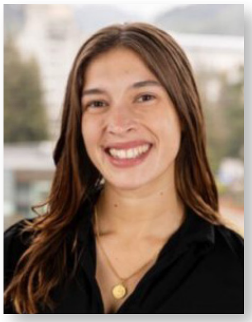

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Does Manufacturing Matter?

FORWARD LINKAGES AND DOWNSTREAM GROWTH IN THE MALAYSIAN SOLAR INDUSTRY

ISHANA RATAN

ABSTRACT

In light of rapidly rising climate change threat, emerging economies are vying to build a domestic solar industry across the value chain. Scholars argue that industrial policy that targets manufacturing and learning from foreign direct investment (FDI) creates forward linkages in downstream segments of the supply chain in emerging economies. Amidst the US-China trade war, China rerouted solar manufacturing to Malaysia, Vietnam, Thailand and Cambodia to avoid United States and European Union tariffs. Does this new manufacturing relocation lead to more installation among local countries that receive upstream FDI? Drawing upon bilateral solar panel trade data, interviews with local Malaysian firms and descriptive evidence on patterns of Malaysian solar installation, I find that Chinese production relocation had no effect on local solar installation. Rather, exports from mainland China fueled solar technology cost reductions to Malaysian firms, while Chinese panels manufactured in Malaysia are typically destined for export to Western countries. Indeed, even while Malaysia hosts American, Japanese, and South Korean manufacturers, the vast majority of panels are imported from China. Further, Chinese manufacturers in Malaysia profit more from exporting to the United States rather than selling to locals, so panels

produced in Malaysia are not consumed in the local market. This calls into question existing industrial policy scholarship that emphasizes the localization of production for downstream market growth and indicates that escalating global trade tensions can lead to inefficient externalities that do little to benefit local markets through technology transfer.

Keywords: climate change, global value chains, industrial policy, international trade, foreign direct investment, renewable energy

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INTRODUCTION

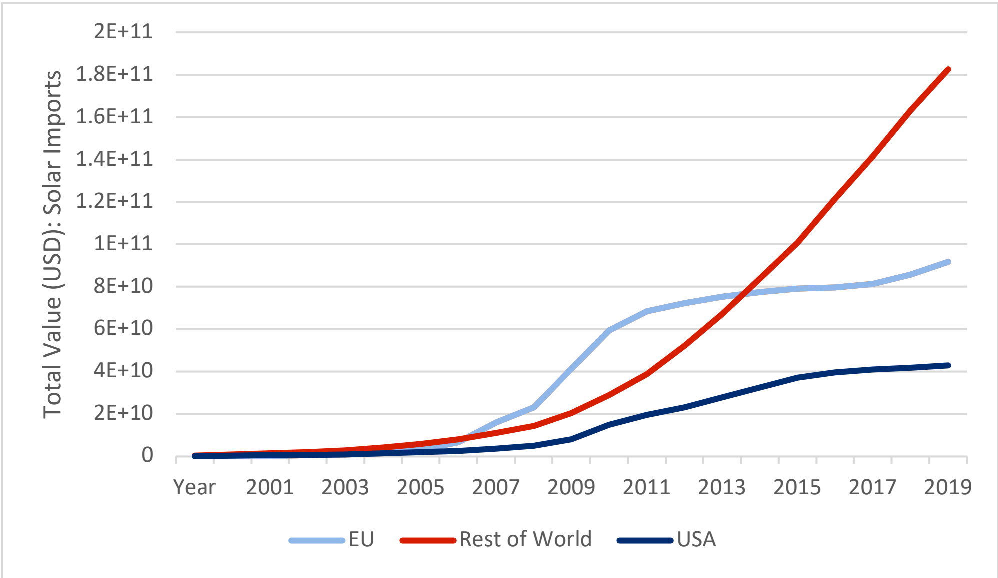
Tariffs on Chinese exports to the United States and European Union, have reshaped global supply chains across a variety of critical industries from washing machines, steel to semiconductors and solar panels (Fajgelbaum and Khandelwal 2021). The latter, solar panels, are an essential component of the global energy transition. As the US and EU have escalated tariffs on the import of solar modules from China beginning in 2012 and 2013 respectively, Chinese firms have rearranged supply chains to manage the new transaction costs of old trade partners (Bradsher 2014; Ball et al. 2017). While significant attention has been drawn to the impacts of tariffs on the energy transitions in the US, EU and China, these trade disputes also reshape solar value chains for often-overlooked middle-income countries caught in the crossfire of international competition (Yean Tham, Yi, and Ann 2019; Andres 2022; Houde and Wang 2022).

In particular, tariffs on solar imports led Chinese firms to offshore and scale up existing solar panel manufacturing in Malaysia, Thailand, Cambodia and Vietnam to circumvent antidumping (AD) duties (Ball et al. 2017). These four countries, currently under investigation by the US Department of Commerce for a new round of anti-circumvention tariffs received an inflow of Chinese manufacturing investment and scale-up of local solar production, albeit managed by Chinese firms seeking to reroute a large portion of trade to the US (Wong, Singh, and Casey 2022; Jackson, Lewis, and Zhang 2021). A growing literature on global value chains contends that foreign manufacturing investment can create spillovers in downstream segments of the supply chain by reducing the material costs of inputs and transaction costs of procurement for domestic firms (Javorcik and Spatareanu 2005b; Blalock and Gertler 2008). This working paper seeks to evaluate the degree to which Chinese production localization shaped local solar markets through a combination of regression analysis and a qualitative case study of the Malaysian solar industry. Contrary to scholarship which emphasizes the localization of manufacturing for technology transfer (Jackson, Lewis, and Zhang 2021), I find that cost reductions to solar project owners in Malaysia occurred not through manufacturing localization, but by importing panels from mainland China itself.

Through a combination of regression analysis, firm level descriptive statistics and interviews with Malaysian solar firms, I show that manufacturing production relocation, in and of itself, had little impact on the local market for solar panels or installed solar capacity. To begin, I introduce literature that emphasizes the potential impacts of foreign manufacturing investment on the local solar industry in a host country. I complement this local linkage argument with an alternative account emphasizing the role of global supply chains in shaping trade patterns. I propose that the unique circumstances surrounding Chinese production relocation - namely avoiding Western tariffs - complicate the likelihood of forward linkages to local suppliers.

First, I show that while countries with an AD decreased solar module imports from mainland China, the rest of the world imported more Chinese products - countries like Malaysia found a new, low-cost source of solar panel supply. Figure 1 illustrates this trend, plotting total value of solar from China imports to the EU, US and rest of world over time. While the EU and US taper their share of Chinese exports after tariffs (2012 and 2013, respectively, per the color-corresponding lines), imports elsewhere soared.

Figure 1: Solar Module Imports from China, 2000-2019



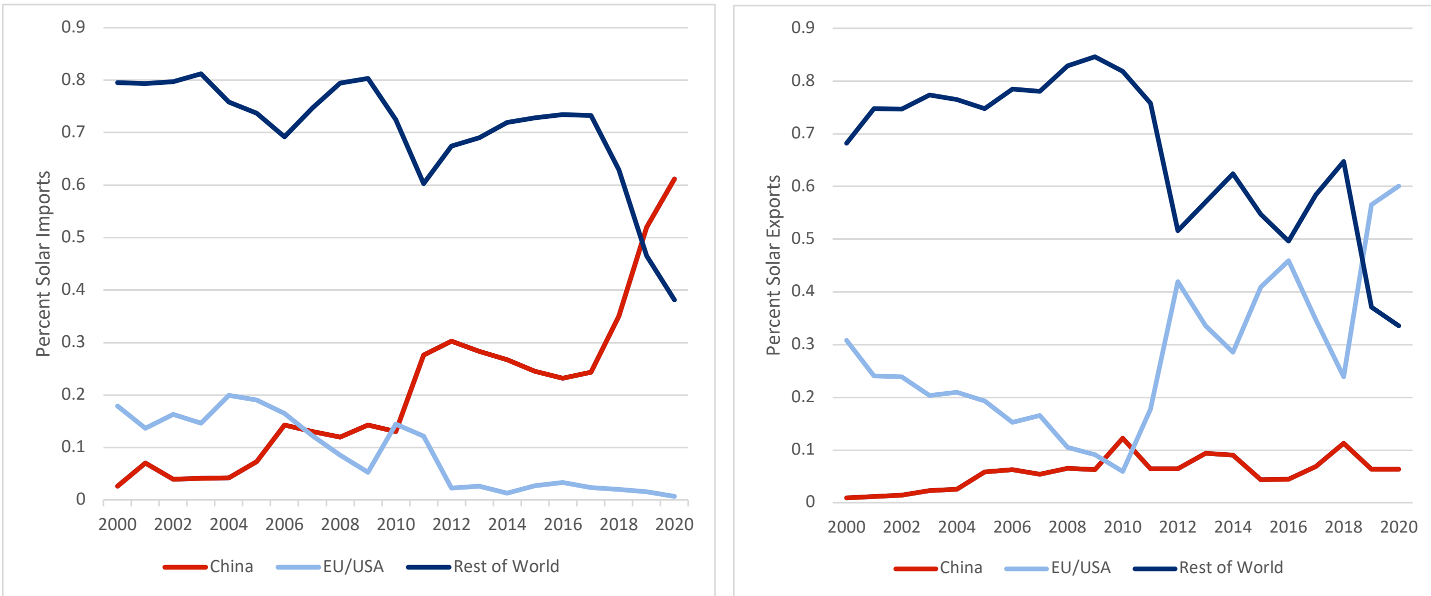
Source: United Nations Comtrade (2023).

Second, exports from the four Southeast Asian countries (Malaysia, Thailand, Cambodia and Vietnam), now destinations under investigation by the US Department of Commerce for tariff circumvention, increased to countries with active AD duties, namely the US and EU. Simply put, panels manufactured in Malaysia were exported to countries with tariffs against China, not purchased by local firms. While Malaysian firms did use Chinese panels, they were imported from China, rather than produced locally. Figures 2A and 2B show that solar imports from China did increase to these four Southeast Asian countries, yet so did exports from these states to the US and EU, consistent with a strategy of tariff circumvention.[1]

I supplement this statistical analysis with interviews from 12 Malaysian solar companies (15 individuals) and firm-level descriptive evidence. Interviews confirm that local firms in Malaysia imported solar directly from mainland China after the imposition of tariffs, while Malaysian produced (Chinese-owned) solar was exported to the US and EU, rather than being utilized by other Malaysian firms in the domestic market. Taken together, these results indicate that global declines in the cost of solar technology, perhaps even fueled by tariffs, allowed Malaysia to import low-cost modules and leave costly German suppliers behind, rather than some localized benefit from Chinese production facilities to Malaysia. In contrast, manufacturing factories in mainland China, facing a lower profit from exporting to the US and EU, increased exports to countries like Malaysia. Prior to the imposition

[1] Despite lack of export data from Chinese manufacturers themselves, it is plausible that the large uptick in Southeast Asian exports to countries with tariffs on China is not purely coincidental given the complementary qualitative evidence.

Figure 2: Imports (left) and Exports (right) of Solar Modules to/from Southeast Asian States, 2000-2018



Source: United Nations Comtrade (2023).

of tariffs on China, the US and EU were top export destinations for Chinese solar panels. Yet, after the imposition of tariffs in 2012 and 2013, respectively, Chinese import value stalled to Western markets, while continuing to rise in the rest of the world. Overall, the vast majority of local solar project owners imported panels directly from China, and indeed benefitted significantly from cost declines - though not due to localized production spillover.

SOLAR INDUSTRY SUPPLY CHAIN FRAGMENTATION

Chinese industrial policy and subsequent oversupply upended global supply chains for solar modules, with unintended consequences for middle-income countries caught between the US-China geopolitical rivalry. Successful Chinese production subsidization led to a massive increase in the quantity of solar panels available on the global market, deeply undercutting higher cost production in the US and Europe (Zhang and Gallagher 2016). Between 2005-2008, Chinese manufacturing expansion was fueled by local production incentives and early demand-side measures (Zhi et al. 2014). Local governments offered land incentives, tax breaks and accelerated permitting processes, particularly localities with rapidly rising energy demand and existing glass and metal manufacturers well positioned to enter the solar industry (Nahm 2017; Corwin and Johnson 2019.)

Throughout the implementation of both national and local industrial policies, new Chinese manufacturing leaders made their initial public offerings (IPO) in the global marketplace: Suntech (2005), Trina (2006) and Yingli, JA Solar and China Sunergy (2007) (Fu and Zhang 2011; Zhang and Gallagher 2016). In addition to industrial policy, the 2008 global financial crisis solidified the lead of the largest Chinese solar module manufacturers, which received supportive finance from the China Development Bank (CDB), a Chinese development finance institution, which in this case supported solar manufacturing export growth (Andrews-Speed et al. 2013; Nahm 2023). While the Chinese government cut subsidies to smaller firms with low production capacity, the largest national champions received concessional CDB finance during the crisis (Zhi et al. 2014). On the other hand, German and American competitors struggled in the face of falling global demand and limited national government support.

The rapid expansion of Chinese manufacturing capacity, supported both by state finance and bottom-up industrial policy, eroded profits for American and European solar manufacturers struggling to match low-cost Chinese exports (Ball et al. 2017). Tariffs from the US were first enacted in 2012, followed by the EU in 2013 (Goldenberg 2012; Halper and Stein 2022). This first round of trade barriers was followed by subsequent 2014 tariffs initiated by Solar World Americas, which doubled the import price of solar panels from China to the US. In response to these first tariffs, Chinese solar manufacturers invested and scaled up manufacturing facilities in Malaysia, Thailand, Cambodia and Vietnam.

Under certain conditions, namely sufficient human and technological capital to integrate foreign technology, foreign manufacturing investment can lead to forward linkages and growth in local industries (Xu 2000; Blanton and Blanton 2007). Foreign investment can convey significant positive externalities to developing countries, including higher local wages (Lipsey and Sjöholm 2004; Feenstra and Hanson 1995) and local firm productivity (Blomström and Persson 1983; Javorcik 2004; Helpman 2006; Havranek and Irsova 2011). As the most productive firms from their respective countries of origin, multinational corporations (MNCs) can bring skills, technology, and production standards to developing countries in which they operate (Greenhill, Mosley, and Prakash 2009; Malesky and Mosley 2018).

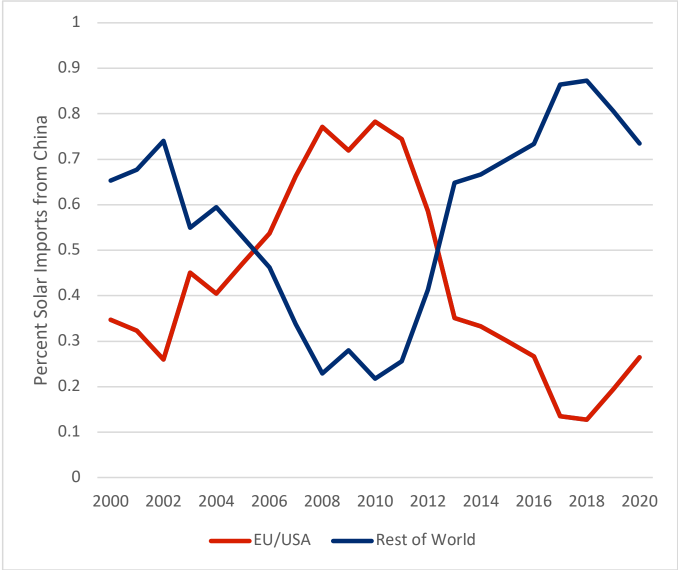
Where foreign firms form 'forward linkages' with domestic firms, locals face both lower costs of material inputs and can learn from foreign firms' expertise (Blalock and Gertler 2008; Havranek and Irsova 2011; Javorcik and Spatareanu 2005a). Beyond the direct cost of inputs and transaction costs of procurement, foreign firms can convey substantive knowledge about best practices to local firms and workers (Borensztein, Gregorio, and Lee 1998; Hanushek and Kimko 2000). One pathway by which these linkages form is through the spatial proximity of manufacturing firms to local solar installers. The transaction costs of procurement may be lowest for domestic firms most proximate to manufacturing facilities, which can more easily learn about and secure contracts with upstream suppliers (Saggi 2002). I propose that (1) these demonstration effects may allow local firms located near Chinese manufacturers to acquire products at a lower cost than far-away competitors due to locals' relatively high exposure to foreign partners.

> ***Hypothesis 1:*** *In Malaysia, areas near foreign solar manufacturing facilities install more solar than areas far away from foreign solar manufacturing.*

Beyond localized impacts for Malaysian solar project owners, tariffs from the US and EU caused broader shifts in global production chains. Chinese investors modified their production strategy by shifting (1) exports from Western partners to emerging markets without trade barriers and (2) increasing their solar cell and module production in Southeast Asia to export modules manufactured in these countries on to countries with tariff barriers. First, imports from mainland China tapered off among countries with AD duties. Sales to the US became less profitable with new tariffs, while imports from China continued rising to the rest of the world. The US and EU originally comprised 78.2 percent of China's total solar exports in 2010, but by 2015 accounted for a mere 29.9 percent of solar panels that the world imported from China, as shown by Figure 3 (UN Comtrade 2023; Author's calculation).

To offset these losses in the American and European markets among factories in mainland China, Chinese manufacturers shifted solar cell and module manufacturing facilities to nearby Southeast Asian countries, diverting production through these locations as strategy to circumvent US and EU tariffs (Wong, Singh, and Casey 2022). Figure 4 shows how the average fraction of solar imports

Figure 3: Percentage of Chinese Solar Imports to US and EU versus Rest of World

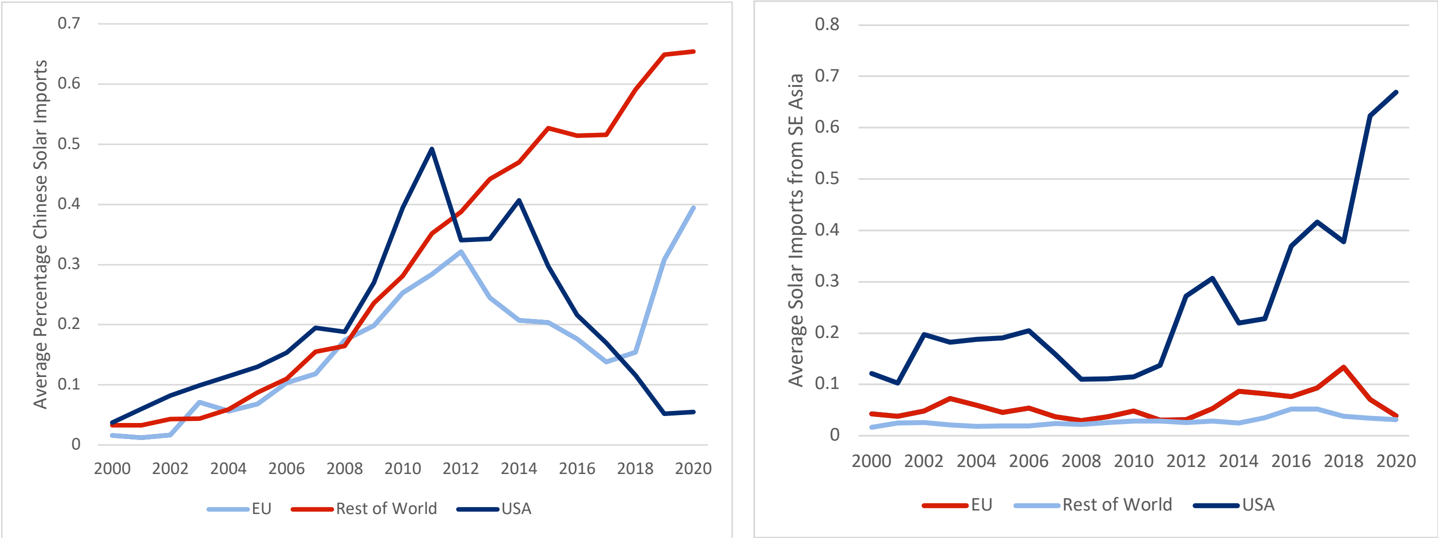


Source: United Nations Comtrade (2023); Author's calculation.

from China declined precipitously for the US and EU after tariff imposition, while rising steadily for the rest of the world (Figure 4A), while for the US in particular, imports from Southeast Asia rose rapidly following tariff imposition (Figure 4B).

I propose that (2) AD-imposing countries imported a lower percentage of solar panels from China in comparison to countries that did not impose AD duties and (3) AD imposing countries import a greater percentage of solar panels from Southeast Asia, due to solar manufacturers' tariff circumvention-motivated production relocation. Taken together, these hypotheses propose an alternative

Figure 4: Average Percentage of Solar Imports from China (left) and Southeast Asia (right)



Source: United Nations Comtrade (2023) narrative to the localization of production. Practically speaking, Malaysia did experience cost reductions, but not through local linkages from new foreign manufacturers.

> ***Hypothesis 2:*** *Countries with an AD duty against China import significantly less solar from China than countries without AD duties.*

> ***Hypothesis 3:*** *Countries with an AD duty against China import significantly more solar from Southeast Asia than countries without an AD duty against China.*

CASE STUDY: SOLAR MANUFACTURING AND INVESTMENT IN MALAYSIA

This section provides a history of solar manufacturing and investment in the case of Malaysia, which received an unexpected influx of Chinese solar manufacturing investment following escalation of US and EU tariffs. I focus on the Malaysian case due to its importance as a country caught in the crossfire of the US-China trade dispute and richness of data on domestic household and firm-level solar installation under specific policy initiatives: the Feed in Tariff (2011-2018), and three large scale auction rounds (2017-2018, 2019-2020, 2021).[2] This Malaysian government data, in conjunction with interviews with 12 firms (14 individuals) conducted in the spring of 2023, allows me to evaluate the procurement patterns of local solar firms and rule out the forward linkage argument (Hypothesis 1). I first provide background on Chinese manufacturing relocation to Malaysia before detailing the procurement choices of Malaysian solar project owners based on qualitative interviews.

Solar manufacturing in Malaysia

Solar supply chain fragmentation during the US-China trade war set the stage for Chinese solar manufacturing investment in Malaysia. Chinese firms specifically offshored manufacturing capacity to Malaysia following European quota impositions in December 2013 and in 2014, a sharp increase in US tariffs from 26.71 to 78.42 percent on solar cells and 27.64 percent to 49.79 for modules (Bradsher 2014; Cardwell 2014; Commission 2013). JA Solar, JinkoSolar and LONGi all shifted production facilities to Malaysia in 2015, with JA and JinkoSolar located in Pinang, and LONGi in Sarawak. These three facilities accounted for over one-third of total Malaysian solar exports in facility capacity (i.e., number of production lines) at the time of construction — though in output, they likely account for a greater share of production.[3] Other firms also sought Malaysia as a manufacturing destination to avoid European quotas. South Korean Hanwha Q-Cells located their manufacturing facility in Selangor, near the capital of Kuala Lumpur, and Panasonic from Japan invested in the industrial area surrounding inland Ipoh (Achu and Yvonne 2016; Colville 2017).

The fact that all Chinese solar manufacturing facilities in Malaysia are in Special Economic Zones (SEZs) indicates limited impact. As Chinese investment leads in global development finance, a growing body of literature assesses the degree to which Chinese investments and the structure of business interactions legitimately convey positive externalities to local markets (Chen 2019; Springer, Evans, and Teng 2021; Tang 2022). In particular, SEZs were intended to serve as vehicles for development, creating enclaves to both entice foreign firms and mediate technology transfer to locals(Alkon 2018). However, research finds mixed evidence for their efficacy in achieving positive developmental outcomes in practice (Brautigam, Farole, and Xiaoyang 2010; Bräutigam and Xiaoyang 2011). While manufacturing may facilitate downstream market growth via lower component

[2] This data is also *complete*; other proprietary sources of data like the World Electric Power Plant data base do not include residential solar installation and have high missingness among small projects under 1 megawatt (MW).

[3] Chinese panels have shorter manufacturing and turnaround times than the specialized, and more labor/time intensive Japanese and American counterparts.

costs and the availability of foreign expertise, the fact that solar manufacturing facilities were located in SEZs is an early indicator that solar panels were not destined for local consumption.

However, it is possible that other manufacturers were better positioned to convey positive externalities to the Malaysian market, given that Chinese firms were not the only players in Malaysian solar manufacturing. Two American firms, First Solar and Sun Power, constructed manufacturing facilities in Malaysia prior to 2011, while South Korea and Japan each have one manufacturing facility, respectively. Yet, spillover to the Malaysian market is unlikely for these other foreign producers due to technological characteristics. Both American firms have niches in upscale solar components, producing high efficiency but higher-cost panels destined for US and European markets. Arizona-based First Solar produces thin film Cadmium Telluride (CadTel) panels, at the cutting edge of industry innovation, while California-based SunPower specializes in high efficiency monocrystalline panels (Bradsher 2014). Both of these products sell at a premium relative to low-cost Chinese polysilicon photovoltaic panels and are likely unaffordable for domestic investors.

The two other manufacturing facilities in Malaysia are owned by Korean Hanwha and Japanese Panasonic, both large industrial conglomerates. Panasonic's manufacturing facility is in Kulim Hi-Tech Industrial Park in the central district of Kedah, but the company has operated in Malaysia since 1976, indicating a high level of local market integration and familiarity. In a 2016 interview, the Panasonic Malaysian Managing Director Cheng Chee Chung stated that the "internal mission here in Panasonic Malaysia is to enrich the lives of Malaysian families by promoting eco, healthy and comfortable lifestyles" (Hamid and Achu 2016). However, Panasonic's market share has declined, and it shuttered the Malaysian facility in 2022 (Hall 2022). In the last five years of Panasonic's Malaysian operations, share value fell by 39 percent; this contraction in growth may have complicated spillover to the local market, due to the contraction in operations and subsequent labor and learning opportunities for local firms (YahooNews 2022).

Hanwha Q-Cells, which began production in southern industrial hub Cyberjaya in 2015, has fared somewhat better despite price pressures from Chinese overproduction. Hanwha Q-Cells was borne out of a merger with German solar manufacturer Q-Cells, which was suffering under price pressure from Chinese manufacturing (Hanwha 2015). However, as a conglomerate, Hanwha leveraged its ability to internally source cell components, while Chinese solar module manufacturers must source components from external suppliers (Colville 2017). Hanwha also uses an advanced type of p-multi (multi-crystalline) PERC cell, relative to the Chinese p-mono (monocrystalline) PERC cells. This technical advantage allows Hanwha to produce a differentiated, slightly higher quality than Chinese competitors. That said, these cells are then marginally more expensive, and less accessible to local firms. From a technology-oriented perspective, Chinese manufacturers produce the lowest-complexity product at the lowest cost. While American and Asian investors have operated in the Malaysian solar market for a longer duration, interview evidence detailed next indicates that these other foreign suppliers were simply too "high cost" for local Malaysian firms relative to importing from mainland China.

Portrait of a Malaysian Solar Project Owner

When Chinese production relocated to Malaysia between 2014-2015, Malaysia was in the process of implementing a Feed in Tariff (FiT) (2011-2015) and Net Energy Metering (NEM) (2015-2018) (Joshi 2018). As solar manufacturing relocation occurred in the middle of solar subsidy implementation, Malaysia is an ideal case in which to examine whether manufacturing production positively impacted local solar installation. The FiT and NEM policies allowed firms to sell solar back to the grid, and were both limited to small scale projects (maximum of 5 megawatts in size) and firms with domestic holdings.[4] In this section, I leverage interviews with 12 firms (15 individuals) to develop a profile of the modal solar project owner in Malayisa, and their process of selecting component suppliers from the range of possible manufacturers. This complements a quantitative analysis of spatial solar installation in Malaysia in the following section.

The average Malaysian solar investor is a domestic firm, with operations in construction, electrical engineering, warehousing or manufacturing (Interview #3, May 30, 2023; Interview #4, May 31, 2023; Interview #9, June 22, 2023; Interview #12, July 8, 2023). These firms range from small firms operating in one industrial park to engineering, procurement, and construction (EPC) firms that work both in Malaysia and more recently in neighboring Asian countries like the Philippines and Thailand (Interview #5, May 31, 2023). As one interviewee put it, Malaysia has a particularly diverse solar ecosystem, with both large-scale projects the size of multiple football fields, and small scale projects generating energy for schools (Interview #9, June 22, 2023). However, even with this diversity in the type of solar investors and their respective size, interviewees unanimously suggest a single narrative in terms of how manufacturing matters for the cost of components.

Interviews with both large and small firms overwhelmingly suggest that solar project owners import panels directly from mainland China (Interview #1, May 15, 2023; Interview #2, May 16, 2023; Interview #3, May 30, 2023; Interview #4, May 31, 2023; Interview #6, June 6, 2023; Interview #7, June 7, 2023; Interview #10, June 26, 2023; Interview #11, July 4, 2023; Interview #12, July 7, 2023). Interviewing firms of all sizes, with two of the largest EPCs in Malaysia alongside a number of small- and medium-sized firms, allowed me to rule out the possibility that procurement strategy (i.e., importing from mainland China versus sourcing local panels) varies by firm size. However, multiple firms across size categories indicated the vast majority — 99 percent by one interviewee's estimate — of solar panels installed on Malaysian rooftops are imported from mainland China (Interview #1, May 15, 2023; Interview #3, May 30, 2023; Interview #4, May 31, 2023; Interview #6, June 6, 2023; Interview #7, June 7, 2023).

Chinese factories on the mainland profit more from selling to Malaysia, and the rest of the world, relative to the US and EU after the imposition of tariffs. Chinese firms producing in Malaysia, on the other hand, reap a higher profit from exporting solar back to the US instead of selling to locals (Interview #1, May 15, 2023; Interview #3, May 30, 2023; Interview #8, June 10, 2023). Despite the lack of localized production networks, interviewees do not report difficulty in accessing imported Chinese equipment. This is, perhaps, most surprising for small firms that do not have established connections to global solar component suppliers. Yet, even for smaller firms like warehouse owners and boutique construction companies, importing solar panels from mainland China is the most cost-effective solution (Interview #2, May 16, 2023; Interview #6, June 6, 2023). A large firm reports being contacted by Chinese suppliers in search of likely customers (Interview #1, May 15, 2023), while smaller companies work with EPCs that have connections outside of China and can easily source panels from abroad (Interview #2, May 16, 2023).

Since the Malaysian solar industry has a variety of both large and small domestic players, small firms can draw on the experience of their larger industry peers. Furthermore, other Malaysian-made solar panel alternatives cannot compete with imports from Chinese manufacturers. A representative from a medium-sized firm specifically noted that American, Japanese and South Korean panels manufactured in Malaysia are now relatively costly to Chinese imports, although in the early days of the market, South Korean cells were used for some local installations since Western or other Asian imports

[4] Under the FiT firms sold electricity produced back to the grid at a fixed above-market rate, while in the NEM 1.0-3.0 schemes, companies install solar for self-consumption and sale to the grid at the spot price. Policy design is not the focus of this paper, but to be precise, the FiT and NEM are different policies in their compensation structure. NEM provides lower returns and is most attractive to companies using high quantities of energy. Interview evidence indicates that while the NEM was less attractive in compensation, it was reasonably successful at generating local firm interest in solar energy.

were the only available options (Interview #2, May 16, 2023). Notably, no interviewees mentioned quality differentials between different suppliers.

China's impact on the global economy has made its mark on Malaysia not through production localization, but instead lowering the cost of components and allowing smaller firms to afford the high capital costs of clean technology. Two interviewees report capital costs as a constraint to expansion, with one medium-size firm noting that EPC has become a more profitable alternative to project ownership, as capital costs and upfront investment becomes exponentially prohibitive as project size increases (Interview #3, May 30, 2023; Interview #4 , May 31, 2023).

While solar firms in Malaysia have certainly benefitted from China's manufacturing scale up, barriers to widespread solar implementation remain. Three interviewees mentioned the potential for regional power trading networks among Association of Southeast Asian Nations (ASEAN) countries to open up new sources of demand for solar sales, given the national government recently reversed a ban on selling electricity across the border to Singapore (Ibid, Interview #6, June 6, 2023). Another noted financial gaps as a key area for improvement in order to boost market growth (Interview #5, May 31, 2023). While Chinese manufacturing overcapacity has allowed Malaysian firms to swap out costly German panels for low-cost alternatives (Interview #2, May 16, 2023; Interview #10, June 13, 2023), there is still room for domestic policymaking to support the local market, given, per the results of this working paper, few local linkages between upstream foreign suppliers and local firms.

RESEARCH DESIGN: MANUFACTURING AND SPATIAL SPILLOVER

The first component of the analysis evaluates whether areas near foreign manufacturing facilities benefit from lower costs of procurement, and in turn install a greater amount of solar than area further afield. The complementary analysis provides descriptive evidence as to whether the EU and US significantly decrease their imports of Chinese solar modules after the imposition of AD tariffs. With the same cross-national dataset from UN Comtrade, I also find descriptive support that Southeast Asian countries (Malaysia, Thailand, Vietnam and Cambodia) subject to the 2022 US Department of Commerce investigation increased exports to the United States and European Union after these Western states imposed AD duties on Chinese imports (Wong, Singh, and Casey 2022; UN Comtrade 2023).

First, I describe the measurement strategy for dependent and independent variables across the respective three analyses. Then, I introduce a regression to estimate the relationship between Malaysian solar installation and proximity to Chinese, American and other manufacturing facilities, finding no evidence that areas near manufacturers of any nationality experienced a disproportionate increase in solar investment — though solar installation did increase overall. Complementary results indicate a significant relationship between (1) a decrease in imports from China among countries that imposed AD duties and (2) these same AD duty countries increased imports from Southeast Asian states subject to the Department of Commerce probe. The qualitative and quantitative evidence suggest that cost savings to local Malaysian companies stem from Chinese production efficiencies, rather than local manufacturing relocation.

Variables

DEPENDENT VARIABLE The first analysis estimates the relationship between proximity to Chinese manufacturing and local solar installation and takes total solar installed (megawatts) in each of the 89 districts comprising Peninsula Malaysia as the dependent variable. This includes five of the eight total solar manufacturing facilities in Malaysia, excluding the LONGi and SundEdison plants in Sarawak.[5] The government dataset of project-level solar applications encompasses over 10,000 projects, with 611 firm-level installations and over 9,000 households; for this analysis, I subset to firms.

The dependent variable for the second and third analyses leverage imports data from UN Comtrade to calculate the annual value of solar imports from China, and Malaysia, Thailand, Cambodia and Vietnam (HS Code 854140). The first dependent variable measures the percent of solar imports from China as a fraction of total imports based on primary value (see Appendix Table A3-A4). The second replicates this measure, but with the fraction of solar imports from the four Southeast Asian states to which Chinese manufacturing was rerouted after the imposition of tariffs. I include an additional robustness check with share of Chinese imports based on quantity (Appendix Table A5-A6).[6]

INDEPENDENT VARIABLES The first analysis uses dummy variables taking the value of 1 if a solar manufacturer from a given country operates in a given district-year in Peninsular Malaysia and 0 otherwise. There are separate dummy variables for each manufacturer (Chinese, United States, Japan, South Korea), given each entered the market at a different date. Given the unit of analysis, I use raster data superimposed over the administrative level 2 boundaries of Malaysia to calculate control variables: population, gross domestic product, infant mortality and land area. This information is not readily available at the district level, so I use Python to calculate summary statistics for the aggregated overlay of kilometer raster shapefiles for the respective controls in 2011-2018 in lieu of available government data at this level of aggregation.

In the second two analyses, my primary independent variable is a binary indicator taking the value of 1 if a country has imposed an AD duty on Chinese imports in a given year, and 0 otherwise. I source data on AD duty imposition from Global Trade Alert, which notes the year of imposition and also removal, which is essential because the EU removed tariffs against Chinese solar imports in 2018 (Evenett 2009). I account for a battery of controls: democracy, gross domestic product, land area, fossil fuel consumption, electricity consumption, trade, foreign direct investment (World Bank 2023) political constraints (Henisz 2023) and corruption (PRS Group 2023), each lagged by one year.

Analysis 1: Manufacturing and Local Linkages

The first analysis examines the relationship between proximity to manufacturing facilities and solar installation among Malaysian districts. I use ordinary least squares regression (OLS) with district-year fixed effects and cluster-robust to estimate the relationship between manufacturer location by country of origin (China, United States, Japan and South Korea) and solar installation. Figure 5 shows regression coefficients for each manufacturer in a Malaysian district, taking the value of 1 in years a manufacturer from a given country operates in a district and 0 otherwise. The full regression table is located in Appendix Table A2. Overall, manufacturing facility operation in a given district is not associated with higher levels of solar installation across different manufacturers.

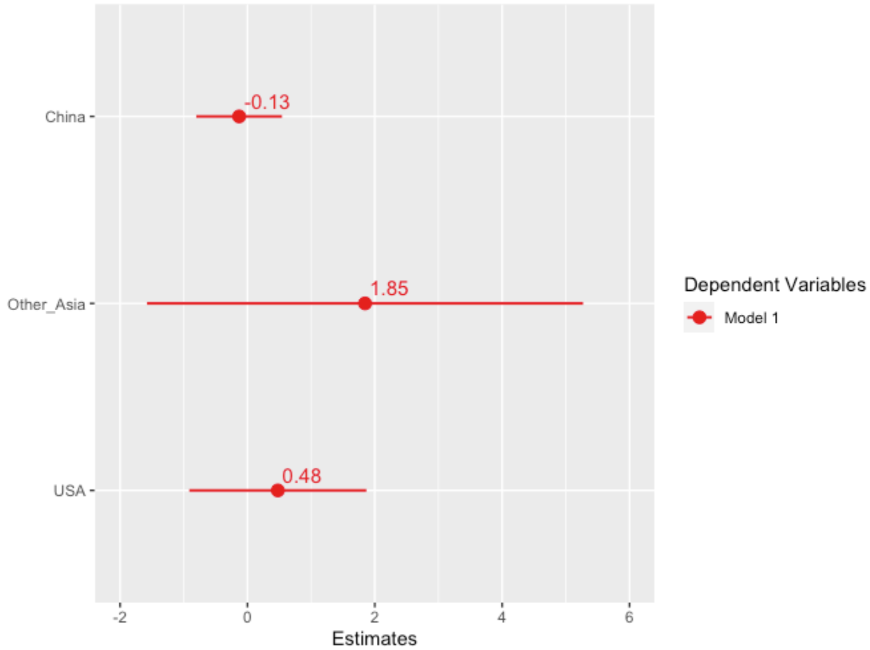
Analysis 2: Solar Supply Chains - Imports from China and SE Asia

To assess whether AD duty imposition corresponded with a reduction in the import of solar panels from China, I employ linear regression with country-year fixed effects and standard errors clustered at the country level. In Model 2, the primary independent variable is an indicator of AD duty imposition taking the value of 1 in all years an AD duty is active, and dependent variable is the percentage

[5] This is consistent with FiT subsidy dispersal; subsidy awards for Sarawak occurred under a distinct mechanism than Peninsular Malaysia and are therefore not subject to comparison.

[6] There is greater missingness for this variable, particularly for imports from SE Asia, where positive Primary Value is recorded but no quantity.

Figure 5: Chinese Manufacturing Spatial Analysis

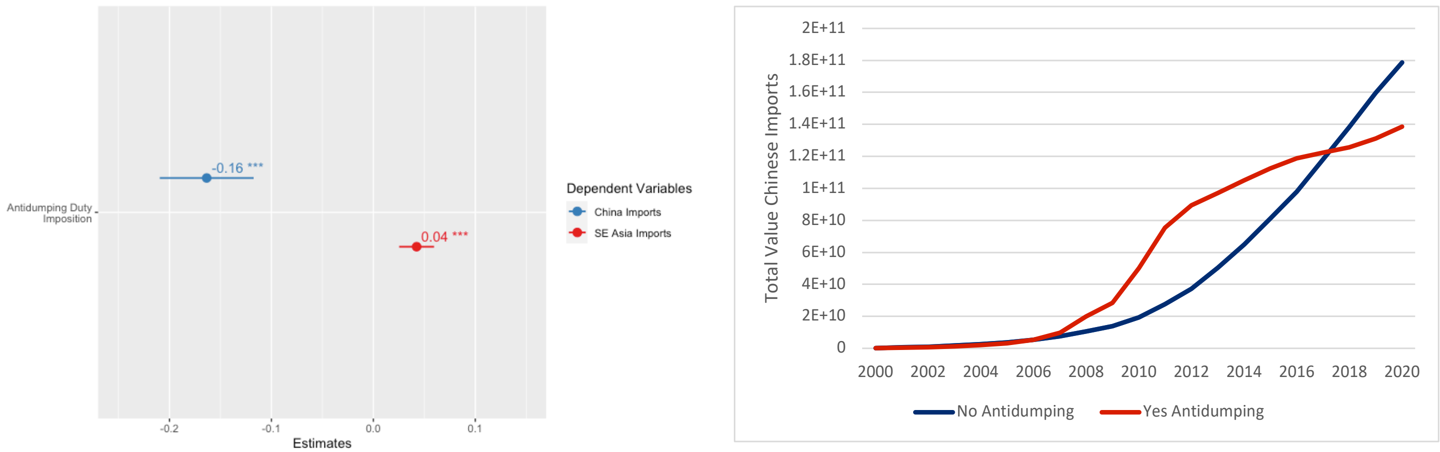


Source: Author's elaboration based on original data and the Malaysian Sustainable Energy Development Authority.

of a country's solar imports sourced from China in a given year. I then evaluate whether Southeast Asian countries subject to the US Department of Commerce investigations for tariff circumvention export a larger quantity of solar panels to countries after the imposition of AD duties. The regression model and independent variable is consistent with Model 2, but the dependent variable is share of solar imports from Malaysia, Thailand, Vietnam and Cambodia after AD duty imposition.

Figure 6A provides a forest plot comparing coefficients on the variable *Antidumping_i,t* for *Model 2* and *Model 3*, respectively, and Figure 6B visualizes the value total solar imports from China over time among countries imposing AD duties and those that do not. Per the expected effects of escalating protection on production chains, AD countries reduce imports from China after tariffs are imposed

Figure 6: Forest Plots (left) and Total Chinese Imports by Tariff Status (right)



Source: Author's elaboration based on International Country Risk Guide, United Nations Comtrade Dataset, Varieties of Democracy (V-DEM), World Bank World-wide Governance Indicators.

but increase solar imports from alternative Southeast Asian suppliers. This complements interview evidence discussed, indicating that Malaysian firms source directly from the Chinese mainland, while panels manufactured at Chinese facilities in Malaysia are destined for export to tariff-affected countries.

CONCLUSION

While Chinese industrial policy certainly has shaped the local solar industry in emerging markets, it is likely not through the relocation of production facilities and technology transfer via forward linkages to local markets. Both spatial patterns of solar investment growth and interviews with solar firms themselves indicate that while cost reductions did indeed occur due to Chinese solar panels, it was not through production localization. Rather, there was an across-the-board reduction in costs for all firms in the Malaysian market that likely occurred elsewhere in similar economies. Indeed, interviewees note that American and European solar components were relatively costly, and in addition to ever-important government subsidies, the cost reduction in switching from German to Chinese modules was a significant factor in scaling up Malaysian solar. In sum, the cost of components' steady decline, fueled by China and its earlier industrial policies, allowed for industry growth abroad.

There is a second lesson to be learned regarding the degree to which host countries can capture value and build a solar industry via manufacturing. Beyond employing a few thousand workers, there is limited evidence that multinationals' solar manufacturing production facilities provide additional value added to the local solar industry. Manufacturing alone is not sufficient to build a local solar industry. Demand side policies like the FiT and NEM arose in every interview as key for getting the market off the ground in the early stages. While large, international firms like Enel Green Power and Applied Energy Services (AES) Corporation can bid for big projects across the globe, it takes time for locals to gain experience in a new sector like solar. Subsidies allowed business conglomerates with experience in construction to experiment with solar, and grow to become industry leaders.

Malaysia is now past the need to subsidize many small firms. They have moved on to large scale auctions, and many of the original FiT recipients like Cypark and Gading Kencana have built large scale projects the size of several football fields. Small firms are continuing to expand in solar services and project ownership, which are both poised to expand as cross-border power trading with Singapore has been codified. Grid interconnection is yet another frontier that unlocks profit potential for renewable energy producers, as storage remains a cost barrier. While a replication of China's solar module cost reductions in these other segments of the supply chain is less than likely in the immediate future, it bears to keep in mind that for emerging markets, modular, affordable components are important for small firms to enter the market, and for local industries to grow from the bottom up. Many countries have far less solar in the energy mix than Malaysia, and the experience of Malaysian locals in scaling up solar production via both supply chain linkages and demand-side subsidies may be informative for those that have yet to grow.

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APPENDIX

Table A1: Summary Statistics

Variable	Length	Mean	Min	Max
Percent Imports from SE Asia	3807	0.034	0	1
Percent Imports from China	3807	0.224	0	1
Antidumping	3986	0.048	0	1
Democracy (V Dem)	3985	0.52	0.015	0.926
Political Constraints	2887	0.301	0	0.726
GDP	3819	11627.693	99.757	123678.702
Population	3905	48340160.7	80410	1411100000
Land Area	3705	894738.922	300	16381390
Carbon Emissions	3839	4.39	0	47.657
Fossil Fuel Consumption	2305	66.073	0	100
Electricity Consumption	2255	3997.776	22.482	54799.175
Trade	3569	15.837	11.171	20.555
Net FDI Inflows	3839	11595462242.295	-330338474188.053	733826501994.516
Corruption (ICRG)	3080	2.66	0	6

Source: International Country Risk Guide, United Nations Comtrade Dataset, Varieties of Democracy (V-DEM), World Bank Worldwide Governance Indicators.

Table A2: Solar Manufacturing and Installation (MW) in Malaysia

	Model 1	Model 2	Model 3	Model 4
(Intercept)	92.087*	92.539*	91.331*	88.596*
	(36.158)	(36.345)	(36.128)	(36.455)
China	-0.130	-0.022	-0.144	0.226
	(0.328)	(0.322)	(0.331)	(0.327)
USA	0.477	0.539	0.503	0.920
	(0.682)	(0.699)	(0.663)	(0.643)
Other Asia	1.847	1.888	1.878	2.241
	(1.661)	(1.657)	(1.673)	(1.704)
Median GDP	0.009	0.023***		
	(0.010)	(0.006)		
Electricity Consumption (Log)	0.089*		0.129***	
	(0.040)		(0.026)	
Land Area	-0.070	-0.189***	-0.038	-0.346***
	(0.044)	(0.048)	(0.045)	(0.058)
Num.Obs.	1008	1008	1008	1008
R2	0.091	0.087	0.090	0.062

	Model 1	Model 2	Model 3	Model 4
R2 Adj.	0.085	0.081	0.084	0.058
AIC	3070.7	3073.7	3070.2	3098.2
BIC	3114.9	3113.0	3109.5	3132.6
Log.Lik.	-1526.334	-1528.848	-1527.105	-1542.120
F	7.178	8.200	8.304	8.065
RMSE	1.10	1.10	1.10	1.12
Std.Errors	HC2	HC2	HC2	HC2

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Source: Author's elaboration based on International Country Risk Guide, United Nations Comtrade Dataset, Varieties of Democracy (V-DEM), World Bank Worldwide Governance Indicators.

Table A3: Percent Imports from China and Antidumping

	Model 1	Model 2	Model 3	Model 4
(Intercept)	-64.889***	-53.176***	-53.899***	-33.206***
	(7.052)	(7.215)	(6.880)	(6.432)
Antidumping	-0.210***	-0.194***	-0.248***	-0.103***
	(0.031)	(0.034)	(0.030)	(0.021)
Democracy (V Dem)	0.007	0.029	0.014	0.034
	(0.119)	(0.125)	(0.140)	(0.110)
FiT	0.035	0.036	0.041+	
	(0.023)	(0.023)	(0.022)	
Political Constraints	0.065	0.083	0.043	
	(0.055)	(0.056)	(0.054)	
GDP per capita (log)	-0.037	0.018	0.023	0.126***
	(0.032)	(0.037)	(0.030)	(0.023)
Population	0.177	0.126	0.171	0.165+
	(0.147)	(0.146)	(0.148)	(0.087)
Land	-0.818**	-0.735**	-0.842***	0.448
	(0.278)	(0.245)	(0.175)	(0.388)
Carbon Emissions	0.011	-0.063		
	(0.127)	(0.123)		
Fossil Fuel Consumption	0.005*	0.003		
	(0.002)	(0.003)		
Electricity Consumption (Log)	0.019	0.082		
	(0.059)	(0.066)		
Trade (log)	-0.972		-0.003	
	(0.885)		(0.770)	
Net FDI Inflows (log)	-0.004		-0.003	

	Model 1	Model 2	Model 3	Model 4
	(0.004)		(0.004)	
Corruption	0.012	0.011	0.003	
	(0.014)	(0.013)	(0.013)	
OECD Membership	0.089	0.096	0.072	0.033
	(0.067)	(0.067)	(0.075)	(0.077)
Kyoto Protocol	-0.068***	-0.083***	-0.082***	-0.022
	(0.020)	(0.019)	(0.020)	(0.018)
Num.Obs.	1736	1892	2024	3632
R2	0.593	0.576	0.594	0.438
R2 Adj.	0.560	0.544	0.565	0.409
AIC	-1232.0	-1315.2	-1302.2	-590.0
BIC	-511.3	-566.6	-516.4	531.7
Log.Lik.	747.982	792.602	791.112	476.013
RMSE	0.16	0.16	0.16	0.21
Std.Errors	by: PartnerISO	by: PartnerISO	by: PartnerISO	by: PartnerISO

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Author's elaboration based on International Country Risk Guide, United Nations Comtrade Dataset, Varieties of Democracy (V-DEM), World Bank World-wide Governance Indicators.

Table A4: Percent Imports from SE Asia and Antidumping

	Model 1	Model 2	Model 3	Model 4
(Intercept)	-6.555+	-6.185*	0.706	1.194
	(3.476)	(3.053)	(1.787)	(1.399)
Antidumping	0.049**	0.053**	0.067***	0.066***
	(0.018)	(0.016)	(0.017)	(0.016)
Democracy (V Dem)	-0.074	-0.093	-0.060	-0.036
	(0.059)	(0.071)	(0.041)	(0.026)
FiT	-0.008	-0.013	-0.010	
	(0.009)	(0.010)	(0.007)	
GDP per capita (log)	-0.025+	-0.024*	0.007	0.012
	(0.015)	(0.011)	(0.010)	(0.009)
Population	0.120*	0.126**	0.060*	0.041*
	(0.055)	(0.048)	(0.030)	(0.021)
Land	0.099	0.051	-0.026	-0.029
	(0.099)	(0.068)	(0.064)	(0.065)
Carbon Emissions	0.071	0.078*		
	(0.044)	(0.035)		
Fossil Fuel Consumption	-0.000	-0.000		
	(0.001)	(0.001)		

	Model 1	Model 2	Model 3	Model 4
Electricity Consumption (Log)	0.012			
	(0.015)			
Trade (log)	0.127		0.109	
	(0.366)		(0.246)	
Net FDI Inflows (log)	-0.000		0.000	
	(0.002)		(0.001)	
Corruption	0.006	0.006	0.006*	
	(0.004)	(0.004)	(0.003)	
OECD Membership	-0.038	-0.044	-0.031	-0.033
	(0.062)	(0.064)	(0.046)	(0.046)
Kyoto Protocol	-0.005	-0.003	-0.000	-0.000
	(0.011)	(0.010)	(0.009)	(0.007)
Num.Obs.	1766	1988	2543	3632
R2	0.529	0.515	0.485	0.457
R2 Adj.	0.490	0.479	0.455	0.429
AIC	-4617.8	-5107.5	-6365.1	-9177.1
BIC	-3878.5	-4329.8	-5524.0	-8055.4
Log.Lik.	2443.912	2692.767	3326.555	4769.563
RMSE	0.06	0.06	0.07	0.07
Std.Errors	by: PartnerISO	by: PartnerISO	by: PartnerISO	by: PartnerISO

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Author's elaboration based on International Country Risk Guide, United Nations Comtrade Dataset, Varieties of Democracy (V-DEM), World Bank World-wide Governance Indicators.

Table A5: Total Value of Imports from China and Antidumping

	Model 1	Model 2	Model 3	Model 4
(Intercept)	-18.371+	-19.532*	-25.371**	-14.983*
	(9.486)	(9.725)	(9.551)	(6.427)
Antidumping	-0.051*	-0.059**	-0.088***	-0.046***
	(0.023)	(0.023)	(0.023)	(0.011)
Democracy (V Dem)	-0.138	-0.106	-0.113	0.096
	(0.160)	(0.164)	(0.133)	(0.101)
FiT	-0.033	-0.027	-0.029	
	(0.022)	(0.021)	(0.022)	
Political Constraints	0.119	0.116	0.129+	
	(0.079)	(0.077)	(0.072)	
GDP per capita (log)	0.092+	0.085+	0.099*	0.107***
	(0.048)	(0.044)	(0.041)	(0.026)
Population	0.041	-0.016	0.017	-0.044

	Model 1	Model 2	Model 3	Model 4
	(0.129)	(0.118)	(0.121)	(0.070)
Land	0.160	0.249	0.774	0.688+
	(0.506)	(0.532)	(0.570)	(0.414)
Carbon Emissions	0.331*	0.249*		
	(0.137)	(0.122)		
Fossil Fuel Consumption	-0.001	-0.001		
	(0.003)	(0.003)		
Electricity Consumption (Log)	-0.119+	-0.082		
	(0.068)	(0.073)		
Trade (log)	0.102		-0.569	
	(0.908)		(0.893)	
Net FDI Inflows (log)	-0.006		-0.003	
	(0.004)		(0.003)	
Corruption	0.004	0.006	-0.001	
	(0.010)	(0.009)	(0.010)	
OECD Membership	-0.038	-0.037	-0.027	-0.092+
	(0.045)	(0.044)	(0.049)	(0.053)
Kyoto Protocol	-0.008	-0.017	-0.015	-0.023
	(0.026)	(0.024)	(0.025)	(0.019)
Num.Obs.	1736	1892	2024	3632
R2	0.677	0.667	0.651	0.565
R2 Adj.	0.651	0.641	0.625	0.542
AIC	-1296.1	-1473.9	-1327.8	-1705.2
BIC	-575.5	-725.3	-542.0	-583.5
Log.Lik.	780.061	871.946	803.905	1033.619
RMSE	0.15	0.15	0.16	0.18
Std.Errors	by: PartnerISO	by: PartnerISO	by: PartnerISO	by: PartnerISO

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Author's elaboration based on International Country Risk Guide, United Nations Comtrade Dataset, Varieties of Democracy (V-DEM), World Bank Worldwide Governance Indicators.

Table A6: Total Value of Imports from SE Asia and Antidumping

	Model 1	Model 2	Model 3	Model 4
(Intercept)	1.128	2.419	5.628*	4.551*
	(3.740)	(2.676)	(2.569)	(1.877)
Antidumping	-0.008	-0.009	-0.005	-0.007
	(0.015)	(0.015)	(0.015)	(0.014)

	Model 1	Model 2	Model 3	Model 4
Democracy (V Dem)	0.079	0.061	0.003	0.004
	(0.064)	(0.067)	(0.042)	(0.027)
FiT	-0.006	-0.004	-0.005	
	(0.005)	(0.005)	(0.005)	
GDP per capita (log)	-0.018	-0.005	0.006	0.006
	(0.015)	(0.011)	(0.008)	(0.006)
Population	0.043	0.028	0.041+	0.027*
	(0.028)	(0.024)	(0.021)	(0.014)
Land	-0.045	-0.083	-0.126	-0.112
	(0.142)	(0.096)	(0.142)	(0.112)
Carbon Emissions	0.047+	0.036		
	(0.027)	(0.025)		
Fossil Fuel Consumption	-0.001	-0.000		
	(0.001)	(0.001)		
Electricity Consumption (Log)	0.011			
	(0.018)			
Trade (log)	-0.356		-0.032	
	(0.328)		(0.228)	
Net FDI Inflows (log)	0.000		-0.001	
	(0.001)		(0.001)	
Corruption	0.004	0.001	0.001	
	(0.004)	(0.004)	(0.003)	
OECD Membership	0.011	0.009	0.018**	0.013*
	(0.007)	(0.007)	(0.007)	(0.006)
Kyoto Protocol	0.001	-0.003	-0.000	0.001
	(0.010)	(0.010)	(0.010)	(0.006)
Num.Obs.	1766	1988	2543	3632
R2	0.714	0.676	0.630	0.587
R2 Adj.	0.690	0.653	0.608	0.565
AIC	-4844.0	-5243.6	-6934.7	-10233.2
BIC	-4104.7	-4465.9	-6093.6	-9111.5
Log.Lik.	2557.011	2760.808	3611.371	5297.609
RMSE	0.06	0.06	0.06	0.06
Std.Errors	by: PartnerISO	by: PartnerISO	by: PartnerISO	by: PartnerISO

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Source: Author's elaboration based on International Country Risk Guide, United Nations Comtrade Dataset, Varieties of Democracy (V-DEM), World Bank Worldwide Governance Indicators.

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