INTERNATIONAL MONETARY FUND

Europe’s Shift to Electric Vehicles Amid Intensifying Global Competition

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WP/24/218

2024
OCT

WORKING PAPER

WP/24/218

IMF Working Paper

European and Research Departments

Europe's Shift to EVs Amid Intensifying Global Competition[*]

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Authorized for distribution by Oya Celasun and Rafael Portillo
October 2024

ABSTRACT: European countries have set ambitious goals to reduce their carbon emissions. These goals include a transition to electric vehicles (EVs)—a sector that China increasingly dominates globally—which could reduce the demand for Europe's large and interconnected auto sector. This paper aims to size up the tradeoffs between Europe's shift towards EVs and key macroeconomic outcomes, and analyze which policies may sharpen or ease them. Using state-of-the-art macroeconomic and trade models we analyze a scenario in which the share of Chinese cars in EU purchases rises by 15 percent over 5 years as a result of both a positive productivity shock for car production in China and a demand shock that shifts consumer preferences towards Chinese cars (given China's dominance in the EV sector). We find that for the EU as a whole, the GDP cost of this shift is small in the short term, in the range of 0.2-0.3 percent of GDP, and close to zero over the long term. Adverse short-run effects are more significant for smaller economies heavily reliant on the car sector, mainly in Central Europe. Protectionist policies, such as tariffs on Chinese EVs, would raise the GDP cost of the EV transition. A further increase in Chinese FDI inflows that results in a significant share of Chinese EVs being produced in Central European economies, on the other hand, would offset losses in these economies by supporting their shift from supplying the internal combustion engine (ICE) production chain to that of EVs.

RECOMMENDED CITATION: Wingender, Philippe, Jiaxiong Yao, Robert Zymek, Benjamin Carton, Diego Cerdeiro, and Anke Weber, "Europe's Shift to Electric Vehicles Amid Intensifying Global Competition," IMF Working Paper 24/218.

JEL Classification Numbers:	D57, D 58, F10, F13, Q58
Keywords:	Electric vehicles; green transition; trade; tariffs; global value chains.
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[*] We thank Helge Berger, Oya Celasun, Geoffroy Dolphin, Geoff Gottlieb, Pierre-Olivier Gourinchas, Petya Koeva Brooks, Krzysztof Krogulski, Natalija Novta, Rafael Portillo, Gregor Schwerhoff, Petia Topalova, Yizhi Xu, and participants at IMF European and Research Department seminars, for very helpful comments and suggestions. Estefania Cohn Bech provided excellent research assistance.

Contents

1. Introduction

The European Union (EU) has set ambitious and much-needed climate goals, with the ultimate objective of making its economy climate neutral by the middle of this century. These plans include a rapid transition to electric vehicles (EVs). In March 2023 the European Commission set out targets for emission reductions from cars, as part of its “Fit for 55” package. The need for Europe to enhance its energy security by limiting its dependence on fossil fuel imports, and changing consumer preferences are also contributing to the shift towards EVs.[1] Current regulations require a 55 percent reduction in CO2 emissions for new cars and 50 percent for new vans from 2030 to 2034 compared to 2021 levels, and 100 percent CO2 emission reductions for both new cars and vans from 2035. To meet these targets, third-party estimates suggest that sales of battery EV cars in the EU must make up around 65 percent of total new car sales by 2030 and that by 2035 all new car sales should be fully electric (Figure 1). With fully electric vehicle sales currently accounting for about 15 percent of total car sales in Europe, this represents a quantum leap. While Europe is one of the world’s largest auto manufacturers, it has yet to gain competitiveness in the production of EVs, having invested heavily in internal combustion engine (ICE) technologies. The EU has also seen an increase in the share of EVs produced in China, which supplied more than 20 percent of new battery-electric cars purchased in the EU in 2023, up from just below 3 percent in 2020 (ACEA, 2024). Given the importance of the car sector for many European economies, it is natural to ask about the economic implications of the shift towards EVs in the continent. This paper uses state-of-the-art models to study the macroeconomic implications of Europe’s transition to EVs, and how policies can ease or sharpen any tradeoffs.

The EV sector is one that China increasingly dominates, including in key segments of the supply chain such as batteries (Duthoit, 2023). Within China, EVs already account for about a third of domestic vehicle sales, making up more than half of global EV sales. The significant take-up of EVs in China has been spurred by the availability of cheap EVs, with the sales-weighted average price of electric cars (before purchase subsidy) already being lower than that of internal combustion engine (ICE) cars (IEA, 2024). China’s increased production capacity has only recently started translating into a meaningful amount of EV exports, and the trend is exponential, with exports more than quadrupling over the last three years. In 2023, China exported over 4 million cars, making it the largest auto exporter in the world, of which about one-third were electric (IEA, 2024). The EU is China’s largest export market. In 2023, 21.7 percent of battery-electric car sales in the EU were made in China, of which Chinese brands accounted for 7.6 percent sharply up from 2.9 percent (made in China) and 2 percent (Chinese brands) in 2020 (ACEA, 2024). In terms of total (ICE+EV) car sales, battery-electric vehicles made in China and by Chinese brands correspond to about 3 and 1 percent, respectively. The average purchase price of battery-electric vehicles in the EU averaged 46,000 euros, more than twice the average price of those imported from China. Chinese EVs sold in Europe are still about 20 percent cheaper than similar models made by European manufacturers.

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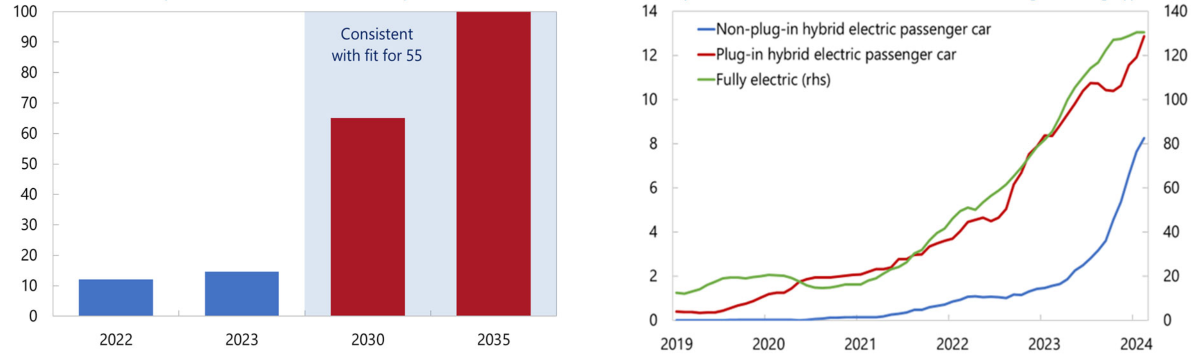
[1] The EY 2023 Mobility Consumer Index survey shows an increase in EV-buying intent since 2020, albeit with a plateau between 2022 and 2023 for the case of fully-electric vehicles. Some analysts have pointed to concerns about charging infrastructure, large depreciation rates, and uncertainty about government policies (Goldman Sachs, 2024).

Figure 1. EV Sales and Size of Europe's Automotive Sector

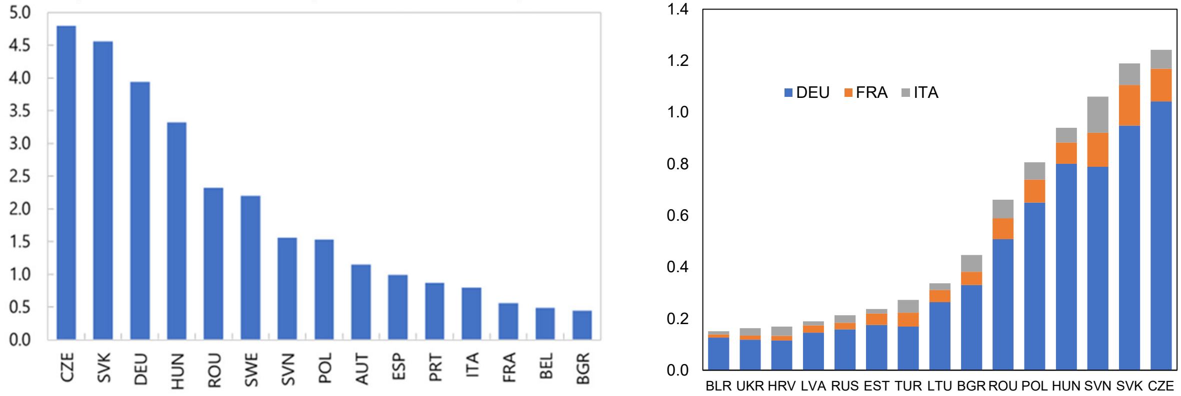
EU: Battery EV Sales
(Percent of total car sales)

China: Exports of EVs
(Thousands of cars, 12-month moving average))



Size of the EU Automotive Sector
(sectoral value added as percent of GDP, 2019)

Total Value Added to Foreign Auto Sector
(percent of domestic GDP, 2019)



Sources: CEIC; China Customs; IEA; European Commission; OECD Input-Output Table; and IMF staff calculations.
Notes: The size of the EU automotive sector is calculated as the value added of the auto sector as percent of GDP using the OECD input-output table. Total value added to foreign auto sector is measured as a country's input (intermediate goods and services) to the auto sector of a foreign country (Germany, France, or Italy).

The rise of China as a global EV exporter has been a source of concern for European policymakers and carmakers. Transport equipment is Europe's largest industrial sector. Direct and indirect employment by the automotive sector accounts for about 7 percent of total EU employment (ACEA, 2023) and its share in GDP ranges from 4-5 percent in Czechia, Slovakia, Hungary, and Germany to around 0.5 in France, Belgium and Bulgaria. As a result of decades of supply-chain deepening, it is also a highly interconnected sector, with Central, Eastern, and Southeastern European (CESEE) economies accounting for a nontrivial share of inputs into automobile production of Germany, France and Italy (EA3). Policymakers have already been concerned for some time about how employment in some regions of Europe would be affected by the shift towards EV production. Concerns related to increased competition from Chinese EVs have come on top of this concern—fueled by perceptions of unfair competition—and revolve around European car firms' competitiveness and the labor market implications of reduced car production in Europe. In this context, the EU initiated an investigation on subsidized EVs from China, which has led to the introduction of additional provisional tariffs on Chinese EV imports in June 2024. Combined with existing EU (most-favored nation) tariffs, total tariffs can reach almost 50 percent for some EV producers based in China.[2]

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[2] Tariffs were calculated based on estimates of how much state aid each firm received, while companies that cooperated with the EC probe saw their duties cut. Tariffs apply to Chinese firms and subsidiaries of EU and U.S. firms operating and exporting out of China.

Despite concerns about the potential welfare implications of the shift to EVs amid more intense competition, there have been few quantitative assessments to date. This is primarily because it is still too early to see some of the potential effects clearly in the data. While this makes structural general equilibrium models particularly well suited to perform analyses of their implications, studies to date have mostly focused on using descriptive statistics and historical experiences to come up with predictions for future developments (explained in more detail below). An exception is a recent trade model-based analysis by the Kiel Institute, which shows the medium- to long-term trade impacts from EU tariffs on Chinese EVs. However, to the best of our knowledge, there is no comprehensive model-based analysis that captures both the short-term dynamic and steady state GDP effects of the dual shocks.

Our paper aims to fill this gap by quantifying the tradeoffs between the shift to EVs and key economic outcomes and analyzing which policies may sharpen or ease them. To do so, the paper employs state-of-the-art macroeconomic and trade models. First, we use GIMF, a multi-region, micro-founded, dynamic general equilibrium model of the global economy, to simulate the short-run impacts of the dual shocks of the EV transition and growing penetration of Chinese EV imports (the model is described in Kumhof and others, 2010; Anderson and others, 2013). We also use a dynamic multi-country, multi-sector quantitative trade model based on Cuñat and Zymek (2024) to describe the long-run steady state effects at a more granular level. While GIMF is restricted to a limited number of sectors and countries/regions, the trade model allows for an arbitrary number of country/regions.

EVs are a new technology that is evolving very rapidly, and hence it is too early to predict countries' ultimate comparative advantages with any degree of certainty. For this reason, we base our main scenario on an episode from recent history that is considered transformative for the global auto sector - the rise of Japan's auto sector in the 1960–1980s. Amid high energy prices, smaller, more fuel-efficient Japanese cars started taking larger market shares in the U.S., eventually peaking at around 15 percent in the mid-80s. This rapid penetration created trade tensions that resulted in the adoption of "voluntary export restraints." Eventually, Japanese car makers adapted to the new policy and trade environment by increasing FDI in the U.S. This led to a period of decline and stabilization in import shares of the U.S. Based on those insights, we calibrate our models so that China achieves a similar increase in market penetration as Japan did in the 80s but over a shorter time span of 5 years—about twice as fast as in the U.S.-Japan experience.

A crucial methodological question is how to model the rise of Chinese EV market shares in Europe. There are several ways this can be done but the exercise is constrained by the structures of GIMF-GVC and the trade model. Both models have a single representative automotive sector since existing inter-country input-output data do not yet distinguish between ICE and EV production. To sidestep this issue, we assume that i) unobserved to us, the automotive sector contains two car types – ICE and EVs – with broadly similar production structures; and ii) China enjoys an emerging relative productivity advantage in the EV car type.

In practice, this means that our so-called EV-shock scenario combines two shocks. The first is a generic supply shock that increases total factor productivity (TFP) in China's automotive sector as a whole. In itself this is insufficient with reasonable productivity differentials to generate a large enough increase in China's market penetration and the envisaged end-share of 15 percent Chinese market penetration over 5 years. The second shock is a policy-driven shift towards EVs that benefits demand for Chinese vehicles disproportionally due to an assumed comparative advantaged in the (not directly observable) EV type of car sector output. The extent and pace of China's emerging comparative advantage is assumed to be such as to generate the 15 percent-point increase in Chinese market share over 5 years. In terms of macroeconomic impacts, this is observationally equivalent to a preference shift towards Chinese car-sector output. However, our assumptions about the distinct ICE and EV varieties of this output also allow us to explore the emissions implications of different EU responses to the EV shock.[3]

In all our simulations, we consider a baseline steady state where China's productivity growth does not take place and where the EU does not introduce an EV transition target (and thus consumers do not develop a preference for Chinese cars). This allows us to quantify the effects of both shocks, namely the policy-driven demand shock and the China productivity shock. We then consider the impact of protectionist policies adopted in response to the growing import shares. And finally, we look at how European economies could be affected by a further scaling up of Chinese FDI that would lead to 40 percent of Chinese EVs sold in Europe being produced in Europe, similar to Japan's late 1980s experience in the U.S.

For the EU as a whole, we find that the output cost of the transition to EVs is nontrivial but small in the short-term, with a decline of about ¼ percent in real GDP for most countries over 5 years, and close to zero over the long term. While the productivity increase in China benefits consumers in all EU countries through cheaper cars and inputs, the demand shift away from ICE vehicles produced in Europe towards Chinese EVs negatively impacts output. However, there is significant heterogeneity across countries. Losses are more significant for economies heavily reliant on the car sector, mainly in Central Europe, as demand for their inputs would shrink significantly. Hungary and Czechia see a 1 percent and 1.5 percent decline in real GDP over 5 years, respectively, with the negative GDP impact persisting in the steady-state. On the other hand, EU economies that do not have a sizable auto production sector benefit from the availability of cheaper EVs imported from China. Results from both models point to some employment losses in the motor vehicle sector, and the need for workers to shift to other sectors, highlighting the need for policies to ease the transition. Tariffs on Chinese EVs would deepen the losses and raise the GDP cost of the EV transition, including for those countries heavily reliant on auto production, while their impact on emissions would be generally modest, provided that they do not cause policy targets to be postponed. An increase in Chinese FDI inflows that results in a significant share of Chinese EVs being produced in Europe, on the other hand, would help the economies receiving the FDI. Effects can be particularly large for smaller (Central European) economies should additional FDI flows go disproportionately to them.

Our paper contributes to several strands of literature. First, it complements existing studies on the impact of the structural transformation implied by the transition to EVs, including due to intensifying competition from China. Those studies, conducted by policy institutions and automotive industry associations, have generally followed a mostly descriptive approach, often relying on simple partial-equilibrium simulations (e.g., Duthoit, 2023; Mayer and others, 2024, Sebastian and others, 2024). Closest to our work, recent simulations by the Kiel Institute for the World Economy use its trade model (KITE) to shed light on the long-term implications of tariffs on Chinese EV imports on bilateral trade and production in Europe. Like us, they find that such tariffs would lead to a significant decrease in Chinese imports and higher prices for end-consumers. Our paper adds to the analysis of trade patterns and of the GDP, employment, and climate-transition implications of tariffs as well as FDI scenarios using multiple models.[4] Another relevant model-based paper is Ayerst and Noumon (2023) who investigate the impact of electrification on Czechia with a structural model of global value chains, but do not consider the impact of rising competition from China. They show that the transition could be challenging for

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[3] While observationally equivalent to a preference shock, we label this a policy-driven demand shift given that the transition path to achieve the 2035 target is particularly steep and therefore arguably unlikely to be achieved in the absence of policy measures to promote EV adoption.

[4] Kiel's KITE model is based on the widely used *static* multi-country, multi-sector quantitative trade model in Caliendo and Parro (2015). The two models we deploy have a broadly similar production and trade structure but are *dynamic*, with endogenous capital accumulation and international asset trade.

Czechia, leading to a modest increase in output but large losses of employment given a decrease in the labor intensity of production. Our paper is also related to a body of work studying the role of Europe's automotive sector in macroeconomic performance and highlighting the important role of supply chain integration in shock transmission (Boranova and others, 2022; Elekdag and Muir, 2013; and Huidrom and others, 2019). A set of related papers has also focused on how China's dominance in EVs has been supported by supply-side policies, with the sector being among the emerging sectors favored by industrial policies (see IMF, 2024; Rotunno and Ruta, 2024). In this context, Attinasi and others (2024) simulate a scenario where China subsidizes EVs such that their prices drop by 50 percent, leading to large shifts in global EV market shares and a small, 0.1 percent drop in overall EU production.[5]

Our paper complements the growing literature on the potential economic impacts of the green transition, including its potential employment shifts (IMF 2022a; IMF, 2022b; Bluedorn and others, 2022). In line with our findings, these studies confirm that with the right policies, output losses associated with the transition can remain manageable and are likely dwarfed by the long-term costs of inaction. However, they point to some adverse consequences for workers in affected sectors. Notably, for Europe, Celasun and others (2023) examine the labor market implications of electrification in the car industry using the heterogeneity across European countries in the speed of transition to EV production and variation in sectoral and regional exposure to the automotive sector. They find that the transformation of the auto sector is already having an adverse impact on employment in the affected sectors and regions, and provide evidence that active labor market policies can be effective in easing the transition.

The remainder of the paper is organized as follows. To anchor our modeling scenarios, Section 2 first documents key facts about the Japanese experience in the 1960-80 period, and how this compares to China's rise today. Section 3 lays out the models and scenarios used, while Section 4 presents the model results. Section 5 concludes.

2. Letting the past and the present inform possible scenarios

Our model scenarios require us to take a stance on the evolution and extent of China's production advantage in electric vehicles. Since this cannot be ascertained with confidence at this point, we turn to a historical episode as our benchmark, namely Japan's entry into the U.S. car market. In this section we first document the speed and extent of Japan's rise in the 1960–1980s as a global automotive industry player using global input-output data. We then turn to the present and highlight parallels with China's rising role as a key EV manufacturer as well as recent EU policy responses. Finally, we bring the two together to compare the past and present and thereby inform possible model scenarios.

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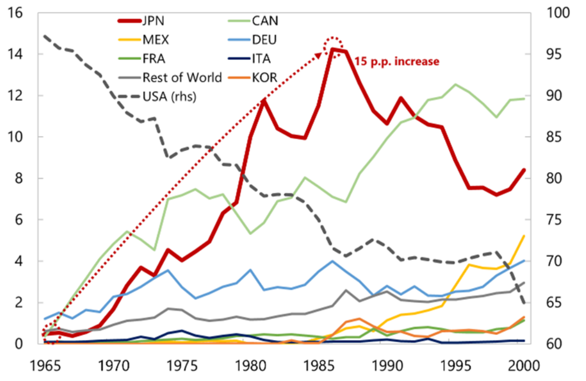
[5] Alochet (2023) and Barwick and others (forthcoming) note that China actually phased out many of its central-government subsidies to the EV sector in 2023. More generally, Barwick and others (forthcoming) find that consumer subsidies significantly increased EV sales in China, with positive effects in China and elsewhere thanks to learning by doing in battery manufacturing. Local content requirements, however, reduce these benefits by shifting battery manufacturing to less efficient producers.

2.1. JAPAN'S RISE IN THE 1960–1980s

The postwar Japanese auto industry underwent three stages of development: rapid domestic expansion during the 1960s, export-led growth during the 1970s, and regionalization through FDI since the early 1980s. Annex I provides a detailed review of the literature documenting Japan's rise. Japanese firms started entering the world export market in the 1960s but were initially unsuccessful. In the U.S., their largest potential market, they suffered from insufficient dealer networks, poor model image, and competition from European firms (Hart, 1992). It was not until the 1970s that penetration in foreign markets increased, with the surge in oil prices and tightening emissions regulations creating a large demand for small and fuel-efficient cars that was unmet by American and European firms. The U.S. only started implementing restrictions to curb Japanese car imports in the early 1980s. As a result, Japanese auto exports to the U.S. rapidly increased during this decade. By the end of the 1970s, growing American imports of Japanese autos amid oil price increases created a trade dispute that led to the adoption of voluntary export restraints that limited Japanese auto export volumes to the U.S. Starting in the 1980s, Japanese firms developed regionalization strategies through FDI to defuse trade tensions and offset the appreciation of the yen, and exports began to diminish (Lin, 1994).

Figure 2. U.S. Passenger Car Market Share (percent)



Sources: World Input-Output Database (WIOD); and IMF staff calculations.

Sources: World Input-Output Database (WIOD); and IMF staff calculations.

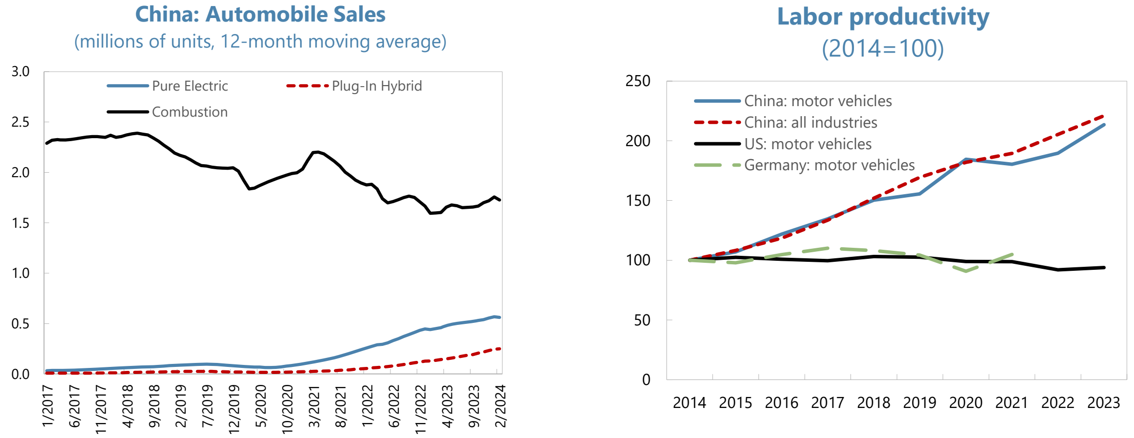
These different phases can be observed in long-run input-output data. While historical data on U.S. market shares of foreign producers are not readily available at a disaggregated level, the market share of a foreign country can be approximated by the ratio of its transport equipment sector's sales to U.S. final demand over total transport equipment sales in the U.S. Such data are available in the long-run World Input-Output Database (Woltjer et al., 2021). Figure 2 shows that the share of imported Japanese cars in U.S. sales rose from close to 0 in 1965 to 15 percent in 1985, and then eventually fell as Japanese producers switched towards supplying the U.S. market via production in the US.

2.2. CHINA'S RISE IN THE 21ST CENTURY

Chinese domestic sales of EVs took off in earnest in 2020 (Figure 3, left panel). By early 2024, EVs made up around 32 percent of total sales in China, with pure-electric vehicles accounting for 22 percent and plug-in electrics the remaining 10 percent. While exports of hybrid vehicles remain modest, pure-electric vehicle exports are more significant. In 2023, around 1.5 million pure-electric vehicles were exported, compared to 5.4 million such vehicles sold domestically (pure electric car sales globally amounted to about 10 million cars, IEA, 2024).

Labor productivity in China's auto sector has been growing at a similar pace as in other manufacturing sectors, significantly faster than labor productivity growth in the auto sectors of the U.S. and Germany. The shift to EVs does not appear to have altered this sectoral growth pattern (Figure 3, right panel). Between 2015 and 2023, labor productivity in China's automobile sector increased at an annualized rate of 8.8 percent, only marginally below the annualized growth rate of 9.2 percent for the entire industrial sector. In all, labor productivity growth in the sector was significantly higher than in the U.S. and Germany.

Figure 3. China: Automobile sales and labor productivity growth



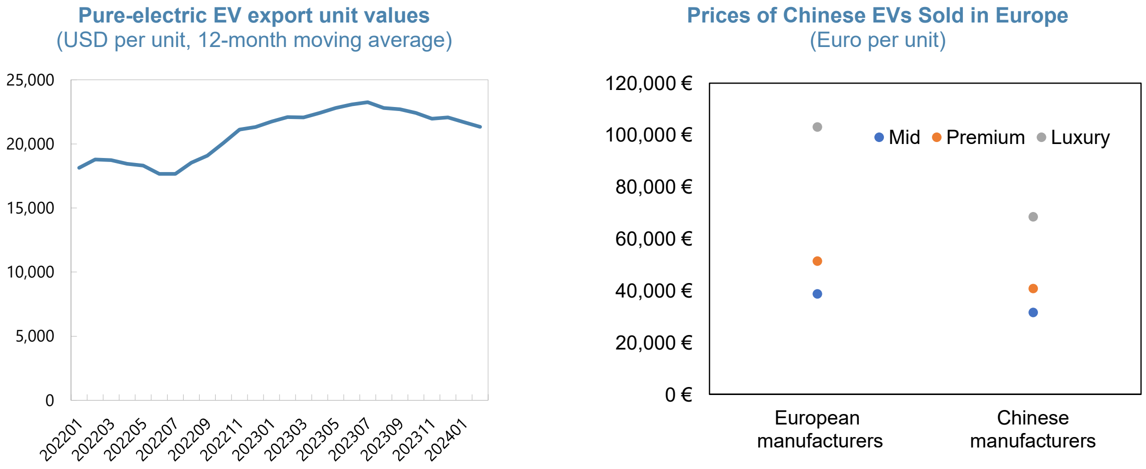
China: Automobile Sales
(millions of units, 12-month moving average)

Labor productivity
(2014=100)

Sources: CEIC; IMF staff calculations.

A price comparison can help evaluate the potential future trajectory of Chinese EV penetration. China's customs data provide a rough sense of the price of pure-electric vehicles exported out of China, with export unit values hovering between USD 18,000 and USD 23,000 (Figure 4, left panel). Industry data provides a more complete picture of Chinese EV prices in Europe. Using data from the European Commission and categorizing EVs sold in Europe by size/segment, we find that as of 2023 Chinese EVs in Europe were selling for about 20 percent less than similar models made by European manufacturers (Figure 4, right panel).[6]

Figure 4. China: EV Exports: Value and Prices of Cars Sold in Europe



Pure-electric EV export unit values
(USD per unit, 12-month moving average)

Prices of Chinese EVs Sold in Europe
(Euro per unit)

Sources: CEIC; China Customs, European Commission, IHS, IMF staff calculations.

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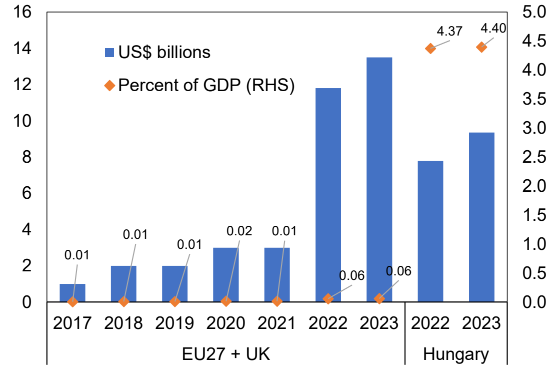
[6] EV markets in Europe and China are characterized by major price discrepancies, with the same cars retailing for significantly more in Europe than in China, likely reflecting price discrimination amid intense competition in the Chinese market. For example, Volkswagen's ID.4 model sells for nearly 50 percent more in Europe than in China, while BYD's Seal U comfort costs nearly double in Europe compared to China (Rhodium Group, 2024) even before the imposition of recent EU additional tariffs.

The European Commission announced in June 2024 additional tariffs on Chinese-made EVs on a provisional basis, as a result of an anti-subsidy investigation. The Commission's investigation determined that EVs produced in China benefit from subsidies that ultimately cause injury to EU EV producers. The additional tariffs, of between 17.4 to 38.1 percent, come on top of existing 10 percent EU (most-favored nation) tariffs on car imports. While they became effective in July 2024, they will become definitive (normally, for a 5–year period) in November 2024 unless a qualified majority (members representing at least 65 percent of the EU's GDP and population) opposes them.

Figure 5. Chinese EV-related FDI in EU
(US$ billions; percent of GDP)



Sources: Rhodium Group, Hungarian authorities, IMF staff calculations.

Notes: Hungary figures exclude some small investments (<$1bn each). Figure excludes Gotion's 25 percent stake in Slovakian battery producer Inobat.

Chinese manufacturers have already started EV-related foreign direct investment (FDI) in the EU (Figure 5). Around 30 percent of 2023 Chinese FDI in the EV sector went to Europe (Rhodium Group 2024). China's global EV investments have also shifted from minerals, to batteries, and most recently to EV manufacturing, with BYD announcing in late 2023 that it would set up a car production plant in Hungary (Rhodium Group 2023). Chinese investments in Europe thus far have been mostly concentrated in Germany, France, the UK and notably Hungary, which received more than half of total of FDI from China in 2022 and 2023. Many Chinese investments have benefitted from European state aid.[7]

2.3. PUTTING IT ALL TOGETHER

Table 1 provides an overview of how the Japanese experience and current situation compare, and how these comparisons inform our model scenarios. Because we see both the EU's climate-driven shift and the productivity lead in EVs by China as starker than what was observed in the Japanese experience, we feed a similar market share increase as in the 1970s in the U.S. much more rapidly. What in the 1970s took place over a bit more than a decade, we now assume could take place within 5 years. In line with the recently announced new tariffs on Chinese EVs, we also explore scenarios in which the EV shock is accompanied by rising trade barriers. Finally, again reflecting on the past and recent experience, we model a scenario in which China switches to serving the EU market partly through FDI.

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[7] For example, the subsidized share (grants and loans) of total investment for Envision AESC (an EV battery factory) in France and Spain amounts to more than 30 and 20 percent, respectively, while for CATL in Hungary it amounts to 11 percent (in addition to a EUR 2 billion industrial park) (Rhodium Group, 2024).

Table 1. Comparing past and present to inform possible scenarios

	1960s-1980s, Japan	Present, China	Proposed scenario
EV-Shock: Demand and Supply	- Large shift prompted by oil price shocks and tightening emissions regulations. - Significant productivity growth differential favoring Japan.	- Very large shift prompted by green transition. - Very large productivity growth differentials.	- 15 percentage point increase in Chinese market share in European market over 5 years. Comparable to Japan's increase in U.S. market share, but in around half the time.
Trade restrictions	- Significant protection enacted within a decade. Equivalent to tariffs of 21 percent at the peak.	- Significant protection announced, with additional tariffs of 17.4-38.1 percent.	- Tariffs: 25-100 percent
FDI	- Within decade of instituting protection, about 40 percent of foreign sales done through affiliates.	- With current rate of FDI, significant share of EU demand will be met through foreign affiliates, with production coming online and ramping up towards the end of this decade.	- 40 percent of Chinese EVs produced in EU

3. Model Specification and Scenarios

3.1 BRIEF SUMMARY OF MODELS USED

To study the potential economic impacts of Europe's EV transition along with the rise of China as a major producer and exporter of EVs, we rely on two complementary structural models. The models are used to simulate both the dynamic and long-run impacts of the transformation of the automotive sector in Europe.

Global Integrated Monetary and Fiscal Model with Global Value Chains ("GIMF-GVC Model")

The first model used to study short- to medium-term dynamics is the IMF's GIMF-GVC. This is a multi-sector, multi-region, forward-looking general equilibrium model of the global economy (Kumhof and others 2010; Anderson and others 2013). GIMF-GVC differs from conventional GIMF applications by the inclusion of trade in intermediate goods (IMF, 2023, Chapter 4; Carton and Muir, forthcoming). This allows to capture important changes that take place along the automotive production chain that can extend across borders.

For our specific application, we consider a 7–region model that includes: Hungary, Czechia, Germany-France-Italy, Rest of Europe, United States, China and Rest of the World. There are three sectors, labeled the "non-tradable sector", the "tradable sector", and the "automotive sector". This last sector differs from the tradable sector by the inclusion of so-called roundabout production, whereby firms in the sector use some of their output in addition to labor and capital for production. The "automotive sector" is also characterized by lower elasticities of substitution to reflect the importance of supplier-specific relations in the production of goods along value chains, which are costly to change in the short-run. Calibration is done using the OECD's Inter-Country Input Output tables. Importantly, the model does not distinguish between EV and ICE automotive production. This is because of insufficient information to calibrate two separate sectors using input-output and macro data. Therefore, instead of explicitly modeling the impacts of shocks to EV production in China, the model makes the simplifying assumption that changes in total Chinese automotive market shares are caused by the growth in the

EV sector. Any differences in simulation outcomes compared to the steady state can then be attributed to underlying shocks in the EV sector. Key assumptions about elasticities of substitution are given in Annex 2.

Dynamic Quantitative Trade Model ("Trade Model")

A second set of simulations is carried out using a many-country, many-sector dynamic quantitative trade model, based on Cuñat and Zymek (2024). In the following, it will be referred to as the "trade model".

In the trade model, final consumption and investment require differentiated tradable inputs from many sectors that are subject to sector-specific bilateral iceberg trade barriers. As in the GIMF-GVC model, there is a single automotive sector in the economy. Economies differ in their reliance on, and productivity in, the different sectors. This creates a motive for international trade in goods and services, both between and within sectors. The resulting sector-level trade flows obey a structural gravity equation (Costinot and Rodríguez-Clare, 2014). Forward-looking agents with a stochastic lifespan make consumption and savings decisions, and differences in technologies and intertemporal preferences lead to cross-border trade in financial assets. This gives rise to an endogenous, non-degenerate distribution of capital stocks, asset wealth and trade balances across countries in the steady state of the model. The model can be used to analyze changes in steady-state trade patterns, real incomes, capital stocks and imbalances for given changes in trade barriers, productivities, and preferences, using "exact hat" algebra (Dekle et al., 2008).[8]

Both models are calibrated using data on trade flows, input and employment shares, fiscal variables and other key dimensions using averages over the period from 2016 to 2019. This calibration ensures that our baseline steady state is not influenced by the large shocks related to the COVID pandemic. This steady state forms the baseline scenario against which alternative scenarios are compared.

While GIMF-GVC allows for a rich analysis of intertemporal conditions notably on short-run changes in output, investment and trade, its description of intra-temporal equilibria is more limited. For instance, GIMF-GVC only has 3 sectors compared to the trade model's 40 sectors, and 7 countries/regions compared with the trade model's 68 countries/regions. Some key differences between the two models are highlighted in Table 2.

Table 2. Key Assumptions for the Structural Models

GIMF-GVC (Short- to medium-term)	Trade Model (Long-run)
Annual multi-region, dynamic general equilibrium model	Steady-state, multi-region, general equilibrium model
7 regions: Hungary, Czechia, France-Germany-Italy, Other Europe, USA, China and Rest of the World	68 individual economies (including 27 from EU, 34 from EUR) and Rest of the World
3 sectors: Non-tradable, Tradable and Automotive sectors	40 sectors, including Motor Vehicles (ISIC C29) + Other Transportation Equipment" (ISIC C30) = Automotive sector
Car sector is roundabout, with lower elasticities of substitution	Roundabout production with sector-specific input shares; compatible with sector-level structural gravity equations (elasticities from Fontagné et al., 2022)

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[8] For a high-level description of the model, and calibration details, see Annex A.II.(II). For full modelling details, see Cuñat and Zymek (2024).

3.2 SCENARIOS

The “EV-Shock”

Our EV-shock scenario combines two shocks to calibrate a 15 percentage points increase in China’s share of EU spending over 5 years. The first is a supply shock that increases total factor productivity (TFP) in China’s automotive sector by 15 percent. The relatively high productivity growth assumed for the Chinese automotive industry implicitly captures the strong productivity growth in Chinese EV production, which has lowered the prices of EVs made in China.[9] The overall TFP shock corresponds approximately to the productivity growth differentials observed between Japan and the U.S. in the 1970s (see Annex Figure A1.1). A pure EV-biased productivity shock in China would have to be unrealistically large to increase in China’s share of EU spending on cars by around 15 percentage points over 5 years. Hence, we introduce a second shock, a policy-driven demand shock, that shifts consumption shares and inputs towards EVs, in line with the rapid electrification required under EU regulation. As explained above, we do not directly observe the EV share of car production in inter-country input-output data. However, in Annex III we show that under the assumption that ICE vehicles and EV are substitutable car outputs with a similar production structure, a generic shift in consumer preferences towards EVs leads to a demand shift towards Chinese car sector output if China enjoys a productivity advantage in the (unobserved) EV variety of car output. In terms of macroeconomic impacts, this is observationally equivalent to a growing “China preference” in the overall car sector by EU consumers.

The EV-shock scenario is modeled in a similar way in GIMF-GVC and trade model. We assume that most of the rise in penetration plays out over only 5 years. In the long run, 16.3 percent of EU car spending goes to Chinese vehicles, compared with just 1.3 percent in the 2016–19 period. However, the trade model only compares steady states in which the two shocks have fully played out. The transition path of the shocked parameters is relevant just for GIMF-GVC, which describes the transition dynamics from a period 0 onwards. The paths of the shocks and their macroeconomic effects are assumed to be fully known to agents in period 0.

Trade restrictions

A second scenario assumes that the EU adopts protectionist policies in response to the increasing market penetration by Chinese EV manufacturers. We assume that these policies take the form of additional tariffs of 25 percent or 100 percent, applied to automotive sector imports from China. We then analyze the impact of these tariffs on GDP when layered on to the “EV shock” scenario and compare to the base case in which there are no shocks: China’s auto-sector productivity remains fixed at pre-2023 values and no policy-induced demand shifts take place in Europe.

Our models allow for a dynamic response of capital accumulation to the introduction of trade barriers, but they do not feature a channel through which trade barriers could endogenously affect the evolution of sectoral productivities and, hence, countries’ comparative advantage in EV production. While there is broad consensus on modelling the gains from trade conditional on given sectoral productivities, there is much less consensus on the existence and magnitude of the dynamic response of comparative advantages to trade-barrier changes, for

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[9] Alternatively, this could have been modeled as the result of government direct and indirect subsidies or a mix of both productivity and subsidy. Given the lack of information needed to calibrate the former, we opt to only use a productivity shock. This assumption should be inconsequential when focusing on the impacts in Europe.

example through learning-by-doing or the so-called infant industry argument. We therefore ignore these potential channels (see Melitz and Redding, 2023 for a recent overview of the literature).[10]

FDI

The third scenario provides a quantification of the effects of a delivery of Chinese EVs to the EU market via FDI. Since neither GIMF-GVC nor the trade model allow for foreign ownership of firms, the FDI scenarios in each model amount to changes in investment-related parameters in the automotive sector in Europe that limit the increase in Chinese import penetration to 10 percentage points in the long run, compared with 15 percentage points in the EV shock scenario. Specifically, this is achieved in GIMF-GVC by reducing the equity premium in the automotive sector in Europe, which makes it cheaper for firms in the sector to borrow for investment purposes. The FDI scenarios also entail reducing the markup in the sector to replicate the increase in competition that should result from the entry of new firms. Finally, the scenarios assume that the increase in demand and input weights for Chinese EVs from the baseline EV shock is partially reversed since part of the new demand for EVs in Europe can now by met by Chinese firms producing domestically.

In the trade model, we introduce an EV-biased EU car-sector productivity catch-up and an increase in EU investment efficiency. The changes in the structural parameters are calibrated so that European imports of Chinese EVs decline from their peak of around 15 percent of total domestic production to 10 percent after around 3 years. This is broadly consistent with the Japanese experience, in which eventually around 40 percent of Japanese cars sold in the U.S. were produced in the U.S. (see Annex 1).

Two versions of the FDI shock are considered in GIMF-GVC. A first version allows for FDI-led increase in investment in all European regions in proportion to the current size of their automotive sector. This is done by assuming that equity premium, markups and demand shifts change by the same magnitude in all four European regions. A second FDI scenario allocates a disproportionate share of the additional investment and demand for European-made EVs to Hungary specifically, consistent with recent FDI patterns. This is achieved by increasing the demand for Hungary automotive production in all European regions. In the trade model, we only consider the case in which this FDI effect is proportional to economies' initial automotive-sector size, and do not provide a separate long-run scenario for Hungary-directed FDI.

4. Simulation Results

4.1 THE "EV-SHOCK"

Figures 6 and 7 show the impact of the "EV-shock" on countries' GDP. While the overall impact on GDP for Europe is small, there is significant heterogeneity across countries. Many economies in the CESEE region—in particular, Czechia, Hungary, and Slovakia—are highly dependent on the automotive sector. Based on the OECD's ICIO database, the automotive sector is around four times larger relative to other regions in terms of factor and domestic value-added shares. Furthermore, the sector is highly capital-intensive and in the case of Hungary and Czechia substantially more productive than the rest of the economy. Therefore, as shown in

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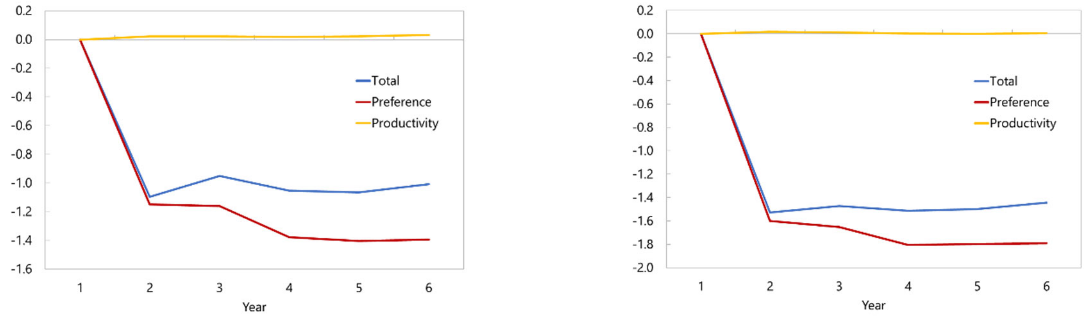
[10] Melitz (2005) shows that support for domestic sectors can potentially deliver additional dynamic gains under strong learning-by-doing effects and low substitutability between foreign and domestic varieties. Barwick and others (forthcoming) analyze the effect of various Chinese subsidies on the EV sector and show that they are consistent with significant learning-by-doing in battery production. They argue that EV manufacturers from other countries who source from these battery manufacturers can benefit from this learning. For the subsidizing of domestic battery producers in other countries to be beneficial, learning potential should be substantial. In WTO contexts, the protection of infant industries to facilitate the dynamic evolution of comparative advantage has so far been confined to the special and differential treatment afforded to developing countries (see e.g. WTO, 2014). For an in-depth analysis of industrial policies in the European context, see Goretti and others (forthcoming).

Figure 6 the potential displacement of activity and labor from the sector resulting from a loss of competitiveness has larger macroeconomic effects for these economies.

- **Short/medium term**. The EV-shock in GIMF-GVC results in GDP losses of 1 percent for Hungary, 1.5 percent for Czechia and around 0.2 percent for Germany, France, Italy and the rest of Europe after 5 years. While the productivity increase in China benefits consumers through cheaper cars and inputs, the policy shock moves demand away from ICE vehicles produced in Europe towards Chinese EVs (Figure 5). This causes production in Europe to fall and imports from China to increase. As shown in the Figure, the negative impact of the demand shock dominates that of the supply/productivity shock, which is slightly positive. CESEE countries, like Czechia and Hungary, are particularly affected given their significant dependence on the automotive sector. Slovakia is not included in the model. The impact in Germany, France and Italy, the hub of the automotive supply chain in Europe is more modest, a result of their much more diversified economies. This is also the case for the rest of Europe. These output losses do not translate one-to-one to the export side, however. While the China EV productivity shock causes European car exports to decline, the policy shock causes exports to *increase*. The reason for this is that European consumers no longer want to buy as many of the cars they manufacture. So domestic producers now export a larger surplus to other markets. Finally, while GIMF-GVC allows for labor to move across sectors in the economy, workers cannot move across countries.

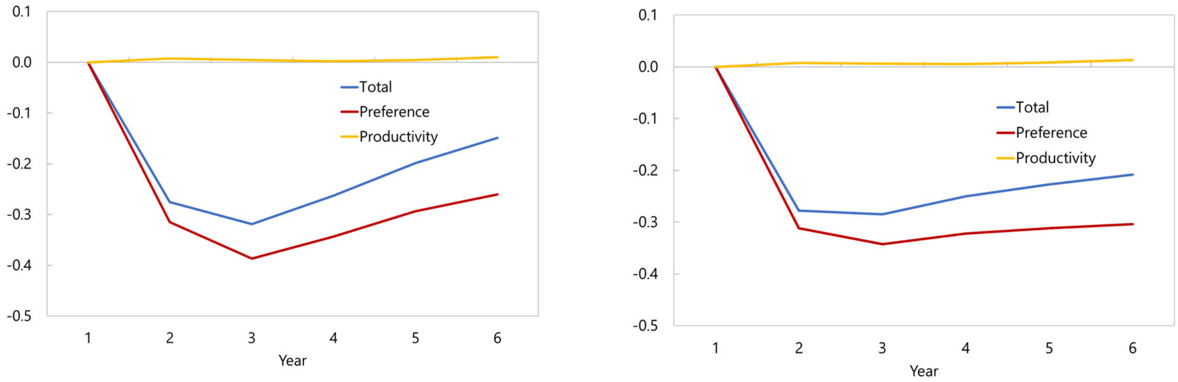
- **Steady-State**. Even in the long run, after economies have fully adjusted, China's penetration of the EU car market leads to sizeable losses for some EU economies in the trade model. As in GIMF-GVC, Hungary and Czechia incur some of the largest losses. However, the trade model highlights Slovakia as the worst affected EU country, with GDP losses exceeding 1 percent in the long run. The cause is a long-run terms-of-trade deterioration for these economies brought about by factors that affect both export and import prices. First on the export side, European economies must sell cars at lower prices, a consequence of stiffer competition from cheap Chinese EVs on world markets. While this affects only a share of their exports, labor reallocation and higher production from the automotive to other tradable sectors pushes European exports further down their partners' demand curves. This higher supply of other tradable goods causes overall export prices to decline. On the import side, all European economies benefit from cheaper Chinese EVs, which improves their terms-of-trade. However, a long run decline in real exchange rates that results from the policy and EV-related demand shifts makes raises the domestic prices of imports. This deterioration has larger macroeconomic consequences for smaller economies, and economies whose exports are relatively concentrated in the car sector – as is the case for Slovakia. On the other hand, countries not reliant on car manufacturing mainly benefit from cheaper EV imports from China, with the overall impact on EU incomes negligible.

Figure 6. GIMF-GVC: GDP Effects of Productivity Shock and Demand Shocks



Hungary

Czechia

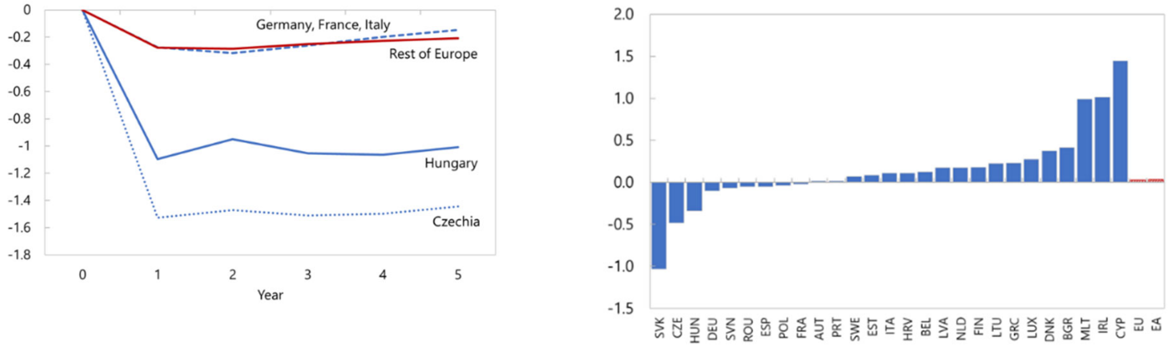


Germany, France, Italy

Rest of Europe

Sources: OECD; PWT; Fontagné et al. (2022); and IMF staff calculations.

Figure 7. "EV-Shock" and GDP Effects



GIMF-GVC: Short-run GDP Effects of EV Shock
(Percent, deviation from steady state)

Trade Model: Steady State GDP Impacts of EV Shock
(Percent, deviation from steady state)

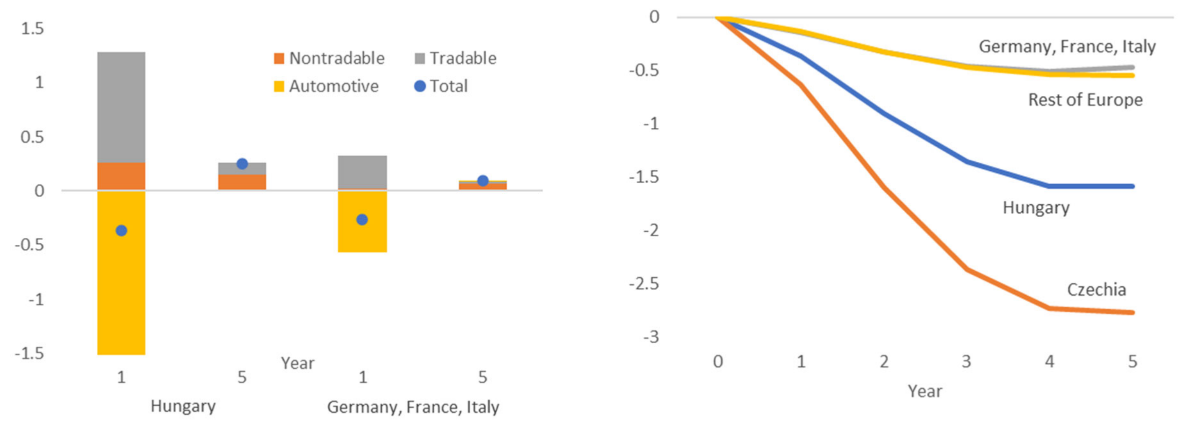
Sources: OECD; PWT; Fontagné et al. (2022); and IMF staff calculations.

We can also use our models to gauge the labor market effects of the EV shock (Figure 8). In addition to output effects, the underlying economic adjustment requires significant labor reallocation for the affected economies. Neither GIMF nor the trade model can capture the potential transitional cost of this relocation such as, for example, the economic and social costs of a period of elevated unemployment or the transition of workers out of the labor force.

- **Short/medium term**. In GIMF-GVC, the EV-shock leads to a small increase in employment after 5 years, but with a large initial reallocation away from the car sector to the tradable and non-tradable sectors as illustrated for the case of Hungary and Germany, France, Italy in Figure 8 below. The reallocation results from a combination of relative changes in sectoral labor demand (from automotive to other tradable and non-tradable sectors) and expenditure switching caused by a depreciation of the exchange rate. After an initial decline, aggregate labor settles at a slightly higher level over the medium term. Wages fall, again by more in the more affected regions. Despite total labor remaining broadly constant over the medium term, its reallocation to the tradable and non-tradable sectors means that labor is now more concentrated in lower productivity sectors in Hungary and Czechia, where the automotive sector enjoys among the highest labor productivity. In contrast, labor productivity is more equally distributed in Germany, France, Italy and the Rest of Europe so that workers who previously worked in the automotive can find employment in other similarly productive sectors. The labor reallocation is therefore less costly for them in terms of overall labor productivity in the economy, while also being smaller in magnitude.

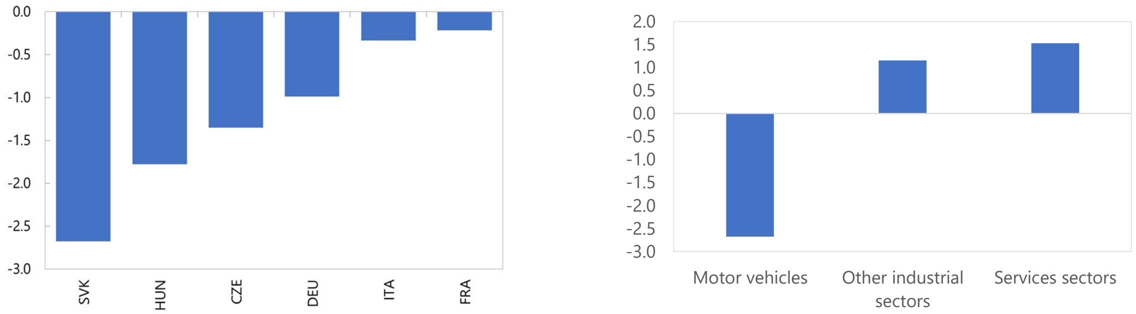
- **Steady-State**. In the trade model, the EV shock implies significant labor relocation away from the auto sector, amounting to as much as 2.6 percent of the workforce in the case of Slovakia, and 1.7 percent in Hungary. Zooming in on Slovakia, as an example, the trade model suggests that, everything else constant, most of these workers are ultimately absorbed by other manufacturing sectors as well as the retail sector. A labor adjustment of this magnitude would likely entail significant transition costs.

Figure 8. Labor Market Effects of EV Shock



GIMF-GVC. Employment Effects of EV Shock
(Percent, deviation from steady state by year)

GIMF-GVC. Wage effects of EV Shock
(Percent, deviation from steady state)



Trade Model: Employment Losses in Motor Vehicle Manufacturing
(Percent of total workforce)

Trade Model: Long-Run Employment Changes by Sector and Sector Groups for Slovakia
(Percent of total workforce)

Sources: OECD; PWT; Fontagné et al. (2022); and IMF staff calculations.

Table 3. Car-Sector Productivity Rise Required to Offset Real Income Loss
(Percent, deviation from steady state)

SVK	2.60
CZE	1.90
HUN	1.80
LUX	1.50
SVN	1.40
DEU	1.20
ESP	1.10
POL	1.00
ROU	0.80
AUT	0.60
FRA	0.60
SWE	0.50

Source: IMF staff calculations.

Finally, an interesting question is how much of a productivity increase is needed in the EU auto sector to overturn steady state welfare losses from the EV shock in the most affected countries. The trade model (Table 3) suggests that modest productivity gains in the car sector could be sufficient to protect average welfare in the EU's main car producers. These productivity improvements, while non-trivial, are only a fraction of the original 15 percent TFP increase for the Chinese automotive sector we assume in the baseline scenario. The main reason for this is that while Chinese EV imports eventually account for 15 to 20 percent of total domestic production, a majority of cars are still produced in Europe. The smaller productivity gains from Table 3 therefore benefit a much larger share of workers and firms. This suggests that policies to encourage innovation in domestic EV production will be an important lever to support the EV transition in Europe.

In this context, it is worth noting that European automakers innovation efforts are on par with those elsewhere. Data for the top 2,500 firms that globally invest most in R&D, from the 2023 EU Industrial R&D scorecard, show that large European automakers' R&D expenses represent 5.5 percent of net sales—compared to 5.3 and 5.1 percent for Chinese and American top automakers, respectively. Similarly, De Santis and others (2024) point out that European transport-related patents during 2020-22 exceed those files by China and the U.S. In all, should these efforts be consistently geared toward improving productivity in the EV sector, the losses from our baseline scenario could be potentially offset.

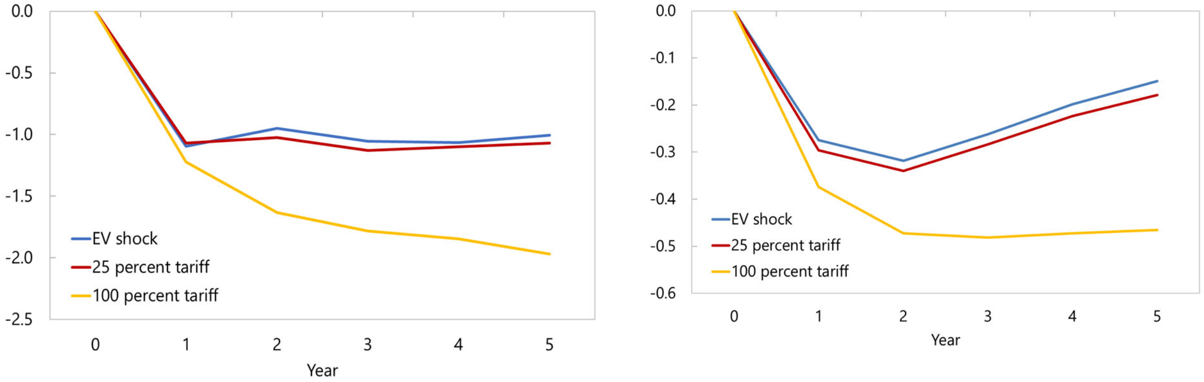
4.2 PROTECTIONIST RESPONSE SCENARIOS

We now turn to the question of different protectionist responses by the EU might affect how the EV shock plays out. We primarily consider the impact of a 25 percent and a 100 percent additional tariff on all Chinese automotive imports into Europe. We find that while such tariffs are effective at reducing car imports from China, they result in worse GDP outcomes, both in the short and long run (Figure 9). The negative impact on GDP operates through several channels. First, tariffs prevent consumers from benefitting from the cheaper EVs, lowering their real disposable income, and their demand for other goods and services. While tariffs do promote some domestic production to compensate for lower Chinese imports, they are not sufficient to fully restore production in Europe's automotive sector. Because the automotive sector features large input-output links, tariffs on Chinese auto sector imports, including intermediate goods, are both lower in the medium- and long-run than for the non-tariff scenario. This suggests that a protectionist response – even one that does not impact the EU's ability to meet its targets for emissions reductions – would likely entail greater output costs for EU economies than status-quo policy. costs for EU economies than status-quo policy.

- **Short/medium term.** The impulse responses in Figure 9 show how GDP is affected by the EV shock and the protectionist policies in GIMF-GVC. We show here that GDP in Hungary and Germany, France, Italy – all of which are relatively exposed to the EV shock – performs worse in the short run with the tariffs, as represented by the yellow and red lines. While the tariffs support employment and promote domestic production in the auto sector and yield some very limited revenue, they do so at the expense of other tradable and non-tradable sectors through exchange rate appreciation and lower investment. They also prevent consumers from benefitting from cheaper cars from China, lowering their demand for other goods and services. In addition, while the tariffs imposed on intermediate inputs from China increase the EU production of such inputs, they also increase input costs from the tariff imposed on Chinese imports and lower labor productivity in the auto sector and therefore real wages for the whole economy. Finally, Hungary and other Eastern European economies specialized in auto manufacturing import relatively more car parts from China, so production costs increase by more with the introduction of tariffs. These factors also explain why output losses caused by tariffs are larger for Hungary (where auto production accounts for a larger share of GDP) than for Germany, France, Italy.

- **Steady-State**. Long-run real GDP is lower, and especially so for the economies that were previously winners from the EV shock. In the context of the trade model, a 25 percent tariff would be sufficient to forestall most of the increase in Chinese car-market penetration. Instead of rising by 15 percentage points, the share of Chinese-imported cars in EU car-sector spending now only rises by 2.5 percentage points. Nevertheless, even though this would entail relatively smaller losses for car producers, these "gains" are more than offset by the higher prices consumers would have to pay for EVs across Europ

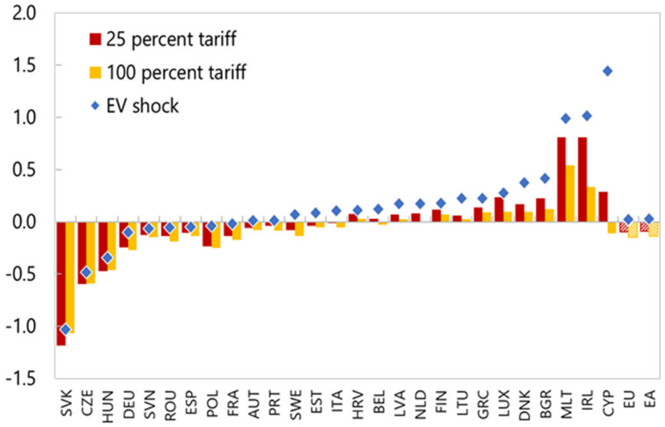
Figure 9. GDP Impact of Protectionist Responses



GIMF-GVC: Short-Run GDP Impact of EV Shock with Tariffs: Hungary
(Percent, deviation from steady state)

GIMF-GVC: Short-Run GDP Impact of EV Shock with Tariffs: Germany, France, Italy
(Percent, deviation from steady state)

Trade Model: Steady State GDP Impacts of EV Shock with Tariffs
(Percent, deviation from steady state)



Sources: OECD; PWT; Fontagné et al. (2022); and IMF staff calculations.

4.3 INCREASED FDI INFLOWS SCENARIO

Finally, we explore what would happen if higher EV demand in Europe is met by Chinese firms producing directly in Europe via increased FDI. We consider two alternatives. The first assumes an increase in Chinese FDI that is proportional to the size of each economies' auto sector. Specifically, this assumes that the structural shocks are of the same size for all European countries, notably the partial reversal of the policy-induced demand shift back towards European production.[12] A second alternative for the FDI scenario assumes instead that Hungary receives a disproportionate amount of FDI, in line with recent patterns (section 2.2). This outcome is achieved in the model by assuming that European demand for Hungarian EVs increases by more than other economies. In both cases, we find that FDI can reduce the output costs of the transition by boosting local EV production (Figure 10).

- **Short-medium term.** Proportional Chinese FDI reduces GDP losses in GIMF-GVC, as shown by comparing the blue and yellow lines. Higher FDI benefits both CESEE and the EA3 block, with the short-run impact on GDP operating mainly through higher investment. The effects on GDP levels after 5 years are around 0.5 percent for Hungary, and 0.15 percent for Germany, France, Italy and the rest of Europe. Hungary-focused FDI turns Hungary into a modest net GDP winner after 5 years. Despite Hungary benefiting significantly more from Chinese FDI inflows, the small size of its economy means that other regions in Europe are largely unaffected by the different allocation as evidenced by the overlapping yellow and red lines in the top-right panel of Figure 10.

- **Steady-State.** The FDI scenario in the trade model undoes some of the economic losses from the baseline scenario in the worst-affected EU economies proportionally. In practice, the distribution of gains compared with the baseline scenario (averted losses) may depend on whether some individual economies are more successful in attracting Chinese FDI than others.

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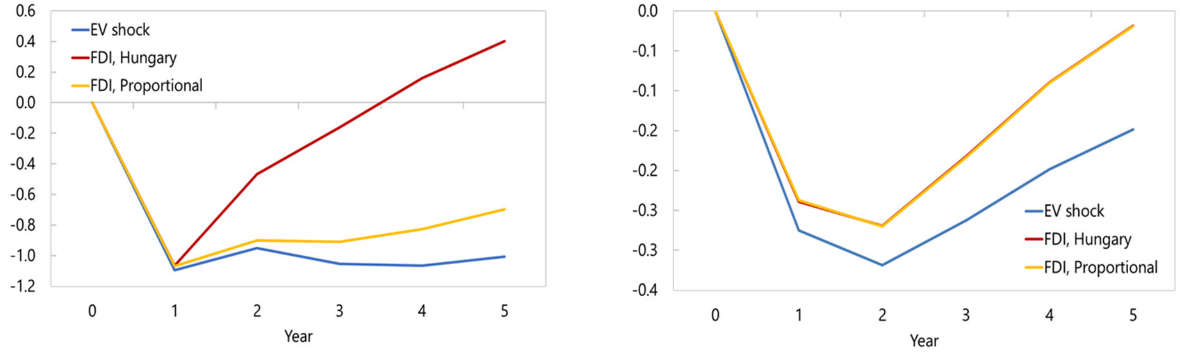
[12] As explained in Section 3.2, since neither GIMF-GVC nor the trade model allow for foreign ownership of firms, this scenario is modeled as the result from declines in equity premium and markups in the automotive sector in Europe, improvements in productivity and investment efficiency, and a partial reversal of the demand shift back towards European-produced cars.

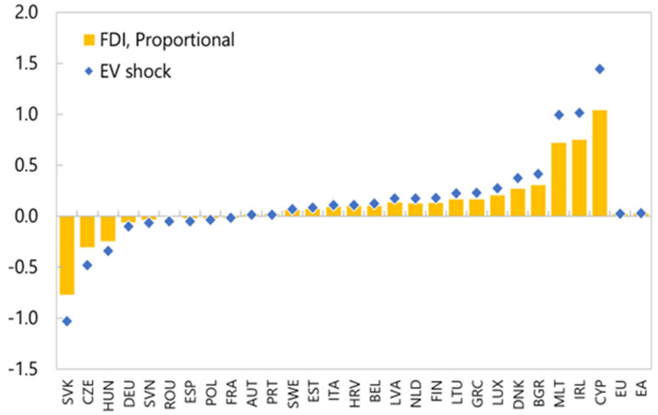
Figure 10. Impact of FDI on GDP



GIMF-GVC: Short-Run GDP Impact of EV Shock with FDI: Hungary
(Percent, deviation from steady state)

GIMF-GVC: Short-Run GDP Impact of EV Shock with FDI: Germany, France, Italy
(Percent, deviation from steady state)

Trade Model: Steady State GDP Impacts of EV Shock with FDI
(Percent, deviation from steady state)



Sources: OECD; PWT; Fontagné et al. (2022); and IMF staff calculations.

5. Climate Implications

In addition to the impact on output, we are interested in the implications of trade restrictions for emissions. Despite having a single representative automotive sector in GIMF-GVC and the trade model, it is possible under mild assumptions to track the share of EVs in EU car purchases each period across the different scenarios. As we show in Annex III, under this novel approach it is sufficient to assume that: i) demand for ICE and EVs, given total demand for cars, can be described by a constant elasticity of substitution function, and ii) that the productivity improvement in the automotive sector in China can be entirely attributed to productivity improvement in EV production. Using projections of the EU's EV adoption path as well as estimates for the average vehicle life span, we can project carbon emissions under alternative tariffs scenarios. By construction, note that the share of EVs approaches 1 in the long run in all scenarios (given our assumption that the "fit-for-55" targets are met). However, it does so at a slower speed in the presence of tariffs than in the EV shock scenario without tariffs, as the increased price of Chinese EVs to EU consumers causes some substitution back towards traditional vehicles during the transition. Using estimates from IEA (2024) on the relative lifetime emissions from EVs, we can compute the additional emissions from this slower path of EV adoption.[13]

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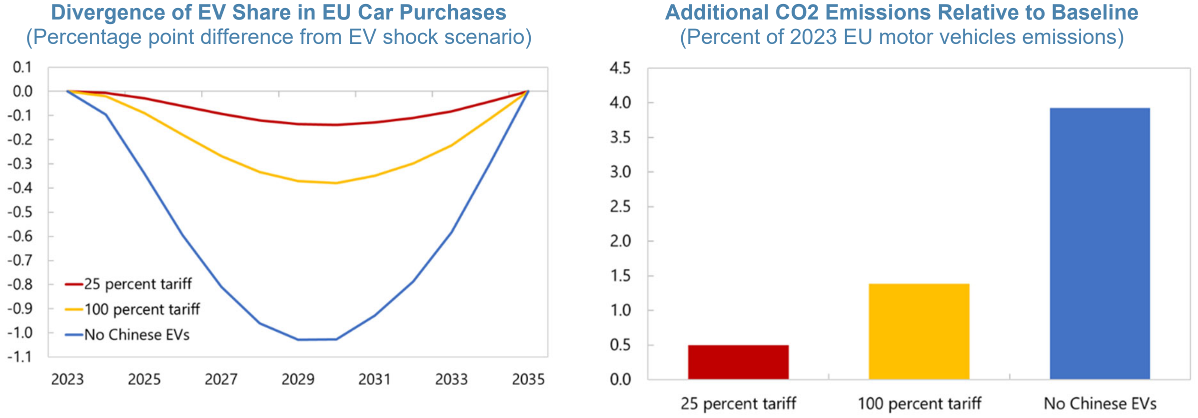
[13] See Annex III for details.

Figure 11 shows the impacts of tariffs on EU EV adoption and emissions from the automotive sector during the transition. While tariffs have an impact on the speed of adoption of EVs, the impacts are modest. Even if we assume that Chinese vehicles are fully banned from the EU market—a case represented by the blue line–the share of EVs in new cars purchased is only reduced by 1 percentage point at peak. Once again, the reason for this is that Chinese EVs constitute a small and declining share of total EVs produced in the EU, at least beyond the first few years. For instance, under the assumption that the EU reaches its transition target along a linear path, in 2030 63 percent of new vehicles sold would be EVs (Annex Table A3.1). Under a 100 percent tariff, Chinese EV imports would amount to less than 10 percent of total new cars sold. A tariff or even a full import ban would not affect the majority of new car purchases.

Consequently, the implications of tariffs on EVs or banning Chinese EVs for emissions are modest too. As can be seen in the right panel of Figure 11, even with a full ban on Chinese vehicles, the additional emissions generated are just 4 percent of 2023 EU car sector emissions. Hence, assuming that climate policies are not changed, the main downside of protectionism is the increased economic cost of the EV transition, as described in the previous Section. This finding hinges crucially on the assumption of an unchanged policy stance towards EVs. If the increased economic cost of the EV transition were to cause a postponement of the EU's EV adoption goals, the additional emissions generated would likely be much larger.

Figure 11. Emissions Impact of Protectionist Responses



Sources: IEA; and IMF staff calculations.

6. Conclusion

Two large structural shifts are looming for Europe's automotive sector, which has long been a driver of integration and growth: first, the green transition, which will require a rapid transition to EVs, and second, increased competition in the EV sector from China. In this paper, we examine the possible consequences of a sharp increase in imports of Chinese autos for the EU macroeconomy. In particular, we examine scenarios in which the Chinese share in EU auto purchases rise from about 1 percent in 2016-19 to 16 percent by 2030, similar to the rise in auto imports from Japan in the 1960s through the 1980s in the United States. The scenarios assume that the increase in imports of Chinese autos results from relative productivity and demand shifts. The analysis allows us to better understand which policies may sharpen or ease the trade offs between the shift towards EVs and macroeconomic outturns.

We find that for the EU as a whole, the GDP cost of a shift towards greater auto imports from China is likely to be small in the short-term and close to zero over the long-term. However, the impacts vary significantly across countries. Real GDP losses are significant in the range of 1-1½ percent over 5 years, and persisting in steady state, for a number of economies heavily reliant on the car sector, mainly in Central Europe, where demand for domestically-produced autos and auto-sector inputs shrinks, production shifts away from a high-productivity sector to lower productivity sectors, and labor earnings fall. Meanwhile, EU economies that are not so exposed to auto production benefit, given the availability of cheaper EVs thanks to Chinese imports. Results from both models point to some employment losses in the motor vehicle sector, and the need for employment to shift to other sectors, highlighting the gains from policies to ease the reallocation of labor during the transition. The simulations also show that the driver of the rise in auto imports from China matters. The costs of the transition would be smaller the more the increase in imports is driven by the relatively high productivity growth in producing EVs is China, and the relatively low price of Chinese vehicles, as opposed to preference shifts towards Chinese autos.

Importantly, tariffs against Chinese autos and auto parts magnify the simulated GDP cost of transitioning towards EVs (assuming 2035 "all EV" goal for new cars can be maintained under tariffs). Tariffs amplify the GDP losses because the GDP gains from shielding the European automotive sector from Chinese competition is not sufficient to compensate for GDP losses due to lower purchasing power for EU consumers and losses imposed on other sectors of the economy through costlier inputs and an appreciated exchange rate, which lower exports and investment. On the other hand, Chinese FDI into EV production in the EU that eases the increase in imports by ramping up European EV production, or seemingly achievable productivity gains in the EU auto sector, can mitigate the income losses for the worst affected EU economies.

It is important to bear in mind the caveats to the model estimates presented in the paper.

First, the transformations looming for the auto sector are large and unprecedented, and there is wide uncertainty on future trends. While we anchor the scenarios largely on Japan's experience in the U.S. market, the outturns could be different. As our historical comparison shows, many of the current and prospective trends for the auto sector—e.g., the productivity growth differentials, policies to encourage EV adoption, consumer preferences for different auto models—could possibly bring about a faster and larger shift than the 1970s experience. At the same time, there has recently been significant pushback by some countries against the forthcoming EU combustion engine vehicle ban. In that context, it is important to be mindful of an inevitable degree of uncertainty around the scenarios and estimates we present.

Second, our models abstract from labor reallocation costs (although this reallocation takes time in GIMF-GVC given wage rigidities), which may lead us to underestimate the economic losses in the short- to medium-term. Proactive policies to help auto sector workers re-skill and find employment in other sectors are critical to limit the costs of the transition (see also Celasun and others, 2023).

Third, in our tariff scenarios we leave out the potential for retaliation and its adverse consequences, which could raise the macroeconomic costs of imposing tariffs significantly.

Finally, our estimates on the emissions implications of the different tariff scenarios also assume that the "Fit-for-55" 2035 targets banning EV sales are met, despite higher EV prices. Postponing current climate goals in the EU because of higher EV prices (due to tariffs on imports) could significantly raise emissions and impact growth (see e.g., Bilal and Kaenzig, 2024).

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ANNEX I. THE JAPANESE EXPERIENCE: LESSONS FROM PAST STUDIES

In this annex we carry out a focused survey of the literature that analyzes the case of Japan's rise. Specifically, the goal is to shed light on the following questions:

(i) *The roles of demand and supply*: What was the relative importance of supply (productivity) shocks in Japan and policy-induced demand shifts in the surge in market share of Japanese brands?

(ii) *Japanese government support*: What was the role of government support in Japan's rise?

(iii) *Trading partners' policy responses*: What were the effects of the different policy responses initiated in the 1980s and to what extent do they account for the higher penetration that resulted in the U.S. than in Europe?

(iv) *Japanese FDI response*: What was the productivity impact of Japanese FDI, which was driven by the need to circumvent border barriers?

(I) THE ROLE OF SUPPLY AND DEMAND SHIFTS

Taken together, the evidence from the literature suggests that while Japan's productivity had been rising for some time, its productivity edge over others took place in the 1970s—in tandem with a shift in demand toward the cars Japan was producing. This is best seen when analyzing the case of the U.S., where restrictions were not put in place until the 1980s.

Table A1.1. Labor Productivity of General Motors and Toyota (US dollars/person)

	GM	Toyota
1950s	8,400	3,583
1960s	13,300	8,639
1970s	12,600	14,250
1980s	16,500	30,167

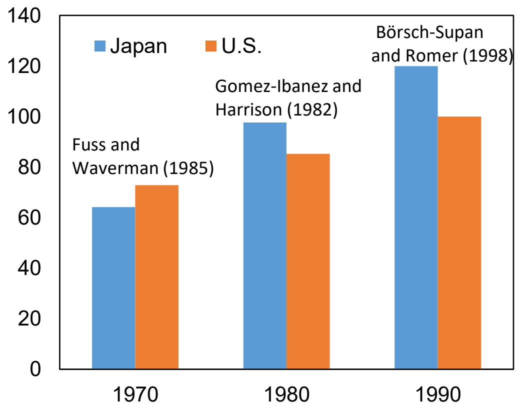
Source: Kawahara (1998).

Note: Labor productivity is in 1960 US dollars.

Japanese firms' productivity started to rise in the 1950s, with an edge established by 1980. Since the 1950s, Japanese auto producers developed and adopted several processes that markedly increased the productivity and product quality, including the just-in-time system, the concentration of production facilities in a single location, defect reduction by assigning quality control to production workers, and a quality circle whereby workers are asked for advice on product improvement (Hart, 1992). The improvement in efficiency can be seen in Table A1.1, where labor productivity of Toyota surpassed that of General Motors in the 1970s.

Various studies have attempted to quantify the productivity of the Japanese auto industry relative to other economies. Fuss and Waverman (1985) estimate annual TFP growth of the Japanese auto industry in the 1970s to be 4.3 percent, much higher than that of the Canadian and U.S. industries at 1.4 and 1.6 percent respectively. Gomez-Ibanez and Harrison (1982) suggest that the cost advantage of Japanese small cars manufactured and shipped to the United States was between 13.0 and 16.1 percent around 1980.

Figure A1.1. Estimated TFP Level in the Auto Industry



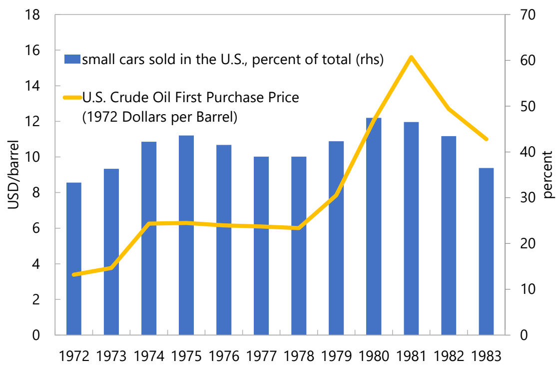
Sources: Fuss and Waverman (1985), Gomez-Ibanez and Harrison (1982), Börsch-Supan and Romer (1998), and IMF staff calculations.

Note: 1990 U.S. TFP = 100.

Combined, the findings by Fuss and Waverman (1985) and Gomez-Ibanez and Harrison (1982) suggest that Japan took over Canada and the U.S. productivity levels at some point during the 1970s. Börsch-Supan and Romer (1998) show that, by the early 1990s, Japan's auto industry TFP was 120 percent of the U.S. and 171 percent of Germany. Taken together, Japan's auto industry productivity growth was 1-3 percentage points higher than in the U.S. during the 1970s and 1980s. Figure A1.1 summarizes the results. Increased productivity and competitiveness helped Japanese firms seize the market share from the U.S.

Large demand shifts since the early 1970s to smaller and more fuel-efficient cars created the conditions for the takeoff of Japanese brands in the United States. The 1970s saw two oil price shocks[1] that led to significant changes in the composition of auto demand in favor of small and fuel-efficient cars (Bresnahan and Ramey, 1993). The increase in demand for small cars was largely unmet by American firms: inventories of small cars remained low despite rapid conversion attempts from standard-size cars to small and intermediate-size cars. This gap was eventually partially filled by Japanese brands. Imported cars increased from between 15 and 18 percent of U.S. domestic sales in the 1970s to 27 percent in 1980, with Japanese imports accounting for 21 percent (Gomez-Ibanez and Harrison, 1982). However, Japanese firms also faced supply constraints and their production almost always reached full capacity (Gomez-Ibanez and Harrison, 1982). The increase in Japanese imports also took place in a period of yen appreciation and rising Japanese car prices (Kwoka, 1984), likely a result of both the demand shift and increasing product quality.

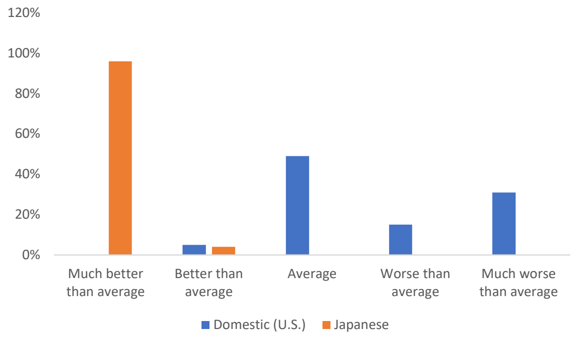
Figure A1.2. The Oil Shock and the U.S. Shift Toward Smaller Cars



Sources: Berry et al. (1999); U.S. Energy Information Administration; and IMF staff calculations.

Slow catchup of American producers in the small-car market further catapulted Japanese producers' rise. Before the 1970s, the U.S. auto industry was characterized by high concentration and low gas prices. Market concentration was high, with only three major producers: General Motors, Ford, and Chrysler. With low gas prices, the supply was mainly of large cars. In response to competition from Japanese firms, American producers attempted downsizing to meet the demand of smaller cars in the late 1970s, but with only partial success. The average U.S. consumer still perceived Japanese cars to be of higher quality, with consumer reports showing that Japanese cars achieved vastly higher quality standards (see Figure A1.3).

Figure A1.3. Consumer Reports Repair Ratings for 1981 Cars in the U.S.



Notes: This figure reproduces the 1981 consumer reports ratings, calculated in Kwoka (1984). Consumer Reports surveys owners' repair experience with approximately 160 models each year. In each category (domestic or Japanese), the percent of models across ratings sums to 100 percent.

Source: Kwoka (1984).

(II) JAPAN'S GOVERNMENT SUPPORT

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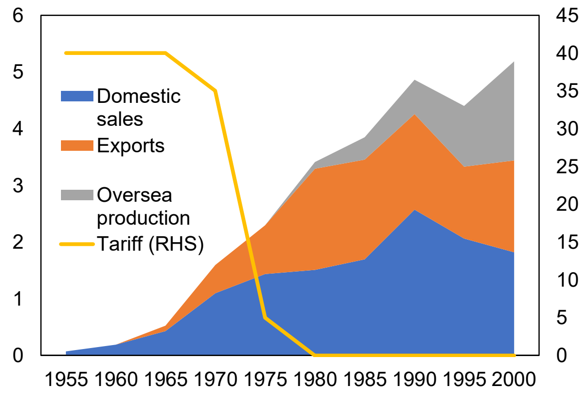
[1] In the United States, real oil prices increased by 28 percent between October 1973 and May 1974 and by 42 percent between February 1979 and March 1980 (Bresnahan and Ramey, 1993).

Government support played an important role in the development of the Japanese auto industry. During the nascent stage of the auto industry's development, Japan's Ministry of International Trade and Industry (MITI) provided high but not prohibitive protection to the automobile industry through import quotas, tariffs, and restrictions to FDI (Nishijima, 2012). This offered Japanese car makers a shielded domestic market before the 1970s. MITI also supported the industry through a combination of low-interest loans and tax privileges before Japan joined the GATT (the precursor of the WTO) in 1964 (Hart, 1992).

Throughout the development stages, the catalytic role played by the MITI is important. Low-cost financing from the Japan Development Bank (JDB) to industries selected by MITI acted as leverage for private finance (Odano and Islam, 1994; Hart, 1992). The signaling effect of JDB lending that the auto industry was the government's targeted industry was far more important than the actual amount of loans that JDB provided. Odano and Islam (1994) estimate that for one-unit increase in JDB loans, there is a 14-unit increase in the private banks' loans to the auto industry between 1955–1985. Rapidly increased financing from banks preceded the expansion of the auto sector (Figure A1.4) and was crucial for its takeoff. MITI provided subsidies to both car producers and their subcontracting firms.

Figure A1.4. Government Support and Liberalization

Toyota's Production and Tariffs on Passenger Cars



Notes: The left chart shows the Japanese tariffs on imported cars along with Toyota's production, domestic sales, and exports (Nishijima, 2012). The right chart presents the fraction of Japanese cars on the U.S. market that were produced in the U.S., based on Japanese assembly plants opening dates and capacity in Hart (1992) and Japanese market shares in Berry et al. (1999).

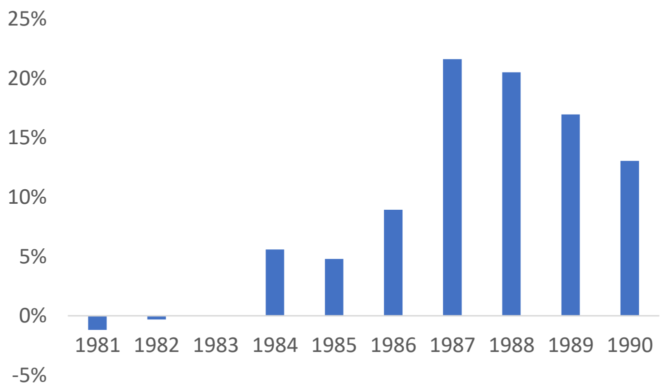
Sources: Odano and Islam (1994), WIOD, Berry et al. (1999), and IMF staff calculations.

Support was eventually phased out. As the auto industry took off, MITI announced and followed a plan to liberalize trade, lifting import quotas in 1960 for buses and trucks, in 1965 for passenger cars, and in 1972 for engines. Tariffs were reduced from 40 percent to 10 percent in 1971, to 5 percent in 1973, and zero percent in 1978, and FDI was liberalized in 1971 (Nishijima, 2012). Such phaseout of protection gave the Japanese auto industry sufficient time to attain international competitiveness.

(III) PROTECTIONIST POLICY RESPONSES STARTING IN THE 1980S, AND THEIR CONSEQUENCES

Voluntary Export Restraints (VERs) were placed on auto exports from Japan to the United States in 1981. Their impact on welfare is estimated to be negative but small as they benefited U.S. producers at the expense of consumers, and they led to quality upgrading by Japanese manufacturers. The VERs were initiated in May 1981 in response to rising Japanese imports, limiting total annual Japanese exports of passenger cars to the U.S. to 1.68 million. The VERs were extended in 1984 and the limit was increased to 1.85 million. From 1985 to 1992, the limit was further raised to 2.3 million. Berry et al. (1999) estimate that the VERs did not raise prices significantly initially but had a larger price impact after five years. The implied tariffs on Japanese cars rose to a peak of 21 percent. They show that the VERs increased the profits of U.S. producers and resulted in moderate net welfare losses to the U.S., while the profits of Japanese firms were less affected. They also find that had the VERs been implemented as a tariff, they would have resulted in a net welfare gain for the United States as the tariff revenue offset consumer losses. Feenstra (1988) finds substantial quality upgrading of Japanese autos under the VERs. Dinopoulos and Kreinin (1988) show that European suppliers, who were excluded from the VERs, benefited by raising prices one-third. They estimate that Europe's welfare gains in 1984 exceeded Japan's losses.

Figure A1.5. VER Implied Tariffs on Japanese Cars

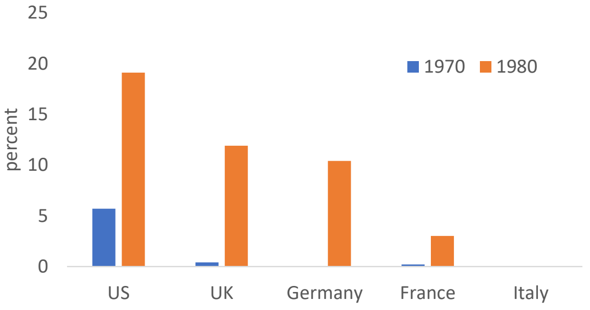


Note: The VER Implied Tariffs are calculated based on average Japanese car prices in Table 3 regression results in Table 5 of Berry et al. (1999).

Europe implemented earlier, and in many cases stricter, restrictions—resulting in lower Japanese penetration. As in the U.S., the restrictions have been estimated to have a negative impact on Europe's welfare. In 1970, the Japanese market share in Europe was extremely small, holding 0.4 percent of the British market, 0.2 percent of the French market, and negligible shares of the German and Italian markets (Mason, 1994). It rose significantly in the 1970s. By 1980, Japan had attained 11.9 percent of the British market and 10.4 percent of the German market (Mason, 1994). However, various VERs were in place in Europe, often in terms of market share and to varying degree of restrictions. In 1976, Britain and Japan agreed to limit Japanese market share to 11 percent. In 1977, France restricted Japanese car imports to be under 3 percent of its market. In 1981, Japan agreed with Germany not to raise its share of the German market by more than 1 percent per year (Denicolò and Garella, 1999). Italy had been one of the most protected markets against Japan, limiting Japanese exports to 2800 cars from 1956 to 1986. As a result, the penetration of Japanese cars was negligible in Italy. Studies have generally found negative welfare impact of the VERs on European countries (Turrini, 1999; Walker, 2015). Except for German luxury car brands who believed they could effectively compete against Japanese car makers, by the late 1980s, many European-owned car makers lagged significantly behind in productivity (Mason, 1994).

(IV) THE JAPANESE FDI RESPONSE, AND ITS IMPACT

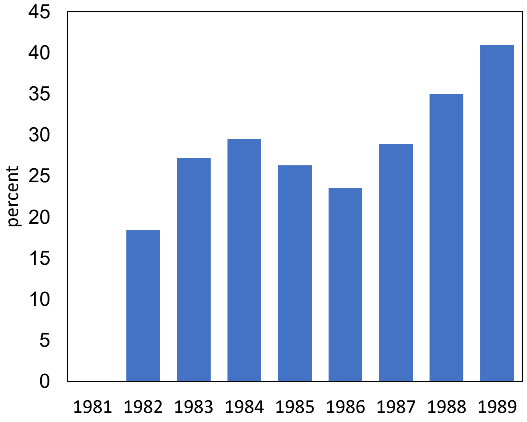
Figure A1.6. Japanese Market Shares in the U.S. and Europe



Sources: Mason (1994) and Berry et al. (1999).

In the 1980s, in response to trade barriers, Japanese firms began to produce vehicles in North America and Europe (Figure A1.6). From 1982 to 1989, Japan's outward FDI increased about eight times in dollar terms (Bayoumi and Lipworth, 1997), close to half of which went to the U.S. Japanese FDI improved overall productivity in the U.S. auto industry through increased competitive pressures and knowledge spillovers. Chung et al. (2003) show that while the overall productivity of the U.S. auto component suppliers increased in the 1980s, there is little evidence of direct technology transfer. U.S. suppliers to Japanese transplants had lower initial productivity and experienced no greater productivity growth than non-Japanese affiliated suppliers. Such adverse selection temporarily inhibited productivity growth in the auto industry. Branstetter (2006) studies knowledge spillovers at the firm level and finds that FDI is a channel of knowledge spillovers for Japanese multinationals undertaking direct investments in the United States. The spillover goes in both directions. Japanese FDI increased the flow of knowledge spillovers from the investing Japanese firms to U.S. firms mostly through R&D and product development facilities, while U.S. firms' spillovers to the investing Japanese firms largely took place through greenfield affiliates.

Figure A1.7. Regionalization of Japanese Auto Industry in the U.S.



Note: This chart presents the fraction of Japanese cars on the U.S. market that were produced in the U.S., based on Japanese assembly plants opening dates and capacity in Hart (1992) and Japanese market shares in Berry et al. (1999).

ANNEX II. STRUCTURAL MODEL DESCRIPTIONS

(I) THE GVC-GIMF MODEL

This annex section provides a high-level summary of the main modeling assumptions and calibration details. See Kumhof and others (2010) and Anderson and others (2013) for an overview of GIMF. Recent applications using GIMF-GVC include IMF (2023) and Carton and Muir (forthcoming).

Households in each region are made up of two groups. A first group are finitely lived households in an overlapping generation structure (OLG) who make consumption, savings, and labor supply decisions. A second group of households are liquidity-constrained, consume all their income every period and follow the labor supply decision set by the OLG households. Both groups contribute to important short-term non-Ricardian properties of GIMF. Short-term dynamics are also affected by habit persistence in consumption and labor supply. The long-term determination of the real global interest rate is ensured by balancing global savings and investment. The real exchange rate serves to adjust each country's saving position (its current account and associated stock of net foreign assets) relative to the global pool.

Firms in monopolistically competitive markets set their profit-maximizing prices subject to nominal rigidities and residual demand for their differentiated products. Firms produce non-tradable, tradable, and automotive goods. Sector sizes are calibrated based on the latest 2023 OECD Inter-Country Input-Output Database. Non-tradables are largely composed of construction and services, while tradables consist mainly of agriculture, mining, manufacturing and transportation activities. The automotive sector includes ISIC sectors D29 Motor vehicles, trailers and semi-trailers and D30 Other transport equipment. Firms in the nontradable and tradable sectors use Cobb-Douglas technology to combine labor and capital, while firms in the automotive sector also use some of the sector's output as intermediate consumption. Intermediate consumption can be sourced either domestically or from foreign producers through global value chains. There is no foreign ownership in GIMF.

Investment is chosen by firms to maximize profits, subject to real adjustment costs. Investment requires inputs sourced both domestically and from foreign regions, which are not perfectly substitutable. Investment also features a financial accelerator mechanism as in Bernanke, Gertler and Gilchrist (1999). Firms need to finance their investment, but their retained earnings are insufficient provide full financing, so they must borrow from financial intermediaries. Corporate risk premia are determined endogenously.

Each region trades with the rest of the world. Trade flows are tracked bilateral in the model and separated into final goods (either for consumption or investment), tradable and GVC/automotive goods. Trade flows react to demand, supply and pricing (i.e., the terms of trade and bilateral real exchange rates) conditions.

Each region's fiscal policy pursues the twin objective of debt sustainability in the long run. i.e., ensuring a non-explosive government-debt-to-GDP path, and output stabilization in the short run. This is achieved in the model by adjusting tax rates, expenditures and transfers endogenously. Monetary policy is similarly set to respond to shocks according to inflation forecast-based targeting. While monetary policy helps shape the economy's dynamics over the first five to ten years, it has no implications on the long-term outcomes in the real economy.

The 7–region model is calibrated using the OECD Inter-Country Input-Output Database for 2023 (OECD 2023). Fiscal ratios are calculated from the IMF's Government Finance Statistics database.

Table A.2.1. GIMF-GVC Regional Calibration
(Percent of world GDP)

	Hungary	Czechia	Germany, France, Italy	Rest of Europe	China	United States	Rest of world
GDP	0.18	0.29	9.58	9.05	16.92	24.84	39.14
Automotive	0.05	0.08	1.03	0.62	1.33	0.93	2.05
Exports	0.15	0.20	2.81	3.38	2.79	2.65	6.09
Automotive	0.02	0.04	0.32	0.26	0.21	0.16	0.39
Imports	0.15	0.20	2.81	3.38	2.79	2.65	6.09
Automotive	0.03	0.04	0.23	0.21	0.16	0.27	0.46

Sources: OECD (2023); and IMF staff calculations.

Elasticities in GIMF are typically calibrated equally across regions, including for trade and the combination of various goods to produce final goods. However, input and trade shares vary by region and partner based on data from the OECD ICIO. The elasticities of substitution for trade in the automotive sector are set at a lower level than other types of goods. Similarly, substitutability between factors and intermediate inputs in the automotive sector is low to reflect the higher costs of changing supplier-specific relations in the production of goods along value chains.

Table A2.2. GIMF-GVC Calibration of Key Trade and Production and Elasticities, All Regions

	Domestic / Imported	Different Regions	Capital-Labor / Intermediate inputs
Consumption	1.5	1.5	
Investment	1.5	1.5	
Tradables	1.5	1.5	
Automotive	1.2	1.2	0.5

Source: IMF staff calculations.

Finally, markups are calibrated to reflect firms' market power by sector and region. Smaller regions in CESEE are assumed to have lower markups for consumption goods than other regions. All regions in Europe are assumed to have lower markups for nontradable and tradable goods than China and the United States. Markups in the automotive sector in Europe are set the lowest at 1.05. China features the highest markup of 1.2 given its growing dominance in global markets.

Table A2.3. GIMF-GVC Calibration of Markups by Sector and Region

	Hungary	Czechia	Germany, France, Italy	Rest of Europe	China	United States	Rest of the world
Consumption	1.05	1.05	1.1	1.1	1.1	1.1	1.1
Investment	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Nontradables	1.1	1.1	1.1	1.1	1.2	1.2	1.2
Tradables	1.1	1.1	1.1	1.1	1.2	1.2	1.2
Automotive	1.05	1.05	1.05	1.05	1.2	1.1	1.1

Source: IMF staff calculations.

(II) THE TRADE MODEL

This annex section describes the main features of the quantitative trade model in non-technical terms. For a technical description of all modelling details, and the “exact hat” algebra used to analyze changes in model parameters, see Cuñat and Zymek (2024).

There is an arbitrary number of economies, and no aggregate uncertainty. Agents in each economy are endowed with a given amount of human capital which they supply inelastically in their home economy’s labor market. All agents face a constant probability of death, and departed agents are replaced by a cohort of newly-borns, keeping aggregate populations constant.

Actuarily fair life insurance is available, and agents optimize their holdings of two assets: capital that is accumulated with a country-specific investment efficiency and depreciates at a common, constant rate; and a freely traded one-period international bond. Agents chose their asset holdings each period to maximize the expected present value of their lifetime utility, and a common interest rate ensures market-clearing equilibrium in the international bond market. The rate of time preference may differ across economies and this together with the above-described demographic assumptions ensures the existence of a unique steady state, independent of initial conditions, with a non-degenerate distribution of international assets and trade balances.

Final consumption, investment and intermediate inputs in each economy are assembled from the output of an arbitrary number of sectors, in Cobb-Douglas fashion. In each sector, countries produce differentiated country-specific varieties and trade à la Armington, with a sector-specific substitution elasticity. All goods markets are assumed to be perfectly competitive. As a result, equilibrium sector-level bilateral trade flows can be described by the structural gravity equation typical of “gravity class” quantitative trade models (Costinot and Rodríguez-Clare, 2014).

Country varieties are produced using capital, labor and intermediate inputs, with production technology featuring a country-specific labor share, and a country-sector specific intermediate-input share. Factor markets are also assumed to be perfectly competitive, and labor and capital can move freely between sectors within economies. There is no cross-border labor mobility, but international capital flows can take place due to the presence of the international bond (that is, an economy’s capital stock can exceed the value of its wealth if its international bond holdings are negative).

In typical *static* gravity-class quantitative trade models, the impact of changes in parameters on equilibrium trade patterns and macroeconomic outcomes can be described by a small set of non-linear equations that requires only the calibration of some key parameters and information on countries’ status-quo trade and world output shares. This is known as “exact hat” algebra (Dekle et al., 2008). The trade model based on Cuñat and Zymek (2024) generalizes this logic to the comparison of steady states in a *dynamic* setting. Specifically, it delivers the standard exact hat algebra for changes in trade patterns and macroeconomic outcomes, *conditional* on some given capital stocks on steady state-trade balances. However, it provides a supplementary set of dynamic “exact hat” equations that characterize the endogenous response of steady-state capital stocks and trade balances to given parameter changes (see Cuñat and Zymek, 2024; Appendix A.5 for details).

Operationalizing the trade model requires four sets of objectives for calibration: i) countries’ bilateral trade shares, world-GDP shares and trade balances in the initial steady state; ii) sectors’ shares in countries economic activity and country-sector specific intermediate input shares; iii) country-specific capital shares; and iv) sector-specific trade elasticities. The first two sets of objects are taken from the OECD’s Inter-Country Input-

Output Tables (ICIO; OECD, 2023), using the average of countries' data for the years 2016–19.[1] The ICIO covers all of global output, split into 76 individual economies and the "rest of the world". Due to limited availability of some of the other data required for calibration, we merge some individual economies covered in the ICIO with the rest-of-the-world group.[2] We also merge some largely non-traded services sectors that are immaterial to our analysis. The final calibration covers 68 individual economies and the rest of the world; and 40 individual sectors, spanning all economic activity across both goods and services. Our consolidated list of sectors is shown in Table A.2.4. For the purposes of all scenarios in the trade model, sectors C29 ("motor vehicles") and C30 ("other transport equipment") are jointly treated as the "automotive sector".

We obtain country-specific labor shares, averaged for the 2016–19 period, from the Penn World Tables (Feenstra et al., 2015). For goods-producing sectors, Fontagné et al. (2022) estimate a recent set of long-run trade elasticities that is compatible with the OECD ICIO's sectoral disaggregation, and we use this set of elasticities. For all services sectors, we set the trade elasticity to 5, as in Costinot and Rodríguez-Clare (2014). Our full set of trade elasticities is shown in Table A.2.4. A handful of other parameters – such as the depreciation rate of capital or the average rate of time preference – are calibrated using standard values from the literature. Reasonable changes in these calibration choices do not have a material impact on our findings.

Table A2.4. TM Sectors and Sectoral Trade Elasticities

Sector name	Code	Trade elasticity	Sector name	Code	Trade elasticity
Agriculture	A01_02	3.19	Other transport equipment	C30	8.93
Fishing	A03	6.99	Manufacturing nec.	C31T33	5.00
Mining, energy	B05_06	3.16	Electricity, gas	D	5.00
Mining, non-energy	B07_08	8.31	Water supply, sewage	E	5.00
Mining services	B09	5.00	Construction	F	5.00
Food	C10T12	4.09	Wholesale and retail	G	5.00
Textiles	C13T15	4.71	Land transport	H49	5.00
Wood products	C16	8.68	Water transport	H50	5.00
Paper products	C17_18	7.98	Air transport	H51	5.00
Coke, petroleum	C19	4.51	Warehousing	H52	5.00
Chemical products	C20	8.25	Postal activities	H53	5.00
Pharmaceuticals	C21	8.54	Hospitality	I	5.00
Plastics	C22	6.86	Publishing, broadcasting	J58T60	5.00
Other non-metallic products	C23	4.81	Telecommunications	J61	5.00
Basic metals	C24	7.12	Information services	J62_63	5.00
Fabricated metals	C25	4.33	Finance and insurance	K	5.00
Electronic equipment	C26	5.38	Real estate	L	5.00
Electrical equipment	C27	4.74	Professional services	M	5.00
Machinery	C28	4.38	Administrative services	N	5.00
Motor vehicles	C29	8.66	Other services	O_T	5.00

Sources: Fontagné et al. (2022); OECD (2023); and IMF staff calculations.

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[1] The most recent set of data available covers the 2016-20 period. We exclude 2020 due to large trade disruptions caused by the Covid-19 pandemic during that year.

[2] The 8 countries individually covered in the ICIO but merged with the rest of the world in our calibration are Bangladesh, Belarus, Brunei, Cambodia, Jordan, Myanmar, Pakistan and Vietnam.

ANNEX III. THE EV SHARE OF AUTOMOTIVE SALES AND EMISSIONS IMPLICATIONS

(I) THE EV SHARE OF AUTOMOTIVE SALES

Both to discipline our scenarios and to assess the climate implications of potential protectionist interventions, we would like our models to track the production and purchases of EVs by (primarily EU) consumers. However, as yet there is no data that comprehensively captures international trade and input-output linkages for EVs among major economies. As a result, the automotive sector in our models is calibrated to data on trade and production linkages for general motor vehicles and transport equipment, rather than for EVs specifically. However, we introduce additional assumptions that allows us to characterize the EV component of automotive trade and consumption.

Both in GIMF-GVC and the trade model, the share of spending by some destination country (group) on the output of a given sector produced by some origin country (group) takes on a CES “gravity” form. Specifically, the share of spending by destination d on the automotive-sector output of origin o in some period t can be written as:

$$s_{odt} = \frac{(\tau_{odt} p_{ot})^{-\theta}}{\sum_o (\tau_{odt} p_{ot})^{-\theta}}, \tag{1}$$

where p_{ot} is the price of cars in the origin market; $\tau_{odt} > 1$ is the ad-valorem equivalent trade barrier between origin$o$ and destination d; and $\theta > 0$ is the trade elasticity. s_{odt} is observable in international trade and input-output data, and our models are calibrated to match it for the relevant countries and country groups.

To identify bilateral EV trade, we introduce two further assumptions. We assume that (unobserved to us) automotive-sector output consists of two substitutable varieties of goods, $i \in \{EV, ICE\}$ – respectively, EVs and traditional vehicles powered by internal combustion engines. Moreover, we assume that:

- ad-valorem trade barriers for the two car types are broadly similar, and their origin prices can be decomposed into two components: a common component (c_{ot}) representing input costs and mark-ups that are assumed to be broadly similar; and an EV-specific component (γ_{ot}) representing the origin’s *relative* productivity in assembling EVs. Hence:

$$p_{ot}^{EV} = \frac{c_{ot}}{\gamma_{ot}}, \quad p_{ot}^{ICE} = c_{ot}. \tag{2}$$

- consumers treat EV and ICE as CES substitutes with substitution elasticity $1+\theta$, and preference weights β_{dt}^{EV} and $1-\beta_{dt}^{EV}$, respectively.

Under these assumptions (1) can be re-written as:

$$s_{odt} = \frac{\beta_{odt} (\tau_{odt} c_{ot})^{-\theta}}{\sum_o \beta_{odt} (\tau_{odt} c_{ot})^{-\theta}}, \tag{3}$$

where

$$\beta_{odt} \equiv \left(\gamma_{ot}^{\theta} \beta_{dt}^{EV} + 1 - \beta_{dt}^{EV}\right). \tag{4}$$

Let x_{odt}^{i} denote the units of vehicle type i purchased by o from d. Then the above implies:

$$\frac{x_{odt}^{EV}}{x_{odt}^{EV} + x_{odt}^{ICE}} = \frac{\beta_{dt}^{EV} \gamma_o^{1+\theta}}{\beta_{dt}^{EV} \gamma_{ot}^{1+\theta} + 1 - \beta_{dt}^{EV}}. \tag{5}$$

Throughout all our scenarios, we assume a fixed path of β_{dt}^{EV} for EU consumers. This path is chosen such that, in the "EV shock" scenario, the share of EVs in EU consumers' total car purchases linearly approaches 1 by 2035, as shown in Table A.3.1.[3] We also introduce a 15 percent TFP shock for China, as described in Section 3.2, which shifts all destination countries car-spending towards China by lowering China's common automotive sector production cost ($c_{CHN.t}$). And finally, we introduce a path of China's relative EV productivity ($\gamma_{CHN,t}$) to achieve a gradual 15-percentage-point increase in China's penetration of EU car purchases in the "EV shock" scenario, as also described in Section 3.2.[4]

Table A3.1. EV Share in EU Automotive Purchases
(Percent)

2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
12	19	27	34	41	49	56	63	71	78	85	93	100

Source: IMF staff calculations.

With the EU's EV adoption path in the "EV shock" scenario calibrated to match Table A.3.1, we can proceed to compute the *changes* to this path in our alternative scenarios. Below, we describe how we compute changes in emissions from changes in the EV adoption path.

(II) EV ADOPTION AND EMISSIONS

Let X_{dt}^{i} denote the stock of vehicles of type i on the road in economy d and period t. Further assume that both vehicle types have a constant probability δ of being retired from use. Then the share of EVs on the road in economy d evolves as follows:

$$\frac{X_{dt}^{EV}}{X_{dt}^{EV}+X_{dt}^{ICE}}=(1-\delta)\frac{X_{dt-1}^{EV}}{X_{dt-1}^{EV}+X_{dt-1}^{ICE}}+\delta\frac{\sum_o x_{odt}^{EV}}{\sum_o(x_{odt}^{EV}+x_{odt}^{ICE})}. \tag{6}$$

From the assumptions described in the previous section, the share of EVs on the road in EU economies converges to 1 as $t \to \infty$. However, by changing the share of new EVs purchased up to 2035, our different scenarios have different implications for how quickly this happens. In turn, a slower convergence to exclusive EV use creates a finite additional amount of emissions relative to the case in which the convergence happens more quickly.[5]

Let E_{dt} denote the car emissions generated by economy d in period t. Then

$$E_{dt}\propto 1-(1-\eta)\frac{X_{dt}^{EV}}{X_{dt}^{EV}+X_{dt}^{ICE}}, \tag{7}$$

where η denotes the relative emissions intensity of EVs compared with ICE vehicles. We can then compare emissions in two scenarios by computing $\sum_{t=1}^{\infty}\left(\hat{E}_{dt}-E_{dt}\right)/E_{d0}$, where "hatted" emissions represent those that derive from an alternative scenario with a different EV adoption path.

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[3] This implies $\beta_{dt}^{EV}=1$ for all years from 2035 into the long run.

[4] Note from equations (4) and (5) that this is isomorphic to introducing a Chinese automotive sector productivity shock (via $c_{CHN.t}$) and an EU preference shift towards Chinese cars (via β_{odt}).

[5] In principle, the *total number* of cars used could also have emissions implications, in addition to the EV/ICE *composition* of the car fleet. While our models do deliver figures for total car usage across different scenarios, the emissions implications of substitution between cars and other goods could only be assessed by delving into the emissions content of each component of the consumption basket. This is beyond the scope of our paper, and we abstract from it here.

Based on numbers from the IEA's EV Life Cycle Assessment Calculator (IEA, 2024), we impose $\eta = 0.5$ and $\delta = 1/15$ (implying an average vehicle lifespan of 15 years). The initial condition is $X_{d0}^{EV} = 0$ for EU economies, and we cumulate the EV share of cars on the road and corresponding emissions using equations (6) and (7) and EU economies' EV purchase shares derived from the EV shock scenario described in Section 4.1, and different protectionist scenarios described in Section 4.2. The output is described in Section 5.