canadian Solar, Renesola, Suntech Power, Trina Solar and Yingli Green Energy) would range from 22.7% to 78.1% over 2010 - 2015, while the percentage increase in sales from US solar manufacturers (REC Solar and SunPower) would range from 16.5% to 21.0%. The overall sales of solar panels across the MSA markets in my sample would increase by 110,522 kW, or 48.0% compared with the baseline scenario when the anti-dumping policy is in place. Since the MSA markets selected in my sample account for 31% of the total markets in United States, the simulated sales across the United States would increase by 356,521 kW.

The increase in US subsidy rates on solar manufacturing changes the competition among Chinese and US solar manufacturers. The drop in the prices of domestic solar panels induces consumers to buy more US solar products. The simulation results in Table 22 show the social welfare change incurred for different market participants and estimate the environmental benefit implied in this policy experiment. Over the period 2010 - 2015, for MSA markets in my sample, the net gain for US consumers, US manufacturers, Chinese manufacturers and US installers would be 109.47, 29.00, 94.07 and 120.91 million dollars, respectively. If I scale the results to all MSA markets across the US, the net gain for US consumers, US manufacturers, Chinese manufacturers and US installers would be 353.13, 93.55, 303.45 and 390.02 million dollars, respectively.

In this counterfactual scenario, the installation capacity in the US solar market would expand by 48.0%. This result can be separated into two parts: first, by matching the subsidy rates with that of China rather than employing the anti-dumping policy, the US would achieve 36.4% growth in installed solar capacity, compared with the baseline scenario (as shown in Simulation I); second, increasing subsidy rates on domestic firms would decrease the price of US solar panels and further expand the solar market by 11.6% (48.0% - 36.4%). However, this subsidy policy would involve a significant cost. Over the period 2010 - 2015, for all MSA markets across the US, the cost for the subsidy policy would be 218.47 million dollars, while the producer surplus for US manufacturers would increase by 94.27 million dollars and US consumer surplus would increase by 80.36 million dollars, compared with the baseline scenario [1].

The increase in solar PV installations would result in greater environmental benefit in terms of reducing greenhouse gas emissions and local air pollutants. The simulation results in Table 22 show that, the greenhouse gas emissions would be reduced by 2.44 million tons and the economic cost of air pollution resulted from natural gas-fired generation would be reduced by 40.46 million dollars, together amounting to total environmental benefit of 83.59 million dollars. If I scale the results to all MSA markets across the US, the reduced greenhouse gas emissions would reach 7.87 million tons and the total environmental benefit would be worth

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[1] 94.27 = 93.55 - (-0.72), and 80.36 = 353.13 - 272.77

269.64 million dollars.

3.4 Simulation IV: Zero Subsidy Rates in China

In this section, I study the simulated market outcome when the anti-dumping duty rates and China's subsidy rates are set to zero, while the US subsidy rates remain unchanged. The logic behind this is that, countries may choose to eliminate subsidy rates on domestic firms when facing anti-dumping allegation, thus avoiding the incidence of anti-dumping duties.

Table 23 presents the change in demand for solar panels in the simulated scenario IV. Simulating consumer purchase price, the percentage increase in sales from Chinese solar manufacturers (Canadian Solar, Renesola, Suntech Power, Trina Solar and Yingli Green Energy) would range from 4.1% to 55.9% over 2010 - 2015, while percentage decrease in sales from US solar manufacturers (REC Solar and SunPower) would range from -0.02% to -0.1%. The overall sales of solar panels across the MSA markets in my sample would increase by 36,869 kW, or 16.0% compared with the baseline scenario when the anti-dumping policy is in place. Since the MSA markets selected in my sample account for 31% of the total markets in the US, the simulated sales across the US would increase by 118,933 kW.

The simulation results in Table 24 report the social welfare change incurred for different market participants and the environmental benefit implied in this policy experiment. Over the period 2010 - 2015, for MSA markets in my sample, the net gain for US consumers, US manufacturers, Chinese manufacturers and US installers would be 37.58, -0.08, 40.63 and 39.99 million dollars, respectively. If I scale the results to all MSA markets across the US, the net gains for US consumers, US manufacturers, Chinese manufacturers and US installers would be 121.23, -0.27, 131.07 and 129.01 million dollars, respectively.

By removing the anti-dumping duties and Chinese subsidy rates, the US solar market would expand by 16.0%, and the increase in solar PV installations would result in greater environmental benefit in terms of reducing greenhouse gas emissions and local air pollutants. The simulation results in Table 24 suggest that, the greenhouse gas emissions would be reduced by 0.81 million tons and the economic cost of air pollution resulted from natural gas-fired generation would be reduced by 13.50 million dollars, together amounting to total environmental benefit of 27.89 million dollars. If I scale the results to all MSA markets across the US, the reduced greenhouse gas emissions would reach 2.63 million tons and the total environmental benefit would be worth 89.95 million dollars.

3.5 Simulation V: Zero Subsidy Rates in the US

In this section, I study the simulated market outcome when the anti-dumping duty rates and US subsidy rates are set to zero but China's subsidy rates remain unchanged. Table 25 presents the change in demand for solar panels in the simulated scenario V. Simulating the consumer purchase price, the percentage increase in sales from Chinese solar manufacturers (Canadian Solar, Renesola, Suntech Power, Trina Solar and Yingli Green Energy) would range from 22.7% to 107.3% over 2010 -

2015, while the sales from US solar manufacturers (REC Solar and SunPower) would decrease by around 1.7%. The overall sales of solar panels across the MSA markets in my sample would increase by 81,931 kW, or 35.6% compared with the baseline scenario when the anti-dumping policy is in place. Since the MSA markets selected in my sample account for 31% of the total markets in the US, the simulated sales across the US would increase by 264,294 kW.

The simulation results in Table 26 report the social welfare change incurred for different market participants and the environmental benefit implied in this policy experiment. Over the period 2010 - 2015, for MSA markets in my sample, the net gains for US consumers, US manufacturers, Chinese manufacturers and US installers would be 82.66, -2.43, 94.18 and 90.34 million dollars, respectively. If I scale the results to all MSA markets across the US, the net gains for US consumers, US manufacturers, Chinese manufacturers and US installers would be 266.65, -7.84, 303.79 and 291.42 million dollars, respectively.

By removing the anti-dumping duties and US subsidy rates, the installation capacity in US solar market would expand by 35.6%. The increase in solar PV installations would result in greater environmental benefit in terms of reducing greenhouse gas emission and local air pollutants. The simulation results in Table 26 suggest that, the greenhouse gas emissions would be reduced by 1.81 million tons and the economic cost of air pollution resulted from natural gas-fired generation would be reduced by 29.99 million dollars, together amounting to total environmental benefit worth of 61.97 million dollars. If I scale the results to all MSA market across the US, the reduced greenhouse gas emissions would reach 5.84 million tons and the total environment benefit would be worth 199.89 million dollars.

3.6 Simulation VI: Zero Subsidy Rates in China and the US

In this section, I evaluate the market outcome when the anti-dumping duty rates, US and China's subsidy rates are all set to zero. Table 27 presents the change in demand for solar panels in the simulated scenario VI. Simulating consumer purchase price, the percentage increase in sales from Chinese solar manufacturers (Canadian Solar, Renesola, Suntech Power, Trina Solar and Yingli Green Energy) would range from 4.1% to 55.9% over 2010 - 2015, while the sales from US solar manufacturers (REC Solar and SunPower) would decrease by around 1.6%. The overall sales of solar panels in the MSA markets of my sample would increase by 34,848 kW, or 15.1% compared with the baseline scenario when the anti-dumping policy is in place. Since the MSA markets selected in my sample account for 31% of the total markets in the US, the simulated sales across the US would increase by 112,414 kW.

The simulation results in Table 28 show the social welfare change incurred for different market participants and the environmental benefit brought by this policy experiment. Over the period 2010 - 2015, for MSA markets in my sample, the net gains for US consumers, US manufacturers, Chinese manufacturers and US installers would be 35.68, -2.29, 40.64 and 37.85 million dollars, respectively. If I scale the results to all MSA markets across the US, the net gains for US consumers, US manufacturers, Chinese manufacturers and US installers would be 115.11, -7.39, 131.09 and 122.09 million dollars, respectively.

By removing the anti-dumping duties and subsidy rates, the US solar market would expand by 15.1%, and the increase in solar PV installations would result in greater environmental benefit in terms of reducing greenhouse gas emissions and local air pollutants. The simulation results in Table 28 suggest that, the greenhouse gas emissions would be reduced by around 0.77 million tons and the economic cost of air pollution resulted from natural gas-fired generation would be reduced by 12.76 million dollars, together amounting to total environmental benefit of 26.36 million dollars. If I scale the results to all MSA markets across the US, the reduced greenhouse gas emissions would reach 2.48 million tons and the total environmental benefit would be worth 85.02 million dollars.

Chapter 4: Welfare Effects Among Different Consumers

4.1 Consumer Demand for Solar Panels

To explore the incidence of trade restrictions on different types of consumers, I use a random coefficient discrete choice model to further capture the heterogeneity in consumer tastes for differentiated solar panels. A product is defined as a solar panel/installer combination, indexed by j. The conditional indirect utility of household i in MSA w from purchasing and installing j during year t is given by

$$U_{ijwt} = X_j \beta_i + \alpha_i p_{jwt} + \lambda_{mr} + \eta_t + \zeta_{jt} + \epsilon_{ijt} \tag{4.1}$$

where X_j is a vector of nonprice product characteristics; β_i is a vector of consumer-specific marginal utilities (assumed random) associated with the different nonprice product characteristics in X_{jt}; p_{jwt} is the consumer purchase price for product j; α_i represents consumer-specific marginal disutility of price (also assumed random across consumers); λ_{mr} is the solar manufacturer and installer fixed effect; η_t is the year fixed effect; ζ_{jt} is the unobserved product characteristics; error ϵ_{ijt} is i.i.d and follows the type I extreme value distribution.

Following the discrete choice demand literature (Berry et al. (1995), Nevo

(2000), Nevo (2001), Fan (2013) and Gayle (2013)), I model the consumer taste parameters (α_i and β_i) for the solar panel characteristics given by

$$\alpha_i = \alpha + \Pi D_w - \sigma \mu_i \tag{4.2}$$

$$\beta_i = \beta + \Sigma v_i \tag{4.3}$$

Where D_w is a vector of demographic variables of MSA w where consumer i resides in, Π is a matrix of coefficients that measure how the consumer tastes for solar panel price vary with the demographic variables, σ is a scaling parameter; μ_i is random draws from a lognormal distribution (i.e., $\ln(\mu_i) \sim N(0,1)$). The lognormal distribution is useful in that it ensures the price coefficient to be negative across consumers (Train, 2009); Σ is a diagonal scaling matrix, and v_i is a random draw from a multivariate standard normal distribution (i.e., $v_i \sim N(0, \mathbf{1})$). The predicted market share of product j is given by

$$s_{jwt}(X_{jt}, p_{jwt}; \alpha, \beta, \Pi, \sigma, \Sigma) = \int \frac{exp(\delta_{jwt} + \mu_{ijwt})}{1 + \sum_{l=1}^{J} exp(\delta_{lwt} + \mu_{ilwt})} dF(\nu) \tag{4.4}$$

where $\delta_{jwt} = X_{jt}\beta + \alpha p_{jwt} + (\Pi D_w) p_{jwt} + \lambda_{mr} + \eta_t + \zeta_{jt}$ is the mean utility across consumers obtaining from purchasing and installing product j; μ_{ilwt} is a consumer-specific deviation from the mean utility level which associates with the consumer tastes for different product characteristics. The parameters are estimated by using simulation-assisted maximum likelihood (Train, 2009). I use 50 random draws from the distribution function $F(\cdot)$ for the numerical approximation of $s_{jwt}(\cdot)$.

The market size is defined as the number of single family homes on the MSA level which are suitable for installing solar PV systems. The observed market share of product j is given by $s_{jwt} = \frac{q_{jwt}}{M_w \times V}$, where q_{jwt} is the actual demand for product j in MSA w during year t, M_w is the number of single family homes on the MSA w, and V is the percentage of buildings which are solar-viable in that MSA area.

4.2 The Supply Side

On the supply side, firms have a marginal cost function that is linear in a vector of cost characteristics. Assuming the solar manufacturer's marginal cost depends on a vector of variables X_t and the solar installer's marginal cost depends on a vector of variables Y_t. Then the joint marginal cost is given by

$$mc_t = \gamma_1 X_t + \gamma_2 Y_t + \kappa + \psi_t \tag{4.5}$$

where X_t includes labor cost, capital cost and technology input in solar panel manufacturing; Y_t includes labor cost in solar installation; κ is installer-year fixed effect; and ψ_t is the proportion of marginal cost that is unobserved by the econometrician, and I assume it to be a random term with zero mean. The labor cost in manufacturing refers to the average hourly compensation cost in manufacturing in the solar brand's origin country; capital cost refers to the one-year lending interest rate in the solar brand's origin country and technology input refers to the panel's technology attribute (i.e., energy conversion efficiency), and labor cost in installation refers to the wage rate for roofing in United States. As in Chapter 2, the estimate of solar manufacturer and installer's joint marginal cost mc_t is given by

$$mc_t = c_t^m + c_t^r = p_t + (T_r * \Delta_{rt})^{-1} s_t(p) + (T_m * \Delta_{mt})^{-1} s_t(p) \tag{4.6}$$

4.3 Data

The data I used mainly come from Lawrence Berkeley National Laboratory (LBNL)s *Tracking the Sun* report series. Since I described this dataset in detail in Chapter 2, I won't repeat it here. The sources for other data used in this Chapter are:(1) US Census Bureau, which provides MSA-level demographic distribution regarding to the median income, education, median age, race, family structure, political orientation, as well as the number of single family homes; (2) US Bureau of Labor Statistics, which provides hourly wage in manufacturing across different counties and hourly wage rate in roofing; (3) World Bank, which provides information on the lending interest rates across different countries; (4) Google Project Sunroof, which estimates the technical solar potential of all buildings in a region based on sunlight, installation size and space, and reports the percentage of buildings that are solar-viable.

In Table 29, I summarize the statistics for the demographics of the MSA markets in my sample. The average of the median income across different MSAs is \$78,280, with a maximum at \$130,520 and minimum at \$50,320. For the education level, I use the percent of population over 25 years old with bachelor degree or higher as a proxy. The average percent of people with bachelor degree or higher across different MSAs is 30.23%, with a maximum at 48.7% and minimum at 13.0%. The average of the median age across different MSAs is 38.78 years old, with a maximum at 49.9 and minimum at 28.7 years old [1]. For the composition of races, I use the percent of white people alone (not Hispanic or Latino) as a proxy. The average percent of white population across different MSAs is 68.89%, with a maximum at 94.25% and minimum at 35.3%. For the information on the family structure, I use the percent of households with children under 18 years old as a proxy. The average percent of households with children across different MSAs is 32.80%, with a maximum at 42.4% and minimum at 22.2%. For the political orientation, I use the percent of people voting for the Democratic candidate in the 2008 presidential election as a proxy. The average percent of democratic supporters across different MSAs is 54.67%, with a maximum at 74.90% and minimum at 33.46%.

4.4 Estimation Results

The demand and marginal cost parameters are estimated jointly by using Generalized Methods of Moments (GMM). The details on the estimation are provided in Appendix C. Following the identification strategy used in Chapter 2, I use BLP instruments as IVs, and the set of BLP instruments consist of three variables (i.e., $BLP\_efficiency$, $BLP\_technology$ and BLP_black).

Table 30 reports the results on both demand and marginal cost parameters

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[1] The place with median age of 28.7 years old is State College Metropolitan Statistical Area in the state of Pennsylvania, in which Pennsylvania State University is located.

estimates. I begin with a discussion of the demand-side parameters. The upper panel of demand side estimation reports the mean marginal utility for each product characteristics (α and β), the panel immediately below this upper panel reports the coefficients (σ and Σ) which measure the variation in taste for each product characteristics, and the lower panel reports the coefficients (Π) on the interaction of price with demographics.

As expected, the estimated price coefficient is negative and statistically significant at the 5% level. It suggests that, on average, the consumers are more likely to choose a solar panel that has a lower price. The coefficient on "Efficiency" is positive and statistically significant, suggesting that consumers prefer solar panels with higher energy conversion efficiency. With high-efficiency panels, the consumers can obtain more solar energy with less amounts of solar panels. The coefficient on the technology dummy is insignificant, but as expected and suggested by its negative sign, consumers seem to regard panels made of polycrystalline cells as an inferior substitute to panels made of monocrystalline cells. The estimated coefficient on the black dummy is negative, suggesting that consumers prefer solar panels with silver frames rather than those with black frames.

The estimated taste variation parameters for price, technology dummy and black dummy are all statistically significant at the conventional significance levels, confirming that consumers are heterogeneous for the price, technology type, and frame color of the solar panels. More than half of the coefficients on the interaction of price with demographics are statistically significant. The interpretation of the estimates is straightforward. Consumers who reside in MSAs with higher median income and a higher proportion of democratic supporters tend to be less price sensitive. This is consistent with the intuition that wealthier consumers are less sensitive to the solar panel prices, and also democrats are more environmental friendly and they are willing to pay higher prices to tackle with climate change. Consumers who reside in MSAs with higher average levels of educational attainment, higher median age, a higher proportion of white people, and a higher percentage of households with children, are more price sensitive.

On the cost-side parameters, the coefficients on the manufacturing wage and lending interest rate are positive and statistically significant at conventional levels of significance, suggesting that the marginal cost increases with the labor and capital cost in the manufacturing. The coefficient on "Efficiency" is statistically significant at the 1% level, suggesting that marginal cost increases with technology input. The positive and significant coefficient on the installing wage suggests that marginal cost increases with the labor cost in the solar installations.

4.5 Policy Experiment

In this section, I explore the distribution of welfare change among different groups of consumers. I revisit the six counterfactual simulations and investigate which groups of consumers benefit or lose the most from the trade restrictions.

Following Small and Rosen (1981), I use the compensating variation to calculate the change in consumer surplus. The formula (3.1) in Chapter 3 implies that consumers who are price-insensitive may benefit more if they experience a positive consumer surplus change, and may lose more if they experience a negative consumer surplus change.

Countries may respond by changing subsidy rates when facing dumping from foreign firms. They may for example raise the subsidy rates on domestic firms, therefore when conducting policy experiments I explicitly take the subsidy policy into account together with the anti-dumping policy. I conduct six counterfactual simulations based on different changes in anti-dumping duty and subsidy rates as in Chapter 3. The procedures for computing and comparing the welfare changes among different types of consumers are as follows: (i) I begin by drawing from the estimated distribution of α_i and β_i in an MSA. I take a total of 50 draws, then compute the consumer surplus for each one of these 50 "consumers"; (ii) Next, I take the average consumer surplus for these 50 consumers and use it as the consumer welfare for the MSA; (iii) I calculate the consumer welfare change (in percentage) for that MSA between baseline and simulated scenarios; (iv) I repeat the above procedures for each MSA and calculate the consumer welfare change for every MSA in my sample; (v) Lastly, I plot graphs to show the distribution of consumer welfare changes against the MSA's demographics.

In simulated scenario I, I study the welfare change among different types of consumers when removing the anti-dumping duties. The lift of the anti-dumping policy will drive down the price of imported Chinese solar products and stimulate their sales. Figure 6 shows the consumer welfare change among MSAs with different demographics in the simulated scenario I. The red line is the line of best fit, and its direction indicates the relationship between changes in consumer surplus and the MSA's demographics. In general, the consumer surplus would increase resulted from removing of the anti-dumping duties, which is consistent with my conclusion in Chapter 3. Consumers who reside in MSAs with higher median income would on average have higher percentage increase in consumer surplus. It suggests that wealthier consumers would benefit more from the removing of the anti-dumping duties. The same result holds for consumers who reside in MSAs with higher average levels of educational attainment, higher median age, a higher proportion of white people, and a higher proportion of democratic supporters. However, consumers who reside in MSAs with a higher percentage of households with children would lose the most in welfare.

One explanation for these results is that, price-insensitive consumers would benefit more from removing of the anti-dumping policy, as indicated by the formula (3.1). In Table 30, the coefficients on the interaction of price with demographics (Π) suggest that consumers who reside in MSAs with higher median income, a lower percentage of households with children, and a higher proportion of democratic supporters, are less sensitive to the solar panel prices. Therefore, consumers of these types would have higher percentage increase in consumer surplus. However, it can not explain the outcome for the consumers who reside in MSAs with higher average levels of educational attainment, higher median age, and a higher proportion of white people.

In simulated scenario II, I evaluate the welfare change among different types of consumers when China matches its subsidy rates on solar manufacturing with that of US. Subsidy policy provides an alternative tool to anti-dumping issues. Figure 7 shows the welfare change among different consumer groups in the simulated scenario II. In general, the consumer surplus would increase, which is consistent with my conclusion in Chapter 3. Consumers who reside in MSAs with higher median income would on average have higher percentage increase in consumer surplus. It suggests that high-income consumers would benefit more from the simulated policy. The same result holds for consumers who reside in MSAs with higher average levels of educational attainment, higher median age, a higher proportion of white people, and a higher proportion of democratic supporters. However, consumer who reside in MSAs with higher percentage of households with children would lose the most in welfare.

In simulated scenario III, I explore the welfare change among different types of consumers when US matches its subsidy rates on solar manufacturing with that of China. The logic behind this counterfactual is that import country can respond by increasing subsidy rates on domestic firms when facing dumping from foreign firms. Figure 8 shows the welfare change among different consumer groups in the simulated scenario III. Consumers who reside in MSAs with higher median income would on average have higher percentage increase in consumer surplus. It suggests that high-income consumers would generally benefit more from the simulated policy. The same result holds for consumers who reside in MSAs with higher average levels of educational attainment, a higher proportion of white people, and a higher proportion of democratic supporters. However, consumers residing in MSAs with a higher percentage of households with children would lose welfare from the simulated policy.

Figures 9, 10 and 11 show the results for the welfare change among different types of consumers in simulated scenario IV, V and VI, respectively, when one or both of the countries set their subsidy rates to be zero. The results are quite similar, and the conclusions are almost the same as what I have discussed in simulated scenario I, II and III.

Chapter 5: Conclusion and Discussion

5.1 Conclusion

In this dissertation, I have examined how the trade war between China and the US affects the social welfare in the fast-growing solar industry with vertical structure between upstream and downstream firms. The solar sector is an important market to study, because as one of the main sources of renewable energy it has the potential to become a dominant energy source.

This dissertation first develops a two-country theoretical model in which the home country imposes an anti-dumping duty on the imports from the foreign country, and examines how the quantities, prices and producer profits will change as a response to the anti-dumping duties. Then I estimate a structural econometric model of consumer demand for solar panels and marginal cost on solar manufacturing which incorporates the vertical structure between upstream solar manufacturers and downstream solar installers. Based on the estimated model, I conduct six counterfactual simulations regarding to different hypothetical changes on anti-dumping duties and subsidy rates. The results of my simulations show that the installation capacity in the US solar market would expand by 36.4% if there were no anti-dumping policies and welfare change for US consumers, US manufacturers, Chinese manufacturers and US installers would reach 272.77, -0.72, 303.77 and 298.37 million dollars (in 2015 US dollars), respectively. Compared with the big losses in Chinese solar manufacturers, the US manufacturers have only gained small profits from the anti-dumping policy.

After studying the welfare change among different market participants, I proceed to explore the effect of the trade restrictions on different consumer groups. I use a random coefficient discrete choice model to further capture the heterogeneity in consumer tastes for solar panel prices. Through six counterfactual simulations based on hypothetical changes in anti-dumping duty rates and subsidy rates, I find that consumers who are relatively less sensitive to solar panel price (i.e., consumers residing in areas with higher median income, a lower percentage of households with children, and a higher proportion of democratic supporters) would benefit more if there had been no anti-dumping policies.

I conclude by highlighting a few caveats of my paper. First, further work needs to be done to model demand. My paper assumes that the demand system is static, however, there still exists a possibility that a wait-or-buy decision may be involved when the consumers choose to install a solar PV system. Thus future research would benefit from making the demand side dynamic. Also, once the households have the solar system installed, they are no longer in the market, so the demand system needs to be modified to account for this feature. Second, my paper has not discussed the effect of anti-dumping policies on US employment and manufactures. It would be very interesting to consider what happens to US employment, as well as to US manufactures when a trade war has been initiated. Has this trade war resulted in more job creation in the US solar manufacturing industry? Have the solar firms invested more in their manufacturing capacity? Has the employment in the solar installer industry changed as a result of the anti-dumping policy? Answering these and other questions will help guide future research and inform trade policy, as well as energy and environmental policies.

5.2 Discussion

In recent years, we have witnessed an increase protectionism policies despite compelling economic arguments in favor of free trade and greater trade openness. There are several motivations for governments in enacting the policies of retraining trade: 1) protect sunrise industries to keep them grow and become competitive globally; 2) protect strategic industries such as water, energy and food; 3) limit unfair competition from foreign industry, such as dumping by undercutting domestic prices; 4) protect local jobs and keep employment. However, some of the government's original intentions in implementing trade policy in favor of protectionism may not be achieved. In my dissertation, the simulation result shows that the profits for US solar manufacturers have only increased a little when the anti-dumping policy is in place. In the next paragraph, I will discuss one similar case - the trade friction in the automobile industry between the US and Japan in the 1990s.

In early 1990s, the US ran a high trade deficit (around \$13 billion) with Japan and the automobile and automobile parts industry accounted for a significantly large portion of this. To remedy the bilateral trade deficit, the US considered to use the trade instruments via the automobile industry as a solution. In May 1995, President Clinton announced 100 percent tariffs on thirteen luxury cars imported from Japan, and these car models include five Lexus (Toyota) models, three Infiniti (Nissan) models, two Acura (Honda) models, two Mazda models, and one Mitsubishi model. However, the tariffs were withdrawn by United States only six weeks after the announcement, because Japan agreed to buy substantially more US auto parts. Levinsohn (1995) studied this topic and estimated what would have happened had the tariffs been put permanently into place. What he had argued is very interesting. He concluded that though Japanese profits in total would have fallen around 12.5 percent, US firms would have been pretty much unaffected by the tariffs, because European firms would have captured many of the lost Japanese sales.

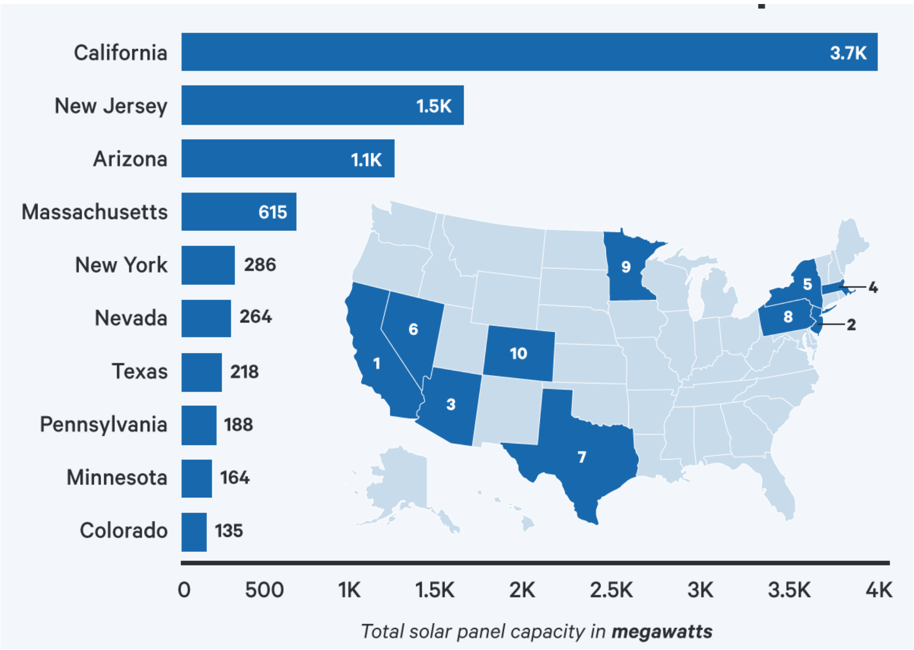

Figure 1: Top 10 states with solar power in 2016

Source: National Renewable Energy Laboratory; U.S. Department of Energy; Tech Insider.

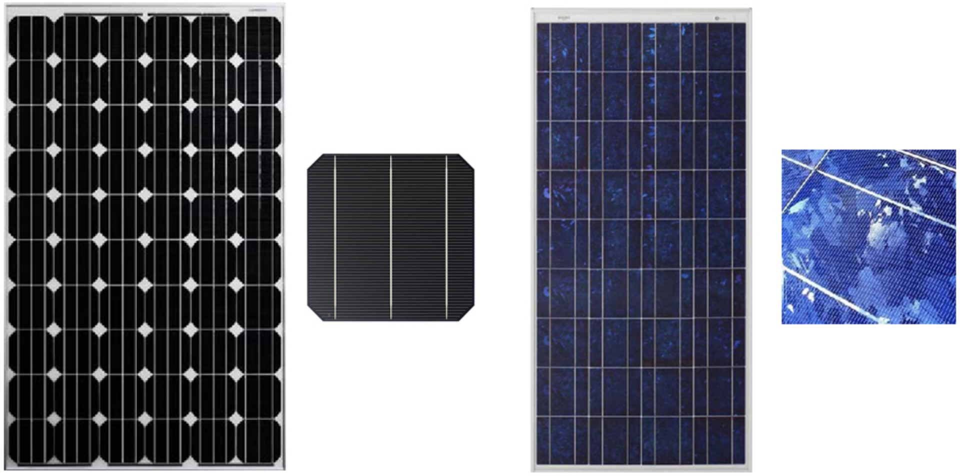

Figure 2: Monocrystalline and polycrystalline solar panels

Source: Alba Energy(albaenergy.com).

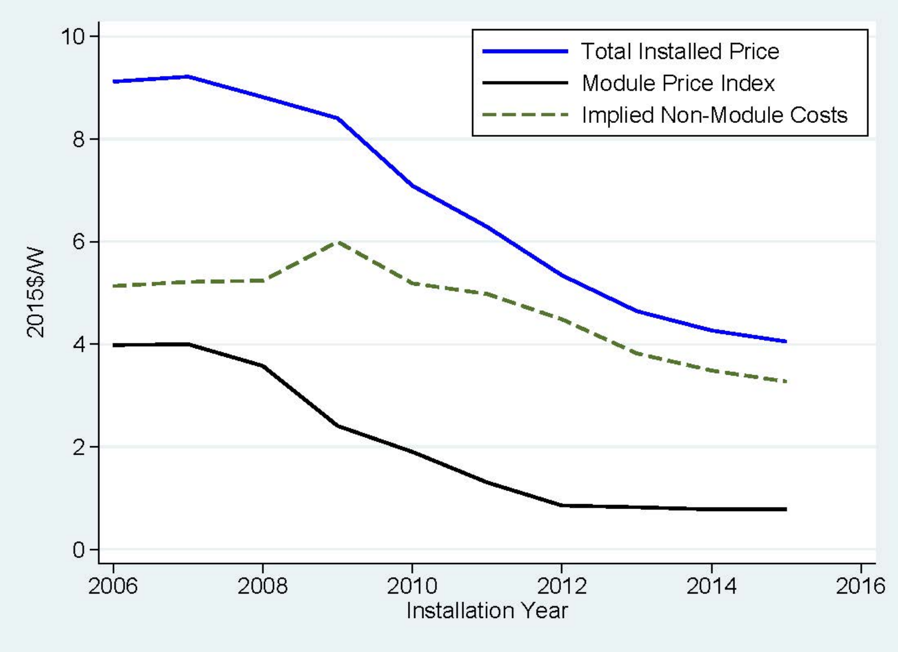

Figure 3: Price decline of residential solar PV

Source: Lawrence Berkeley National Laboratory.

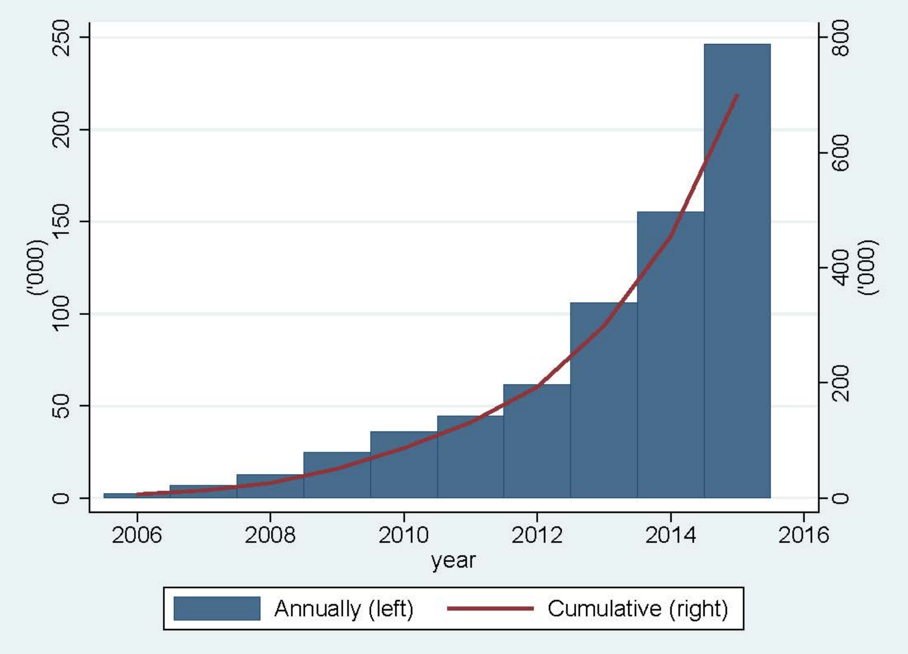

Figure 4: Number of installations of residential solar systems over time

Source: Lawrence Berkeley National Laboratory.

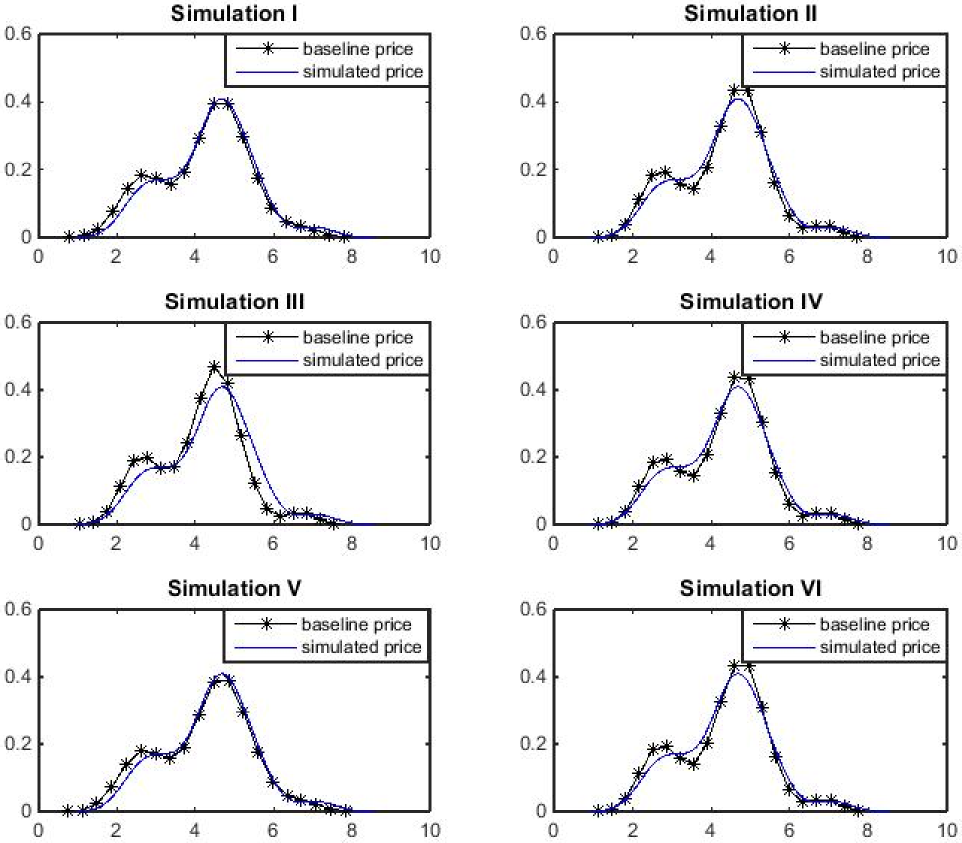

Figure 5: Baseline price and simulated price

Note: Baseline price represents the simulated equilibrium price when the anti-dumping policy is in place; simulated price represents the simulated equilibrium price in the counterfactual scenarios.

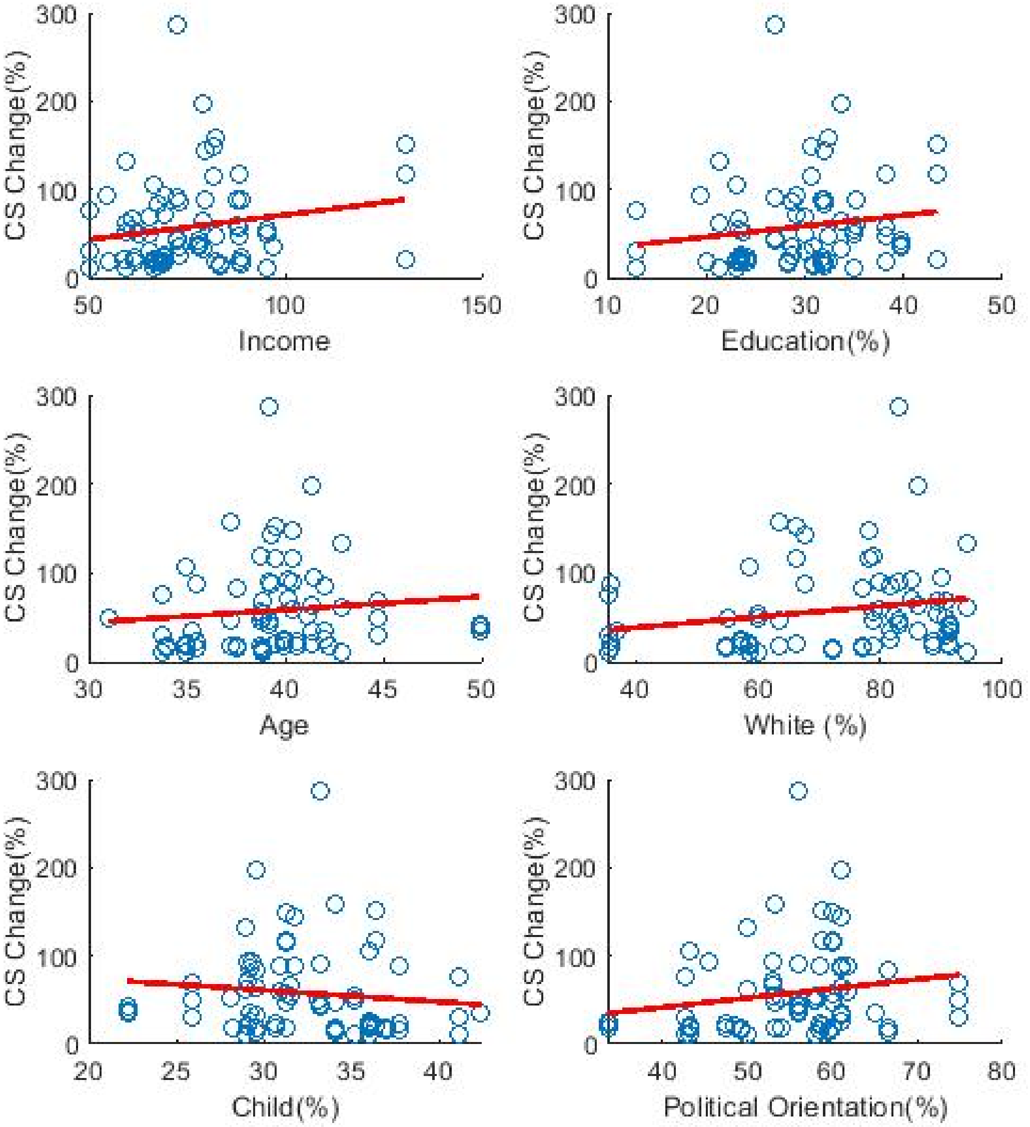

Figure 6: Consumer welfare change across different demographics for simulation I

Note: This figure shows the distribution of consumer welfare change against the MSA's demographics in counterfactual simulation I. Red line is the line of best fit.

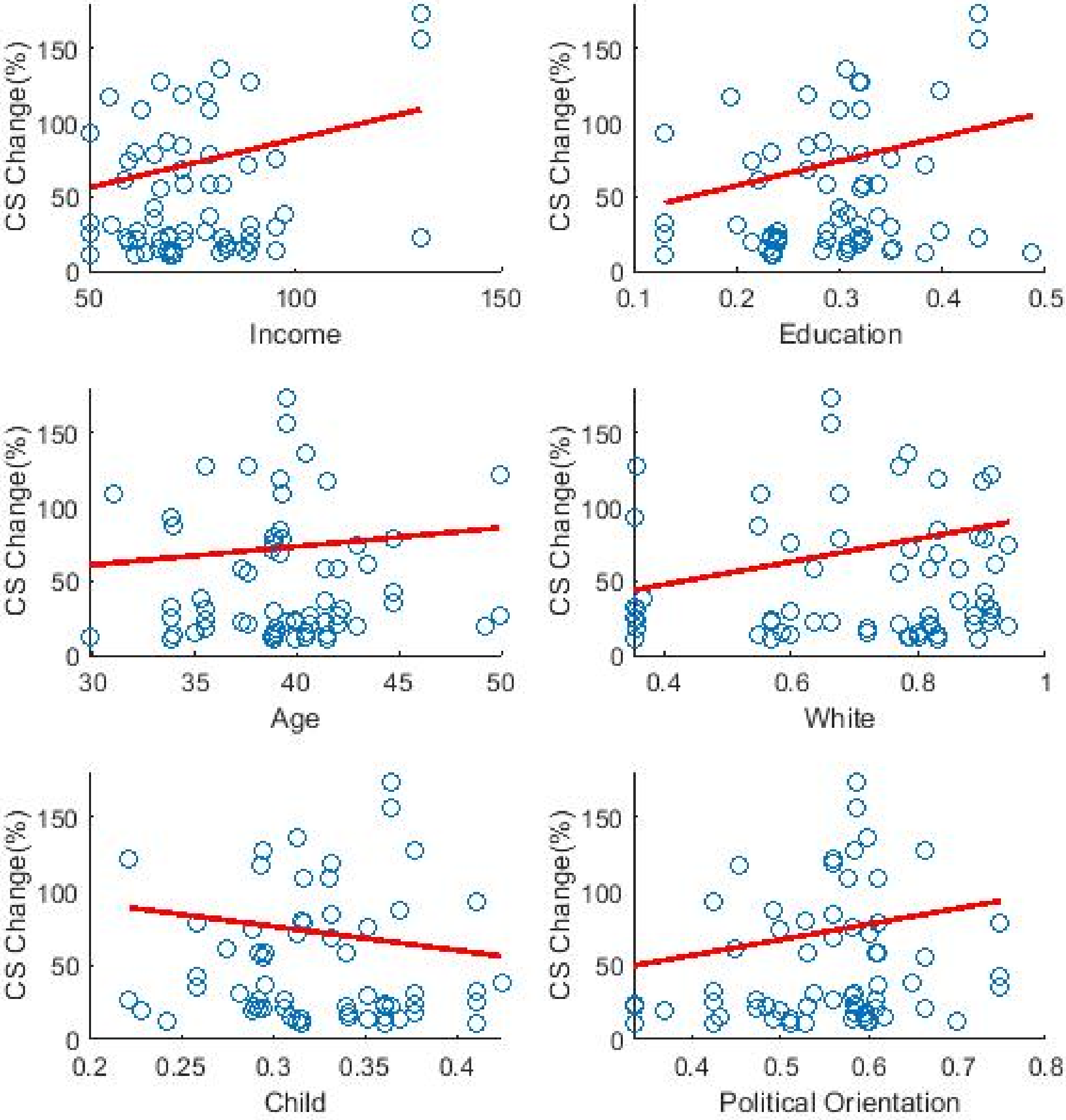

Figure 7: Consumer welfare change across different demographics for simulation II

Note: This figure shows the distribution of consumer welfare change against the MSA's demographics in counterfactual simulation II. Red line is the line of best fit.

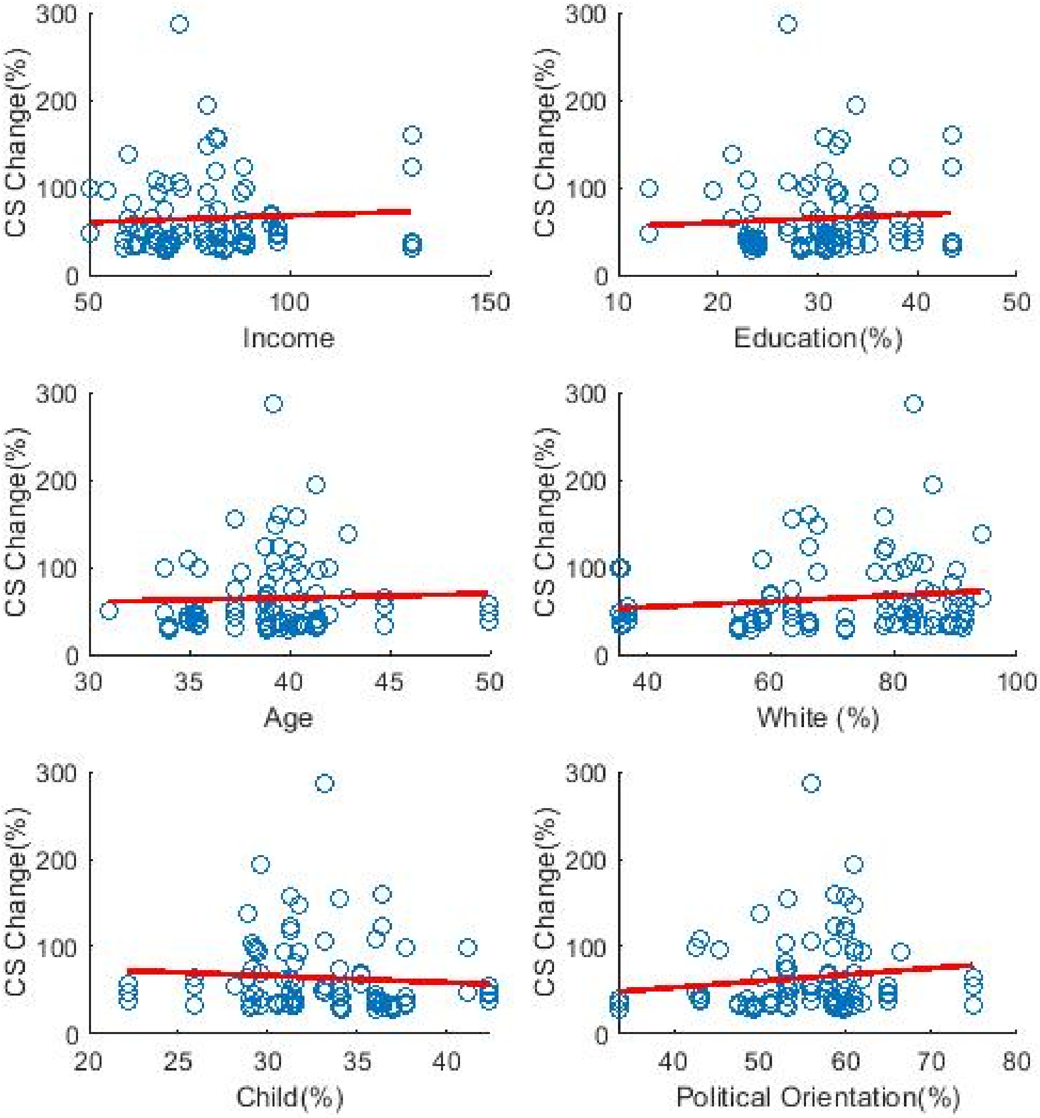

Figure 8: Consumer welfare change across different demographics for simulation III

Note: This figure shows the distribution of consumer welfare change against the MSA's demographics in counterfactual simulation III. Red line is the line of best fit.

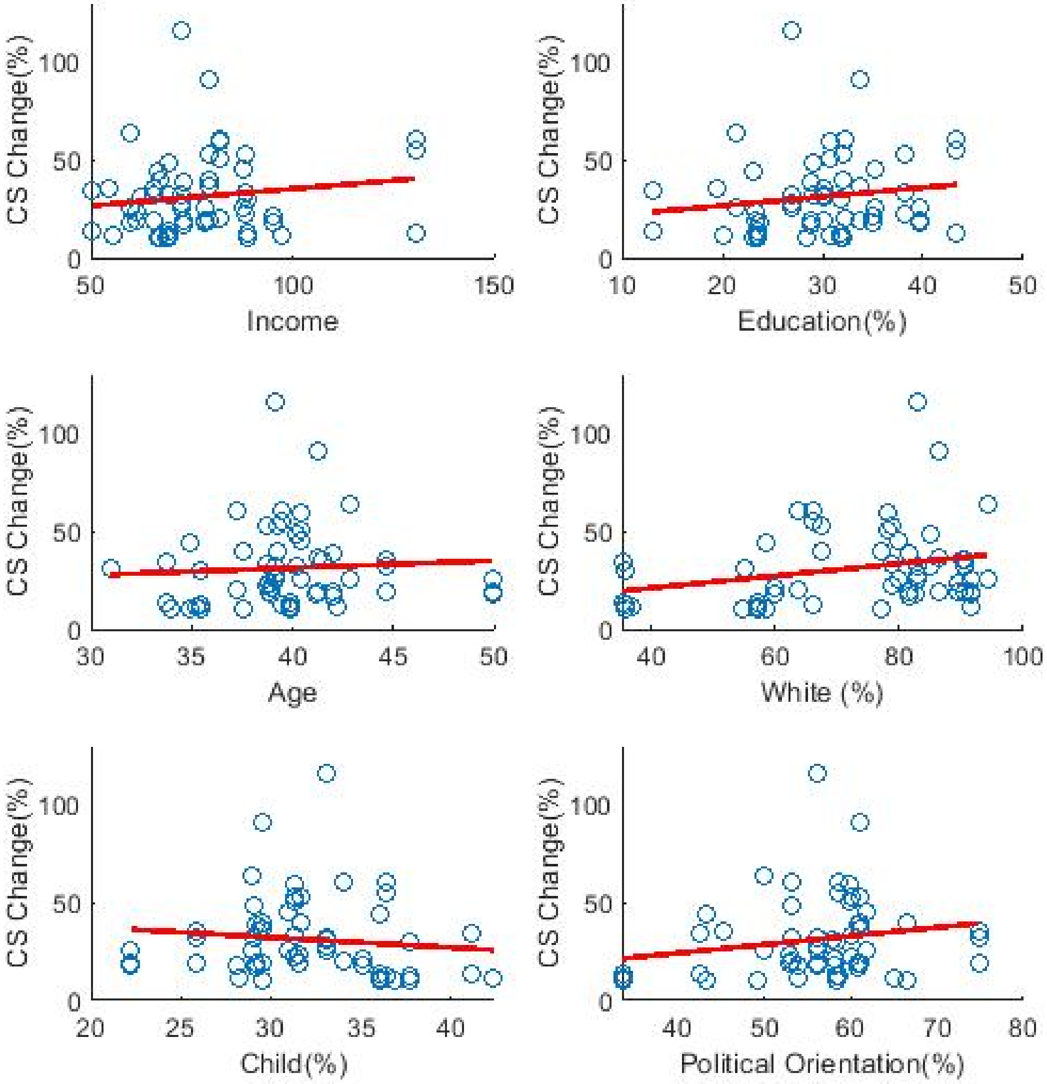

Figure 9: Consumer welfare change across different demographics for simulation IV

Note: This figure shows the distribution of consumer welfare change against the MSA's demographics in counterfactual simulation IV. Red line is the line of best fit.

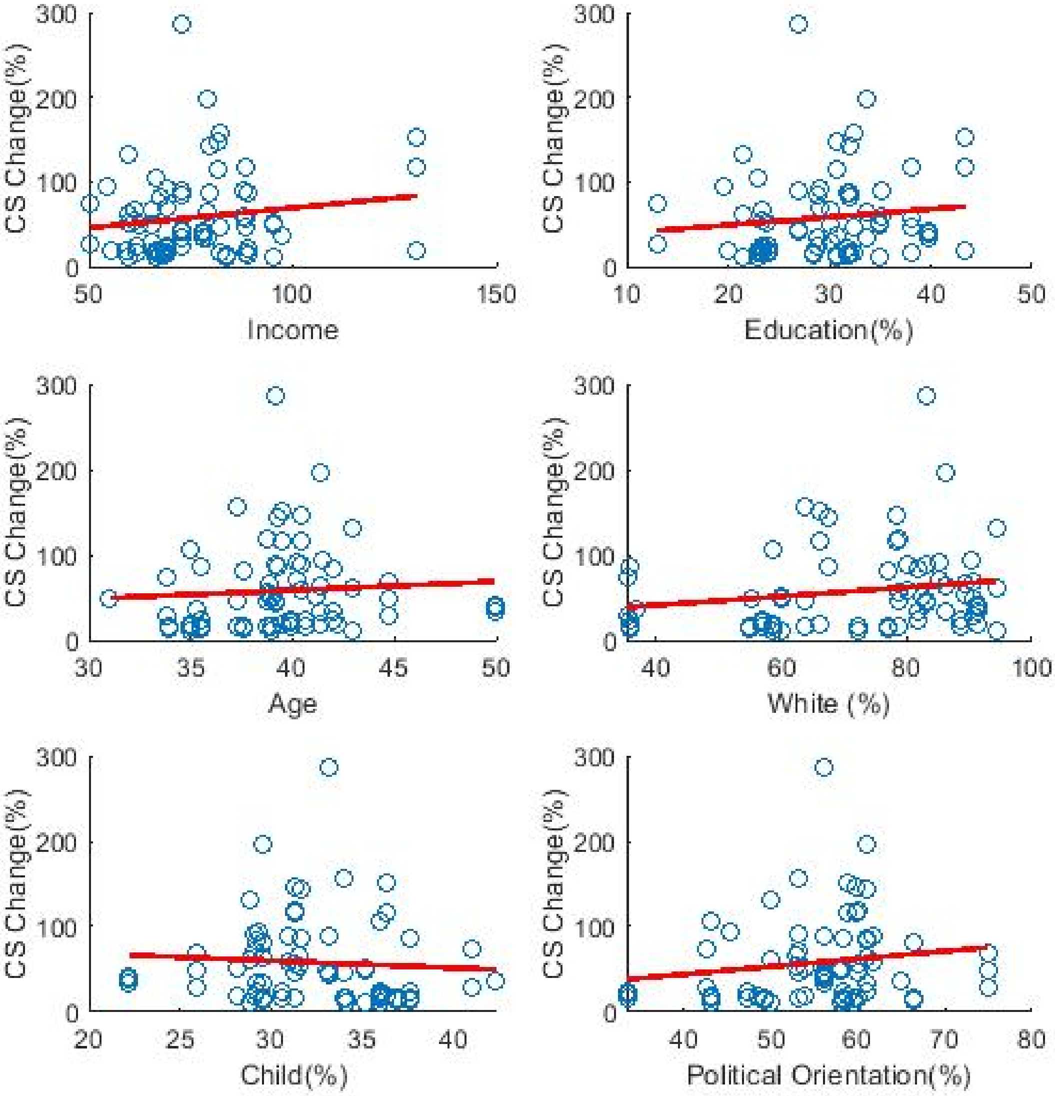

Figure 10: Consumer welfare change across different demographics for simulation V

Note: This figure shows the distribution of consumer welfare change against the MSA's demographics in counterfactual simulation V. Red line is the line of best fit.

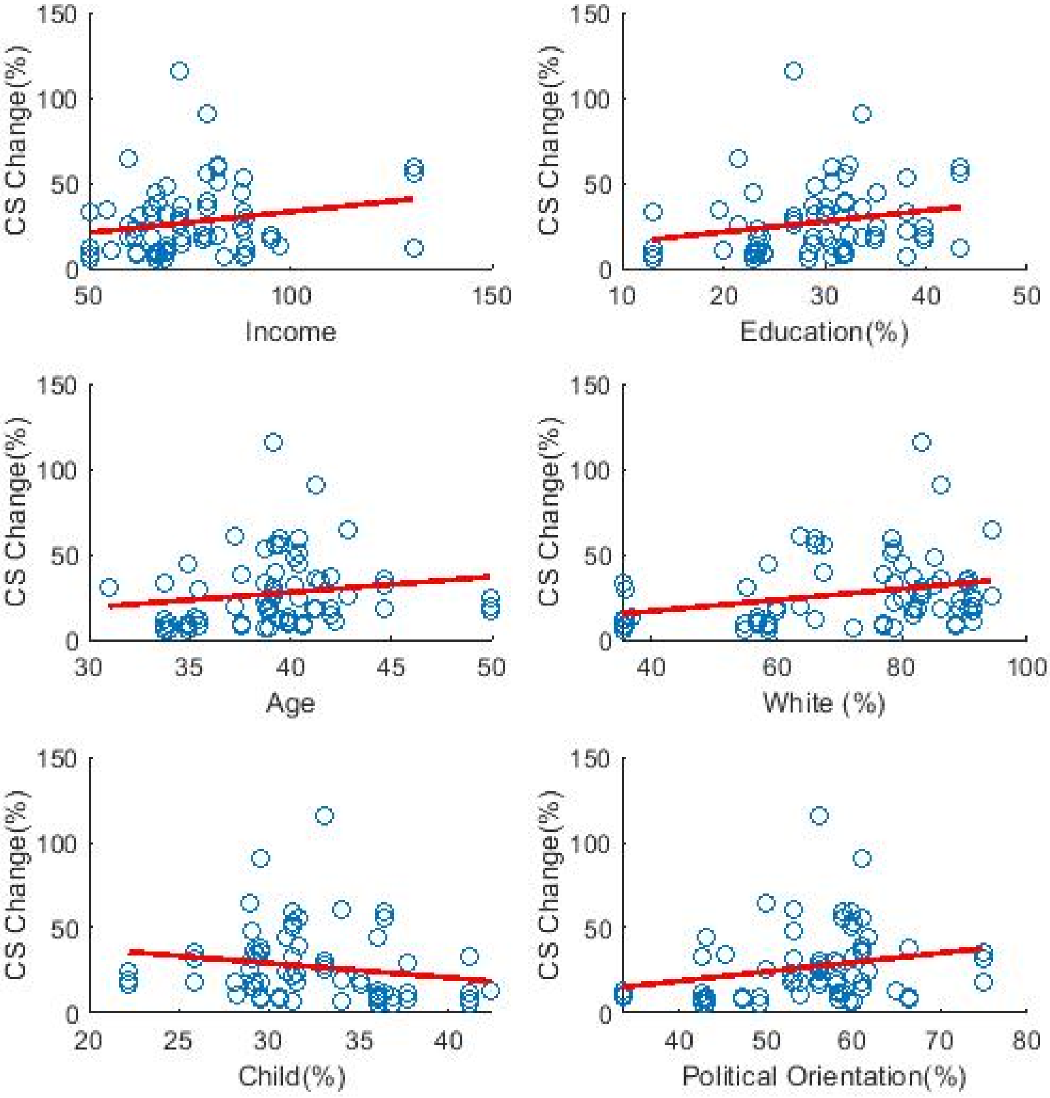

Figure 11: Consumer welfare change across different demographics for simulation VI

Note: This figure shows the distribution of consumer welfare change against the MSA's demographics in counterfactual simulation VI. Red line is the line of best fit.

Table 1: Top 15 manufacturers by market share

Rank	2011	Market Share	2015	Market Share
1	SunPower	17.18%	REC Solar	16.68%
2	Suntech*	13.31%	SunPower	12.90%
3	Kyocera Solar	10.83%	Kyocera Solar	12.66%
4	Sharp	10.20%	Trina Solar*	11.67%
5	Trina Solar*	7.11%	SolarWorld	10.44%
6	Schuco USA	6.19%	Canadian Solar*	7.85%
7	Canadian Solar*	4.62%	LG Electronics	7.41%
8	SolarWorld	4.17%	Hanwha Q CELLS	6.97%
9	REC Solar	4.03%	Hyundai	3.75%
10	BP Solar	3.95%	SunEdison	1.91%
11	Panasonic Group	2.28%	AU Optronics	1.49%
12	ET Solar*	2.01%	Suniva	1.32%
13	Schott Solar	1.42%	Renesola*	0.98%
14	Yingli Green Energy*	1.26%	Axitec	0.47%
15	Centrosolar	1.22%	ET Solar*	0.35%

Notes: This table represents the top 15 manufacturers in US solar market by market share in 2011 and 2015, respectively. The firms with asterisk are Chinese solar makers.

Table 2: Descriptive statistics across years

Panel A	2010	2011	2012	2013	2014	2015
MSA	42	49	45	51	41	42
solar makers	4	6	6	7	7	8
solar panels	10	17	26	35	33	34
installation	1,087	1,612	4,214	6,469	12,821	17,340
Panel B						
MSA	153	150	148	149	137	129
solar makers	109	138	145	161	150	158
solar panels	490	685	831	1,194	1,209	1,343
installation	33,584	41,958	58,598	102,828	151,455	239,490

Notes: This table represents the descriptive statistics for the key variables, including the number of MSAs, the number of different solar makers, the number of different types of solar panels and the number of solar PV installations. Panel A shows the statistics summary for the inside goods and Panel B shows the statistics summary for the whole dataset.

Table 3: List of models for the solar panels

Brand	Model	Brand	Model
Suntech Power	STP180S-24/Ab-1	**SunPower**	SPR-215-WHT
	STP185S-24/Ab-1		SPR-225-BLK
	STP190S-24/Ad		SPR-230-WHT
	STP250-20/Wd		SPR-230NE-BLK-D
Trina Solar	TSM-240PA05		SPR-240E-WHT-D
	TSM-250PA05		SPR-245NE-WHT-D
	TSM-250PD05.08		SPR-320E-WHT-D
	TSM-255PA05		SPR-327NE-WHT-D
	TSM-255PD05.08		SPR-E20-327
	TSM-260PA05		SPR-X20-250-BLK
	TSM-260PD05.08		SPR-X21-335
Yingli Green Energy	YL235P-29b		SPR-X21-335-BLK
	YL250P-29b		SPR-X21-345
Renesola	JC250M-24/Bb	**Canadian Solar**	CS6P-230P
Hanwha Q CELLS	Q.PRO BFR G4 265		CS6P-235PX
REC Solar	REC240PE (BLK)		CS6P-250M
	REC245PE (BLK)		CS6P-250P
	REC250PE (BLK)		CS6P-255M
	REC255PE(BLK)		CS6P-255P
	REC260PE		CS6P-260P
	REC260PE(BLK)		
	REC275TP		

Notes: This table lists all the models of the solar panels in the inside goods.

Table 4: Summary statistics for key variables

Variable	Description	Max	Min	Mean	SD
A. Basic Characteristics					
InstalledPrice	Total installed price (2015$/Watt)	35.96	1.10	5.12	1.65
Subsidy	Government subsidies (2015$/Watt)	4.69	0	0.82	0.77
Price	Consumer purchase price [a] (2015$/Watt)	34.96	1.10	4.30	1.50
Efficiency	Energy conversion efficiency	0.21	0.14	0.17	0.02
Technology	=1, if polycrystalline; =0 if monocrystalline	1	0	0.46	0.50
Black	=1, if solar panel frame is black	1	0	0.20	0.40
B. Geo. and Demo. Var					
Electricity Price	Average electricity price (cents/kWh)	20.93	10.97	16.11	3.01
Education	Percent of people with a bachelor degree (%)	48.70	13.00	30.23	6.45
Income	Median income ($1000) on the MSA level	130.52	50.32	78.28	15.61
Age	Median age (years old)	49.90	28.70	38.78	3.72
Homes	# of single family homes (1,000)	4,631	20	868	1,196
Solar Potential	Percent of buildings that are solar-viable (%)	92	28	72	13
C. Cost Variable					
Manufacturing Wage	Wage rate (2015$/hour) in manufacturing	37.04	1.74	18.84	16.24
Installing Wage	Wage rate (2015$/hour) in roofing	35.67	15.75	23.82	4.63
Interest Rate	Lending interest rate (%)	6.56	3.25	4.67	1.37

Notes: the prices are in 2015 US dollars

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[a] Consumer Purchase Price = Total Installed Price - Government Subsidies

Table 5: List of solar installers

Number	Name	Number	Name
1	SolarCity	6	Sunpower
2	Vivint	7	REC Solar
3	Verengo	8	PetersenDean
4	Sungevity	9	RGS/Real Goods
5	Sunrun	10	All others

Notes: This table lists the ten groups of solar installers in US market. The first nine groups are the nine biggest solar installers as marked by number 1 - 9 and the tenth group is all other solar installers in my data sample.

Table 6: Results for the first-stage regression

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Subsidy	-0.827***			-0.785***		-0.847***	-0.806***
	(0.0581)			(0.0625)		(0.0578)	(0.0621)
$BLP\_efficiency$		0.0742		0.107	0.0726		0.106
		(0.0769)		(0.0734)	(0.0765)		(0.0728)
$BLP\_technology$		0.0404***		-0.00674	0.0407***		-0.00753
		(0.0149)		(0.0147)	(0.0149)		(0.0146)
BLP_black		-0.0424*		0.00516	-0.0388		0.0107
		(0.0253)		(0.0245)	(0.0252)		(0.0243)
Hausman			0.257***		0.276***	0.313***	0.323***
			(0.0634)		(0.0625)	(0.0597)	(0.0596)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Manufacturer-Installer FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,647	1,647	1,647	1,647	1,647	1,647	1,647
F-statistic	383	18.07	12.49	54.33	18.57	116.76	50.12
R-squared	0.339	0.279	0.262	0.344	0.288	0.350	0.356

Note: The variable Subsidy represents the government subsidies received by the consumer for installing a solar PV system; the variables $BLP\_efficiency$, $BLP\_technology$ and BLP_black are the BLP instruments based on the product characteristics; the variable Hausman represents the Hausman instrument. Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 7: Results for the second-stage regression

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Price	-0.0726	-1.167***	0.274	-0.240***	-0.825***	-0.0390	-0.196**
	(0.0852)	(0.212)	(0.300)	(0.0829)	(0.158)	(0.0802)	(0.0776)
Efficiency	28.64***	32.02***	27.57***	29.16***	30.97***	28.53***	29.02***
	(6.833)	(9.209)	(7.269)	(6.861)	(7.992)	(6.844)	(6.839)
Technology	1.445***	1.922***	1.294***	1.518***	1.773***	1.430***	1.499***
	(0.212)	(0.296)	(0.257)	(0.213)	(0.254)	(0.212)	(0.212)
Black	-0.235**	-0.126	-0.269**	-0.218**	-0.160	-0.238**	-0.223**
	(0.106)	(0.144)	(0.116)	(0.107)	(0.125)	(0.107)	(0.106)
Electricity Price	0.0638***	0.106***	0.0505**	0.0703***	0.0929***	0.0625***	0.0686***
	(0.0178)	(0.0249)	(0.0218)	(0.0178)	(0.0213)	(0.0178)	(0.0178)
Education	7.308***	9.041***	6.759***	7.573***	8.499***	7.254***	7.504***
	(0.928)	(1.281)	(1.080)	(0.932)	(1.102)	(0.929)	(0.928)
Income	-0.0502***	-0.0462***	-0.0515***	-0.0496***	-0.0475***	-0.0504***	-0.0498***
	(0.00349)	(0.00474)	(0.00383)	(0.00350)	(0.00410)	(0.00349)	(0.00349)
ln (Age)	3.328***	3.282***	3.343***	3.321***	3.296***	3.330***	3.323***
	(0.421)	(0.566)	(0.445)	(0.423)	(0.492)	(0.422)	(0.421)
Constant	-27.01***	-24.22***	-27.89***	-26.58***	-25.09***	-27.10***	-26.69***
	(1.874)	(2.562)	(2.109)	(1.881)	(2.212)	(1.876)	(1.874)
Manufacturer-Installer FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,647	1,647	1,647	1,647	1,647	1,647	1,647
R-squared	0.313	-	0.235	0.308	0.063	0.311	0.312

Table 8: Estimation result for main specification

	Variables	Estimates	Standard Errors
Demand side parameters			
Means, (α, β)	Constant	-19.809***	(4.321)
	Price	-0.979***	(0.379)
	Efficiency	53.180***	(21.212)
	Technology	-6.429***	(2.393)
	Black	-23.838***	(9.916)
Taste variation, (Σ)	Constant	-1.000*	(0.612)
	Efficiency	13.369***	(3.325)
	Technology	5.960***	(1.260)
	Black	14.617***	(5.034)
Cost side parameters			
	Constant	-6.079***	(1.827)
	Manufacturing Wage	0.050**	(0.024)
	Interest Rate	0.565**	(0.287)
	Efficiency	18.106***	(2.713)
	Installing Wage	0.059***	(0.006)

Note: This table reports the result for the demand and supply estimation based on the mixed logit specifications, in which I use BLP instruments as IVs. The sample is from year 2010 to 2015. On the demand side, Price is the after-subsidy average installed price for solar module (in \$/W); Efficiency represents the energy conversion efficiency; Technology represents the type of solar photovoltaic technology, which is a dummy variable and equals to one if its made of polycrystalline solar cells; Black is dummy variable, which equals to one if the solar module has a black frame; Manufacturing Wage refers to the average hourly compensation cost in the manufacturing in the solar brands origin country; Interest Rate refers to the one-year lending interest rate in the solar brands origin country; Efficiency represents the energy conversion efficiency; Installing Wage refers to the MSA-level wage rate (\$/hour) for the roofing; Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 9: Result for robustness check I

	Variables	Estimates	Standard Errors
Demand side parameters			
Means, (α, β)	Constant	-30.325***	(7.420)
	Price	-0.626**	(0.296)
	Efficiency	47.918	(30.338)
	Technology	-15.271**	(6.615)
	Black	-6.243	(8.596)
Taste variation, (Σ)	Constant	-5.606***	(1.454)
	Efficiency	3.291	(2.777)
	Technology	12.052***	(3.641)
	Black	7.461	(6.072)
Cost side parameters			
	Constant	-7.475***	(1.743)
	Manufacturing Wage	0.054**	(0.022)
	Interest Rate	0.606**	(0.267)
	Efficiency	17.472***	(2.780)
	Installing Wage	0.059***	(0.006)

Note: This table reports estimation result for the demand and supply models by using BLP instruments and government subsidies as instrumental variables. The sample is from year 2010 to 2015. On the demand side, Price is the after-subsidy average installed price for solar module (in $/W); Efficiency represents the energy conversion efficiency; Technology represents the type of solar photovoltaic technology, which is a dummy variable and equals to one if its made of polycrystalline solar cells; Black is dummy variable, which equals to one if the solar module has a black frame; Manufacturing Wage refers to the average hourly compensation cost in the manufacturing in the solar brands origin country; Interest Rate refers to the one-year lending interest rate in the solar brands origin country; Efficiency represents the energy conversion efficiency; Installing Wage refers to the MSA-level wage rate ($/hour) for the roofing; Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 10: Result for robustness check II

	Variables	Estimates	Standard Errors
Demand side parameters			
Means, (α, β)	Constant	-20.748***	(4.263)
	Price	-0.777**	(0.345)
	Efficiency	55.831***	(21.493)
	Technology	-7.475***	(2.302)
	Black	-25.165**	(10.291)
Taste variation, (Σ)	Constant	-0.939*	(0.547)
	Efficiency	13.971***	(3.254)
	Technology	6.468***	(1.223)
	Black	15.399***	(5.190)
Cost side parameters			
	Constant	-6.682***	(2.021)
	Manufacturing Wage	0.051**	(0.025)
	Interest Rate	0.576*	(0.307
	Efficiency	17.954***	(2.700)
	Installing Wage	0.059***	(0.006)

Note: This table reports estimation result for the demand and supply models by using BLP instruments and Hausman instrument as instrumental variables. The sample is from year 2010 to 2015. On the demand side, Price is the after-subsidy average installed price for solar module (in \$/W); Efficiency represents the energy conversion efficiency; Technology represents the type of solar photovoltaic technology, which is a dummy variable and equals to one if its made of polycrystalline solar cells; Black is dummy variable, which equals to one if the solar module has a black frame; Manufacturing Wage refers to the average hourly compensation cost in the manufacturing in the solar brands origin country; Interest Rate refers to the one-year lending interest rate in the solar brands origin country; Efficiency represents the energy conversion efficiency; Installing Wage refers to the MSA-level wage rate (\$/hour) for the roofing; Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 11: Price elasticity, marginal costs, and markups

Variable	Mean	Std.Dev	10%	Median	90%
Price ($/W)	5.122	1.653	3.419	4.964	7.097
Own-price elasticity	-4.199	1.468	-	-	-
Markup for solar manufacturer ($/W)	1.038	0.043	1.022	1.024	1.066
Markup for solar installer ($/W)	1.033	0.032	1.022	1.024	1.045
Joint marginal cost ($/W)	3.079	1.654	1.360	2.905	5.039

Note: This table reports means, standard deviations, as well as the 10th, 50th, and 90th percentiles of price, own-price elasticity, markup for the solar manufacturer and solar installer, and joint marginal cost.

Table 12: Estimation result for adjusted marginal cost

VARIABLES	Adjusted MC
Manufacturing Wage	0.188***
	(0.017)
Interest Rate	1.651***
	(0.202)
Efficiency	18.320***
	(3.224)
Installing Wage	0.055***
	(0.007)
Constant	-10.106***
	(1.324)
Installer FE	Yes
Year FE	Yes
Observations	1,647
R-squared	0.648

Notes: This table reports estimates of parameters in the supply side. The dependent variable is the adjusted joint marginal cost. The independent variables Manufacturing Wage refers to the average hourly compensation cost in the manufacturing in the solar brand's origin country; Interest Rate refers to the one-year lending interest rate in the solar brand's origin country; Efficiency represents the energy conversion efficiency; Installing Wage refers to the MSA-level wage rate ($/hour) for the roofing; Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 13: Demand elasticities with respect to price

	SPR-327	REC260	TSM-250PA	CS6P-250P	STP185S	Q.PRO	YL250P	JC250M
SPR-327	-4.113							
REC260		-3.911						
TSM-250PA			-3.543					
CS6P-250P				-3.800				
STP185S					-4.724			
Q.PRO						-2.932		
YL250P							-4.264	
JC250M								-3.566

Note: The full name for these eight solar models are SPR-327NE-WHT-D, REC260PE, TSM-250PA05, CS6P-250P, STP185S-24/Ab-1, Q.PRO BFR G4 265, YL250P-29b and JC250M-24/Bb, repectively.

Table 14: Anti-dumping and countervailing duties (%)

	Anti-dumping		Countervailing	
	2012	2014	2012	2014
Suntech	31.73	52.13	14.78	27.64
Trina Solar	18.32	26.71	15.97	49.79
Canadian Solar	25.96	52.13	15.24	38.72
Yingli Green	25.96	52.13	15.24	38.72
Renesola	-	78.42	-	38.72

Note: This table reports the anti-dumping and countervailing duties rates imposed on the imported solar panels produced by Chinese manufacturers. Different Chinese manufacturers may face different level of duties. The duty rates were first set by US Department of Commerce in 2012, and then revised in 2014.

Table 15: Breakdown of total installed price over 2010 - 2015

Year	Total Price	Module Price	Non-Module Costs	Module Price/Total Price
2010	7.1	1.9	5.2	26.83%
2011	6.3	1.3	5.0	20.78%
2012	5.3	0.9	4.5	16.03%
2013	4.6	0.8	3.8	17.74%
2014	4.3	0.8	3.5	18.29%
2015	4.1	0.8	3.3	19.24%

Note: This table reports the trend of solar prices from 2010 to 2015. Total Price is the total installed price ($/W), which is decomposed into module price and non-module cost. The data for this table comes from Lawrence Berkeley National Laboratory.

Table 16: Assumptions of parameters in estimating environmental benefit

Parameter	Value	Sources
Number of years	25	Gillingham and Tsvetanov (2014)
Discount rate	3%	Muller et al. (2011)
Full Sunlight hours	4 hours/day	
CO2 emission rate	1.2 lbs/kWh	Zivin et al. (2014)
External cost	$ 0.021/kWh	Gillingham and Tsvetanov (2014), Muller et al. (2011)
Social cost of carbon	$37/tCO2	Inter-Agency Working Group (2013)

Note: Full sunlight hours represents the total amount of full sunlight hours per day. CO2 emission rate represents the average greenhouse gas emission from electricity generation across all regions and hours of day in the US. External cost represents the total external cost of air pollutants produced by natural gas-fired generation.

Table 17: Demand response in simulation I

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	39,626	82,134	42,508	107.3%
	Renesola	456	599	143	31.5%
	Suntech Power	5,945	7,297	1,352	22.7%
	Trina Solar	42,412	75,536	33,124	78.1%
	Yingli Green Energy	8,916	15,877	6,961	78.1%
USA	SunPower	106,410	106,367	-42.3	-0.04%
	REC Solar	25,527	25,430	-97	-0.4%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		230,330	314,281	83,951	36.4%
All markets		743,001	1,013,811	270,810	36.4%

Note: This table reports the demand change for the counterfactual simulation scenario I, when anti-dumping duty rates are set to zero and subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table 18: Welfare effect for simulation I

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	84.56	272.77
Δ US Manufacturers	-0.22	-0.72
Δ China Manufacturers	94.17	303.77
Δ Installers	92.49	298.37
B. Environmental Benefit		
ΔReduced CO2 Emission (tons)	1,853,851	5,980,164
ΔReduced External Cost ($ Million)	30.73	99.14
ΔTotal Environmental Benefit ($ Million)	63.49	204.82

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario I, when anti-dumping duty rates are set to zero.

Table 19: Demand response in simulation II

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	39,626	62,880	23,253	58.7%
	Renesola	456	480	25	5.5%
	Suntech Power	5,945	6,614	670	11.3%
	Trina Solar	42,411	54,317	11,905	28.1%
	Yingli Green Energy	8,916	12,478	3,561	39.9%
USA	SunPower	106,409	106,386	-23	-0.02%
	REC Solar	25,527	25,489	-38	-0.1%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		230,330	269,685	39,355	17.1%
All markets		743,001	869,951	126,950	17.1%

Note: This table reports the demand change for the counterfactual simulation scenario II, when the anti-dumping duty rates are set to zero and China's subsidy rates are set to be equal to that of US. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table 20: Welfare effect for simulation II

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	40.18	129.62
Δ US Manufacturers	-0.09	-0.29
Δ China Manufacturers	43.39	139.96
Δ Installers	42.70	137.75
B. Environmental Benefit		
ΔReduced CO2 Emission	869,050	2,803,387
ΔReduced External Cost	14.41	46.48
ΔTotal Environmental Benefit	29.76	96.01

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario II, when China's subsidy rates are set to be equal to that of US.

Table 21: Demand response in simulation III

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	39,626	82,116	42,490	62.0%
	Renesola	456	599	143	31.5%
	Suntech Power	5,945	7,293	1,349	22.7%
	Trina Solar	42,412	75,481	33,069	78.0%
	Yingli Green Energy	8,916	15,876	6,960	78.1%
USA	SunPower	106,410	128,713	22,303	21.0%
	REC Solar	25,527	29,734	4,207	16.5%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		230,330	340,851	110,522	48.0%
All markets		743,001	1,099,523	356,521	48.0%

Note: This table reports the demand change for the counterfactual simulation scenario III, when the anti-dumping duty rates are set to zero and US subsidy rates are set to be equal to that of China. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table 22: Welfare effect for simulation III

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	109.47	353.13
Δ US Manufacturers	29.00	93.55
Δ China Manufacturers	94.07	303.45
Δ Installers	120.91	390.02
Δ US Subsidies	67.73	218.47
B. Environmental Benefit		
ΔReduced CO2 Emission	2,440,593	7,872,880
ΔReduced External Cost	40.46	130.52
ΔTotal Environmental Benefit	83.59	269.64

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario III, when US subsidy rates on solar manufacturing are set to be equal to that of China.

Table 23: Demand response for simulation IV

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	39,626	61,765	22,139	55.9%
	Renesola	456	474	19	4.1%
	Suntech Power	5,945	6,506	561	9.4%
	Trina Solar	42,412	53,321	10,909	25.7%
	Yingli Green Energy	8,916	12,214	3,299	37.0%
USA	SunPower	106,410	106,388	-22	-0.02%
	REC Solar	25,527	25,492	-35	-0.1%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		230,330	267,200	36,869	16.0%
All markets		743,001	861,934	118,933	16.0%

Note: This table reports the demand change for the counterfactual simulation scenario IV, when the anti-dumping duty and China's subsidy rates are set to zero, while US subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table 24: Welfare effect for simulation IV

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	37.58	121.23
Δ US Manufacturers	-0.08	-0.27
Δ China Manufacturers	40.63	131.07
Δ Installers	39.99	129.01
B. Environmental Benefit		
ΔReduced CO2 Emission	814,165	2,626,338
ΔReduced External Cost	13.50	43.54
ΔTotal Environmental Benefit	27.89	89.95

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario IV, when the anti-dumping duties and China's subsidy rates are set to zero, while US subsidy rates remain unchanged.

Table 25: Demand response for simulation V

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	39,626	82,136	42,510	107.3%
	Renesola	456	599	143	31.5%
	Suntech Power	5,945	7,297	1,352	22.7%
	Trina Solar	42,412	75,540	33,129	78.1%
	Yingli Green Energy	8,916	15,876	6,960	78.1%
USA	SunPower	106,409	104,674	-1,735	-1.6%
	REC Solar	25,527	25,097	-430	-1.7%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		230,330	312,262	81,931	35.6%
All markets		743,001	1,007,295	264,294	35.6%

Note: This table reports the demand change for the counterfactual simulation scenario V, when the anti-dumping duty and US subsidy rates are set to zero, while China's subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table 26: Welfare effect for simulation V

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	82.66	266.65
Δ US Manufacturers	-2.43	-7.84
Δ China Manufacturers	94.18	303.79
Δ Installers	90.34	291.42
B. Environmental Benefit		
ΔReduced CO2 Emission	1,809,245	5,836,272
ΔReduced External Cost	29.99	96.75
ΔTotal Environmental Benefit	61.97	199.89

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario V, when the anti-dumping duties and US subsidy rates are set to zero, while China's subsidy rates remain unchanged.

Table 27: Demand response in simulation VI

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	39,626	61,766	22,140	55.9%
	Renesola	456	474	18	4.1%
	Suntech Power	5,944	6,506	562	9.4%
	Trina Solar	42,412	53,324	10,912	25.7%
	Yingli Green Energy	8,916	12,214	3,298	37.0%
USA	SunPower	106,409	104,694	-1,715	-1.6%
	REC Solar	25,527	25,159	-368	-1.4%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		230,330	265,179	34,848	15.1%
All markets		743,001	855,415	112,414	15.1%

Note: This table reports the demand change for the counterfactual simulation scenario VI, when the anti-dumping duty, China and US subsidy rates are all set to zero. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table 28: Welfare effect for simulation VI

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	35.68	115.11
Δ US Manufacturers	-2.29	-7.39
Δ China Manufacturers	40.64	131.09
Δ Installers	37.85	122.09
B. Environmental Benefit		
ΔReduced CO2 Emission	769,538	2,482,382
ΔReduced External Cost	12.76	41.15
ΔTotal Environmental Benefit	26.36	85.02

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario VI, when the anti-dumping duties, China and US subsidy rates are all set to zero.

Table 29: Summary statistics for the demographics

Demographics	Mean	Median	Max	Min
Income ($000)	78.28	79.31	130.52	50.32
Education (%)	30.23	30.80	48.70	13.00
Age	38.78	38.91	49.90	28.70
Race (%)	68.89	72.16	94.25	35.30
Child (%)	32.80	33.15	42.40	22.20
Political Orientation (%)	54.67	58.08	74.90	33.46

Note: This table reports the summary statistics for the demographic variables on the MSA level. Income represents the median family income (in $1000); Education represents the percent of population over 25 with bachelors degree or higher; Age represents the median age of the population; Race represents the percent of white people (not Hispanic or Latino); Child represents the percent of households with children under 18 years; Political Orientation represents the percent of people voting for the Democratic candidate in the 2008 presidential election.

Table 30: Estimation result

	Variables	Estimates	Standard Errors
Demand side parameters			
Means, (α, β)	Constant	-15.519***	(3.122)
	Price	-0.626**	(0.327)
	Efficiency	27.073*	(15.838)
	Technology	-0.590	(1.199)
	Black	-6.960*	(3.875)
Taste variation, (σ and Σ)	Constant	-3.114***	(0.495)
	Price	1.520***	(0.321)
	Efficiency	-2.642	(3.592)
	Technology	3.152***	(0.824)
	Black	-6.549***	(2.155)
Interaction terms with price, (Π)	Income	0.179**	(0.081)
	Education	-0.164	(0.103)
	Age	-0.130***	(0.047)
	Race	-0.138***	(0.044)
	Child	-0.427***	(0.098)
	Political Orientation	0.030	(0.055)
Cost side parameters			
	Constant	-4.047**	(1.743)
	Manufacturing Wage	0.054**	(0.023)
	Interest Rate	0.523*	(0.279)
	Efficiency	10.615***	(2.964)
	Installing Wage	0.048***	(0.007)

Note: This table reports the result for the demand and supply estimation based on the random coefficients specification. The sample is from year 2010 to 2015. On the demand side, Price is the after-subsidy average installed price for solar module (in \$/W); Efficiency represents the energy conversion efficiency; Technology represents the type of solar photovoltaic technology, which is a dummy variable and equals to one if its made of polycrystalline solar cells; Black is dummy variable, which equals to one if the solar module has a black frame; Income represents the median family income; Education is a dummy variable if the individual has a bachelor degree or higher; Age represents median age; Race is a dummy variable if the consumer is white people (not Hispanic or Latino); Child is a dummy variable if the individual has children under 18 years old; Political Orientation is a dummy variable if the consumer voted for Democratic candidate in 2008 presidential election. On the cost side, Manufacturing Wage refers to the average hourly compensation cost in the manufacturing in the solar brands origin country; Interest Rate refers to the one-year lending interest rate in the solar brands origin country, Efficiency represents the energy conversion efficiency; installing wage refers to the MSA-level wage rate (\$/hour) for the roofing; Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Appendix A: DERIVATION of Δ_{mt}

The derivation for Δ_{mt} is identical to that in Berto Villas-Boas (2007) and I outline the key steps below.

Note that $\Delta_{mt} = \Delta_{pt}^{'}\Delta_{rt}$, where Δ_{rt} is the solar installer's response matrix with $\Delta_{rt}(k,j) = \frac{\partial s_{jt}}{\partial p_{kt}}$ and Δ_{mt} is the solar manufacturer's response matrix with $\Delta_{mt}(k,j) = \frac{\partial s_{jt}}{\partial p_{kt}^{m}}$.

Δ_{rt} can be easily computed. To obtain Δ_{mt}, the only additional computation needed is Δ_{pt}, which represents a matrix of derivatives of all the final prices with respect to all the upstream prices. An element in Δ_{pt} is given by $\Delta_{pt}(k,j) = \frac{\partial p_{jt}}{\partial p_{kt}^{m}}$.

Following Villas-Boas (2007), the first order condition for the downstream solar installer is given by

$$s_{jt} + \sum_{k \in F_r} (p_{kt} - p_{kt}^{m} - c_{kt}^{r}) \frac{\partial s_k(p)}{\partial p_j} = 0 \tag{A.1}$$

I suppress the market index t to avoid a clutter of subscripts. Totally differentiating the above equation with respect to all final prices and an upstream price

p_n^m will yield

$$\sum_{k=1}^{J}\left[\frac{\partial s_j}{\partial p_k}+\sum_{m=1}^{J}\left[\Psi_r(m,j)\frac{\partial^2 s_m}{\partial p_j \partial p_k}(p_k-p_k^m-c_k^r)\right]+\Psi_r(k,j)\frac{\partial s_k}{\partial p_j}\right]\mathbf{d}p_k \\ -\Psi_r(n,j)\frac{\partial s_n}{\partial p_j}\mathbf{d}p_n^m=0 \tag{A.2}$$

Let G be a matrix with element $g(j,k)=\left\{\frac{\partial s_j}{\partial p_k}+\sum_{m=1}^{J}\left[\Psi_r(m,j)\frac{\partial^2 s_m}{\partial p_j \partial p_k}(p_k-p_k^m-c_k^r)\right]+\Psi_r(k,j)\frac{\partial s_k}{\partial p_j}\right\}$. Since $(p_k-p_k^m-c_k^r)$ can be computed directly from the equation (2.6), the calculation of matrix $\mathbf{G}$ is not involved with the upstream price and the marginal cost. Let H_n be a J-dimensional column vector with element $h(j,n)=\Psi_r(n,j)\frac{\partial s_n}{\partial p_j}$. Then equation (A.2) is rewritten as

$$\mathbf{G}\mathbf{d}p-\mathbf{H}_n\mathbf{d}p_n^m=0 \tag{A.3}$$

Finally, the response matrix Δ_p can be calculated with the matrix G and H_n through the following expression

$$\Delta_{pt}=\mathbf{G}^{-1}\mathbf{H}_n \tag{A.4}$$

With Δ_{pt} computed, Δ_{mt} will be obtained, so are the parameters on the supply model.

Appendix B: Standard Logit Model

A standard logit specification of the demand model is as follows. The conditional indirect utility of consumer i in MSA w from purchasing and installing j during year t is given by

$$U_{ijwt} = X_{jt}\beta + \alpha p_{jwt} + D_{wt}\psi + \lambda_{mr} + \eta_t + \zeta_{jt} + \epsilon_{ijt} \tag{B.1}$$

where X_{jt} is the characteristics of solar panels; p_{jwt} is the consumer purchase price; D_{wt} is MSA-level demographic and geographic variables, which include levels of educational attainment, median income, median age and electricity price; ζ_{jt} is the product characteristics unobserved by the econometrician but observed by the consumers and firms; Error term ϵ_{ijt} is i.i.d and follows the type I extreme value distribution; λ_{mr} is solar manufacturer and solar installer fixed effect; η_t is the year fixed effect.

The trans-log version of the predicted market share of solar panel/installer pair j in MSA w during year t is given by

$$\ln s_{jwt} - \ln s_{0wt} = X_{jt}\beta + \alpha p_{jwt} + D_{wt}\psi + \lambda_{mr} + \eta_t + \zeta_{jt} \tag{B.2}$$

where s_{jwt} is the market share of the inside goods and s_{0wt} is the market share of the outside goods.

Appendix C: GMM Estimation

The estimated GMM parameters can be obtained by solving the following objective function.

$$\min_{\alpha,\beta,\gamma,\sigma,\Sigma} \quad \eta^{'} W \Phi^{-1} W^{'} \eta \tag{C.1}$$

where η is a vector of demand residuals (ζ) and supply residuals (ψ); W is a block diagonal matrix of instruments for the demand and supply equations; Φ^{-1} is a weighting matrix; γ is the coefficients on the supply equation; σ is taste variation parameter for the price and Σ are taste variation parameters for the nonprice characteristics. For given values of the mean utilities δ, optimal value for the linear parameters α and β can be solved for analytically. If $X_1 = [p, X]$ and $\theta_1 = [\alpha; \beta]$, then

$$\theta_1 = (X_1^{'} W_d \Phi_d^{-1} W_d^{'} X_1)^{-1} X_1^{'} W_d \Phi_d^{-1} W_d^{'} \delta \tag{C.2}$$

and

$$\gamma = (Q^{'} W_s \Phi_s^{-1} W_s^{'} X_1)^{-1} X_1^{'} W_s \Phi_s^{-1} W_s^{'} Y \tag{C.3}$$

where X_1 is a matrix of regressors in the demand model (p_{jt} and x_{jt}), W_d is a matrix of demand instruments, Q is the matrix of cost shifters in the supply equation, Y is the markup on the supply side and W_s is a matrix of supply instruments. For a given guess of parameters σ_0 and Σ_0, the vector of the mean utilities δ_0 can be recovered by using the contraction mapping method (Berry (1994), Berry et al. (1995) and Nevo (2000)).

$$\delta_{.t}^{h+1} = \delta_{.t}^{h} + \ln S_{.t} - \ln \widehat{S_{.t}}(\delta_{.t}, \sigma, \Sigma) \tag{C.4}$$

where $S_{.t}$ is the observed market share and $\widehat{S_{.t}}$ is the predicted market share. I solve for the mean utilities δ_0 that set the predicted market shares equal to the observed market shares. With δ_0 solved, I can recover the associated values of α_0 and β_0 by using equation (C.2), and compute the corresponding vector for product markups and recover the associate γ_0 by using equation (C.3). In other words, the objective function becomes

$$\min_{\sigma,\Sigma} \quad \eta^{'} W \Phi^{-1} W^{'} \eta \tag{C.5}$$

Once the optimal taste parameters $\hat{\sigma}$ and $\hat{\Sigma}$ are found, the associated parameters $\hat{\alpha}$ and $\hat{\beta}$ can be recovered.

Appendix D: Alternative Simulation Results

Table D1 - Table D12 report the simulation results based on parameters estimated by the structural model which uses BLP instruments and government subsides as IVs. Table D13 - Table D24 report the simulation results based on parameters estimated by the structural model which uses BLP instruments and Hausman instrument as IVs.

Table D1: Demand response in simulation I

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	52,000	82,790	29,790	57.3%
	Renesola	487	596	109	22.3%
	Suntech Power	6,381	7,290	910	14.3%
	Trina Solar	53,100	75,560	22,461	42.3%
	Yingli Green Energy	10,893	15,815	4,921	45.2%
USA	SunPower	106,655	106,425	-230	-0.2%
	REC Solar	25,502	25,421	-81	-0.3%
South Korea	Hanwha Q CELLS	1,042	1,041	-1	-0.1%
Subtotal		256,060	313,941	57,881	22.6%
All markets		826,001	1,012,712	186,712	22.6%

Note: This table reports the demand change for the counterfactual simulation scenario I, when anti-dumping duty rates are set to zero and subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D2: Welfare effect for simulation I

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	91.07	293.79
Δ US Manufacturers	-0.67	-2.15
Δ China Manufacturers	107.43	346.56
Δ Installers	105.63	340.76
B. Environmental Benefit		
ΔReduced CO2 Emission (tons)	1,278,148	4,123,057
ΔReduced External Cost ($ Million)	21.19	68.35
ΔTotal Environmental Benefit ($ Million)	43.78	141.21

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario I, when anti-dumping duty rates are set to zero.

Table D3: Demand response in simulation II

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	52,000	69,378	17,378	33.4%
	Renesola	488	518	30	6.2%
	Suntech Power	6,381	6,850	470	7.4%
	Trina Solar	53,100	61,729	8,629	16.3%
	Yingli Green Energy	10,893	13,587	2,694	24.7%
USA	SunPower	106,655	106,533	-121	-0.1%
	REC Solar	25,502	25,467	-35	-0.1%
South Korea	Hanwha Q CELLS	1,042	1,041	-1	-0.1%
Subtotal		256,060	285,105	29,045	11.3%
All markets		826,001	919,693	93,692	11.3%

Note: This table reports the demand change for the counterfactual simulation scenario II, when the anti-dumping duty rates are set to be zero and China's subsidy rates are set to be equal to that of US. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D4: Welfare effect for simulation II

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	46.26	149.22
Δ US Manufacturers	-0.32	-1.02
Δ China Manufacturers	53.04	171.09
Δ Installers	52.16	168.25
B. Environmental Benefit		
ΔReduced CO2 Emission	641,375	2,068,952
ΔReduced External Cost	10.63	34.30
ΔTotal Environmental Benefit	21.97	70.86

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario II, when China's subsidy rates are set to be equal to that of US.

Table D5: Demand response in simulation III

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	52,000	81,744	29,744	57.2%
	Renesola	488	596	109	22.3%
	Suntech Power	6,381	7,281	901	14.1%
	Trina Solar	53,100	75,502	22,402	42.2%
	Yingli Green Energy	10,893	15,814	4,921	45.2%
USA	SunPower	106,655	119,738	13,083	12.3%
	REC Solar	25,502	27,937	2,434	9.5%
South Korea	Hanwha Q CELLS	1,042	1,041	-1	-0.1%
Subtotal		256,060	329,655	73,594	28.7%
All markets		826,000	1,063,401	237,401	28.7%

Note: This table reports the demand change for the counterfactual simulation scenario III, when the anti-dumping duty rates are set to zero and US subsidy rates are set to be equal to that of China. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D6: Welfare effect for simulation III

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	114.02	367.82
Δ US Manufacturers	27.98	90.26
Δ China Manufacturers	107.22	345.86
Δ Installers	133.03	429.11
Δ US Subsidies	62.74	202.39
B. Environmental Benefit		
ΔReduced CO2 Emission	1,625,147	5,242,409
ΔReduced External Cost	26.94	86.91
ΔTotal Environmental Benefit	55.66	179.55

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario III, when US subsidy rates on solar manufacturing are set to be equal to that of China.

Table D7: Demand response for simulation IV

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	52,000	68,620	16,620	32.0%
	Renesola	488	513	26	5.3%
	Suntech Power	6,381	6,779	398	6.2%
	Trina Solar	53,100	61,037	7,937	14.9%
	Yingli Green Energy	10,893	13,407	2,514	23.1%
USA	SunPower	106,655	106,539	-115	-0.1%
	REC Solar	25,502	25,469	-33	-0.1%
South Korea	Hanwha Q CELLS	1,042	1,041	-1	-0.1%
Subtotal		256,060	283,406	27,345	10.7%
All markets		826,001	914,213	88,212	10.7%

Note: This table reports the demand change for the counterfactual simulation scenario IV, when the anti-dumping duty and China's subsidy rates are set to zero, while US subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D8: Welfare effect for simulation IV

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	43.49	140.28
Δ US Manufacturers	-0.30	-0.96
Δ China Manufacturers	49.93	161.06
Δ Installers	49.11	158.40
B. Environmental Benefit		
ΔReduced CO2 Emission	603,866	1,947,953
ΔReduced External Cost	10.01	32.29
ΔTotal Environmental Benefit	20.68	66.72

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario IV, when the anti-dumping duties and China's subsidy rates are set to zero, while US subsidy rates remain unchanged.

Table D9: Demand response for simulation V

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	52,000	81.794	29,794	57.3%
	Renesola	487	596	108	22.3%
	Suntech Power	6,380	7,291	910	14.3%
	Trina Solar	53,100	75,566	22,465	42.3%
	Yingli Green Energy	10,893	15,815	4,922	45.2%
USA	SunPower	106,655	105,374	-1,281	-1.2%
	REC Solar	25,502	25,220	-282	-1.1%
South Korea	Hanwha Q CELLS	1,042	1,041	-1	-0.1%
Subtotal		256,060	312,698	56,638	22.1%
All markets		826,000	1,008,702	182,702	22.1%

Note: This table reports the demand change for the counterfactual simulation scenario V, when the anti-dumping duty and US subsidy rates are set to zero, while China's subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D10: Welfare effect for simulation V

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	89.26	287.93
Δ US Manufacturers	-2.92	-9.41
Δ China Manufacturers	107.45	346.61
Δ Installers	103.48	333.79
B. Environmental Benefit		
ΔReduced CO2 Emission	1,250,699	4,034,512
ΔReduced External Cost	20.73	66.88
ΔTotal Environmental Benefit	42.84	138.18

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario V, when the anti-dumping duties and US subsidy rates are set to zero, while China's subsidy rates remain unchanged.

Table D11: Demand response in simulation VI

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	52,000	68,623	16,623	32.0%
	Renesola	488	513	26	5.3%
	Suntech Power	6,381	6,779	399	6.2%
	Trina Solar	53,100	61,041	7,941	15.0%
	Yingli Green Energy	10,893	13,407	2,514	23.1%
USA	SunPower	106,655	105,488	-1,167	-1.1%
	REC Solar	25,502	25,268	-234	-0.9%
South Korea	Hanwha Q CELLS	1,042	1,041	-1	-0.1%
Subtotal		256,060	282,162	26,101	10.2%
All markets		826,000	910,200	84,200	10.2%

Note: This table reports the demand change for the counterfactual simulation scenario VI, when the anti-dumping duty, China and US subsidy rates are all set to zero. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D12: Welfare effect for simulation VI

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	41.66	134.40
Δ US Manufacturers	-2.55	-8.23
Δ China Manufacturers	49.94	161.11
Δ Installers	46.96	161.11
B. Environmental Benefit		
ΔReduced CO2 Emission	576,396	1,859,342
ΔReduced External Cost	9.56	30.82
ΔTotal Environmental Benefit	19.74	63.68

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario VI, when the anti-dumping duties, China and US subsidy rates are all set to zero.

Table D13: Demand response in simulation I

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	45,760	81,661	35,901	78.5%
	Renesola	472	597	125	26.6%
	Suntech Power	6,176	7,286	1,110	18.0%
	Trina Solar	47,593	75,229	27,636	58.1%
	Yingli Green Energy	9,923	15,805	5,882	59.3%
USA	SunPower	106,264	106,231	-33	-0.03%
	REC Solar	25,453	25,370	-82	-0.3%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		242,679	313,219	70,539	29.1%
All markets		782,836	1,010,382	227,545	29.1%

Note: This table reports the demand change for the counterfactual simulation scenario I, when anti-dumping duty rates are set to zero and subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D14: Welfare effect for simulation I

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	89.61	289.08
Δ US Manufacturers	-0.24	-0.76
Δ China Manufacturers	100.35	323.70
Δ Installers	98.39	317.37
B. Environmental Benefit		
ΔReduced CO2 Emission (tons)	1,557,675	5,024,759
ΔReduced External Cost ($ Million)	25.82	83.30
ΔTotal Environmental Benefit ($ Million)	53.35	172.10

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario I, when anti-dumping duty rates are set to zero.

Table D15: Demand response in simulation II

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	45,760	66,104	20,344	44.5%
	Renesola	472	501	29	6.2%
	Suntech Power	6,176	6,740	564	9.1%
	Trina Solar	47,593	57,906	10,313	21.7%
	Yingli Green Energy	9,923	13,049	3,126	31.5%
USA	SunPower	106,264	106,245	-19	-0.02%
	REC Solar	25,453	25,419	-33	-0.1%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		242,679	277,003	34,324	14.1%
All markets		782,837	893,560	110,723	14.1%

Note: This table reports the demand change for the counterfactual simulation scenario II, when the anti-dumping duty rates are set to be zero and China's subsidy rates are set to be equal to that of US. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D16: Welfare effect for simulation II

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	44.12	142.31
Δ US Manufacturers	-0.10	-0.31
Δ China Manufacturers	48.13	155.26
Δ Installers	47.25	152.43
B. Environmental Benefit		
ΔReduced CO2 Emission	757,965	2,445,048
ΔReduced External Cost	12.57	40.53
ΔTotal Environmental Benefit	25.96	83.74

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario II, when China's subsidy rates are set to be equal to that of US.

Table D17: Demand response in simulation III

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	45,760	81,646	35,886	78.4%
	Renesola	472	597	125	26.6%
	Suntech Power	6,176	7,283	1,107	17.9%
	Trina Solar	47,593	75,185	27,592	58.0%
	Yingli Green Energy	9,923	15,804	5,882	59.3%
USA	SunPower	106,264	123,562	17,298	16.3%
	REC Solar	25,453	28,720	3,267	12.8%
South Korea	Hanwha Q CELLS	1040	1039	-1	-0.1%
Subtotal		242,679	333,838	91,159	37.6%
All markets		782,837	1,076,897	294,060	37.6%

Note: This table reports the demand change for the counterfactual simulation scenario III, when the anti-dumping duty rates are set to zero and US subsidy rates are set to be equal to that of China. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D18: Welfare effect for simulation III

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	113.99	367.72
Δ US Manufacturers	28.34	91.41
Δ China Manufacturers	100.25	323.388
Δ Installers	126.16	406.98
Δ US Subsidies	64.83	209.13
B. Environmental Benefit		
ΔReduced CO2 Emission	2,013,009	6,493,578
ΔReduced External Cost	33.37	107.65
ΔTotal Environmental Benefit	68.94	222.40

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario III, when US subsidy rates on solar manufacturing are set to be equal to that of China.

Table D19: Demand response for simulation IV

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	45,760	65,177	19,417	42.4%
	Renesola	472	496	24	5.1%
	Suntech Power	6,176	6,652	475	7.7%
	Trina Solar	47,593	57,064	9,471	19.9%
	Yingli Green Energy	9,923	12,831	2,908	29.3%
USA	SunPower	106,264	106,246	-18	-0.02%
	REC Solar	25,453	25,421	-31	-0.1%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		242,679	274,927	32,247	13.3%
All markets		782,837	886,860	104,023	13.3%

Note: This table reports the demand change for the counterfactual simulation scenario IV, when the anti-dumping duty and China's subsidy rates are set to zero, while US subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D20: Welfare effect for simulation IV

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	41.38	133.48
Δ US Manufacturers	-0.09	-0.29
Δ China Manufacturers	45.21	145.84
Δ Installers	44.39	143.18
B. Environmental Benefit		
ΔReduced CO2 Emission	712,096	2,297,084
ΔReduced External Cost	11.81	38.08
ΔTotal Environmental Benefit	24.39	78.67

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario IV, when the anti-dumping duties and China's subsidy rates are set to zero, while US subsidy rates remain unchanged.

Table D21: Demand response for simulation V

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	45,760	81,661	35,901	78.5%
	Renesola	472	597	125	26.6%
	Suntech Power	6,176	7,287	1,111	18.0%
	Trina Solar	47,593	75,232	27,639	58.1%
	Yingli Green Energy	9,923	15,805	5,882	59.3%
USA	SunPower	106,264	104,888	-1,376	-1.3%
	REC Solar	25,453	25,107	-346	-1.4%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		242,679	311,616	68,937	28.4%
All markets		782836	1,005,214	222,378	28.4%

Note: This table reports the demand change for the counterfactual simulation scenario V, when the anti-dumping duty and US subsidy rates are set to zero, while China's subsidy rates remain unchanged. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D22: Welfare effect for simulation V

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	87.72	282.97
Δ US Manufacturers	-2.44	-7.88
Δ China Manufacturers	100.36	323.73
Δ Installers	96.23	310.43
B. Environmental Benefit		
ΔReduced CO2 Emission	1,522,303	4,910,657
ΔReduced External Cost	25.24	81.41
ΔTotal Environmental Benefit	52.14	168.19

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario V, when the anti-dumping duties and US subsidy rates are set to zero, while China's subsidy rates remain unchanged.

Table D23: Demand response in simulation VI

Origin Country	Manufacturer	Baseline (kW)	Simulated (kW)	Demand Change	Percent
China	Canadian Solar	45,760	65,178	19,418	42.4%
	Renesola	472	496	23	5.1%
	Suntech Power	6,176	6,652	476	7.7%
	Trina Solar	47,593	57,067	9,474	19.9%
	Yingli Green Energy	9,923	12,831	2,908	29.3%
USA	SunPower	106,264	104,903	-1,361	-1.3%
	REC Solar	25,453	25,158	-294	-1.2%
South Korea	Hanwha Q CELLS	1,040	1,039	-1	-0.1%
Subtotal		242,679	273,324	30,645	12.6%
All markets		782,837	881,691	98,854	12.6%

Note: This table reports the demand change for the counterfactual simulation scenario VI, when the anti-dumping duty, China and US subsidy rates are all set to zero. The column Baseline represents the simulated demand for solar panels when the anti-dumping policy is in place.

Table D24: Welfare effect for simulation VI

Items	MSA markets in my sample	All MSA markets
A. Welfare (2015$ Million)		
Δ CS	39.48	127.37
Δ US Manufacturers	-2.30	-7.42
Δ China Manufacturers	45.22	145.86
Δ Installers	42.24	136.26
B. Environmental Benefit		
ΔReduced CO2 Emission	676,715	2,182,952
ΔReduced External Cost	11.22	36.19
ΔTotal Environmental Benefit	23.18	74.77

Note: This table reports the welfare changes for US consumer, US manufacturers, US installers and Chinese manufacturers in simulated scenario VI, when the anti-dumping duties, China and US subsidy rates are all set to zero.

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