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Dependent but Diverging: Heterogeneous Value Chain Integration in Central European Automotive Production

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Abstract

Motor vehicle production in the Visegrád Four economies (Czechia, Hungary, Poland, Slovakia) has undergone a profound structural transformation since their EU accession. This transformation has unfolded along two fronts: ever-deepening integration into European and global value chains, and, more recently, the industry's shift to electrification. This paper examines both over 2010–2023. We test a prominent claim in the recent literature: that since 2018, global value chains have been reshoring, regionalising and shortening in response to pandemic disruption and geopolitical risk. Decomposing Eurostat FIGARO input-output tables and measuring production-chain length, we find no support for reshoring, shortening or de-risking: backward linkage and chain length both rose in every country; where domestic sourcing increased, it was not matched by additional domestically generated value; and diversification away from EU suppliers occurred alongside longer, not shorter, chains. Testing a monthly Comext series on lithium-ion battery imports for structural breaks, we find the EV transition offers no exception: battery-import growth and break timing diverge sharply by country, tracking individual firm investments more closely than EU or national policy. These findings are consistent with the Dependent Market Economy framework, which predicts persistent foreign dependence rather than upgrading. But the four countries do not follow one shared trajectory. Slovakia, Czechia and Hungary form a cluster of increasingly import-dependent assembly platforms with lengthening, internationalising chains, while Poland retains a structurally deeper domestic base than the other three, though this gap narrows as all four countries' chains internationalise. The paper's central contribution is to show that a shared institutional exposure to foreign capital does not imply a shared national trajectory, and that treating the V4 as a single regional production platform obscures the differentiated way dependence is deepening within it.

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Keywords: global value chains; automotive industry; Visegrad Four; domestic value capture; supply-chain diversification; electric vehicles

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1. Introduction

The European automotive industry is undergoing a major restructuring. The shift to electric-vehicle powertrains is changing vehicle technology and the inputs required to produce cars. The COVID-19 pandemic exposed vulnerabilities in international supply chains, while geopolitical tensions have increased concern about dependence on particular countries and suppliers. Firms have responded by diversifying suppliers, reconsidering inventories and seeking alternative production locations, while governments have introduced policies intended to strengthen resilience and expand regional production capacity. It remains unclear, however, whether these adjustments have resulted in a retreat from internationally fragmented production.

The Visegrád Four (V4) economies provide a particularly instructive setting in which to study this restructuring. Czechia, Hungary, Poland and Slovakia have become major centers of European automotive production since the 1990s. Foreign direct investment played a central role in this transformation. It combined Western European capital and technology with domestic skilled, relatively low-cost labor and access to the European market (Nölke and Vliegenthart, 2009; Pavlínek, 2018, 2020). The resulting expansion of vehicle assembly and component production generated employment, exports, investment and substantial modernization of manufacturing capacity.

This success has not removed the V4's dependence on foreign firms and imported inputs. Much of the automotive sector remains foreign-owned, and important strategic functions continue to be located outside the region. Pavlínek (2018, 2020) describes this position as an integrated periphery of the European automotive industry. In the V4, the distinction between production capacity and domestic value creation is particularly important: the region has become a major producer of increasingly sophisticated vehicles, yet much of the technology, corporate control and intermediate value embodied in that production continues to originate abroad. Production has therefore become deeply embedded in the region without a corresponding transfer of the higher-value functions associated with the industry.

At the same time, the four countries have not developed in identical ways. Their common origins in FDI-led automotive industrialization increasingly conceal differences in domestic supplier depth, the composition of foreign investment and the functions performed within European

production networks. Poland developed the region's broadest and deepest domestic component base; Czechia retained an inherited engineering and supplier structure that makes it more than a pure assembly platform; Slovakia became the most assembly-intensive of the four; and Hungary combined foreign-controlled automotive production with an increasingly important, foreign-financed battery industry. The V4 should therefore no longer be viewed simply as a relatively uniform Central European assembly corridor. A common model of dependent integration has evolved into increasingly heterogeneous national production structures.

The transition to electric vehicles (EV) has sharpened these differences. Since the middle of the 2010s, European automotive production has faced both a technological shift away from the internal-combustion engine and increasingly strong regulatory pressure to decarbonise road transport. Battery production, power electronics and other EV technologies create opportunities for new investment and industrial upgrading. They also require new materials, technologies and intermediate inputs whose production is highly international. In Eastern Europe, this transition has continued to be driven mainly by foreign firms and shaped by production structures inherited from the internal-combustion-engine era (Pavlínek, 2023). Greater technological sophistication is therefore developing alongside continued dependence on foreign capital, technology and intermediate inputs.

This combination of European integration and changing upstream dependence makes the V4 especially useful for distinguishing different forms of supply-chain restructuring. More procurement from suppliers located within a V4 economy does not necessarily mean more domestic value creation if those suppliers themselves depend heavily on imported inputs. Similarly, a wider geographical spread of foreign suppliers can reduce concentration without shortening the production chain or bringing production closer to Europe. European assembly and Tier-1 supplier networks may become more regionally concentrated even while the inputs embodied further upstream become more internationally dispersed. Localization, diversification, regionalization and domestic value capture need not move together.

We examine how these different dimensions of the V4 automotive production system changed between 2010 and 2023. The analysis has two related objectives. The first is to determine how domestic value creation, GVC participation, production-chain length and the geography of

foreign sourcing evolved as the European automotive industry was restructured. The second is to examine how the green transition exposed differences in the development paths of the four V4 economies. Rather than treating them as a single regional production platform, we investigate the uneven spatial and structural adjustment taking place within a group of economies that share a common history of FDI-led dependent integration.

We address these questions by combining annual input-output evidence with monthly battery-import data. FIGARO inter-country input-output tables are used to trace domestic and foreign value added in the automotive sector and to measure backward and forward GVC participation, following the sectoral-bilateral accounting of Borin and Mancini (2023). We also examine production-chain length, the geographical concentration of foreign sourcing and the regional composition of those inputs. Monthly Eurostat data on lithium-ion accumulator imports provide a higher-frequency indicator of the EV transition: four complementary structural-break procedures (Bai–Perron, Quandt–Andrews sup-F, CUSUM, and a panel test of whether the four countries share a common break date) identify changes in these battery-import series without imposing the break dates, or a shared regional timeline, in advance.

The first main finding is that deeper GVC participation has not brought greater domestic value capture. Backward participation increased in all four countries, while forward participation declined in three of the four; Poland is the exception, where it held essentially flat rather than falling. The direct domestic value-added share of automotive output also fell. Moreover, the annual evidence shows that these changes did not occur smoothly. Foreign-value dependence increased particularly strongly during the post-2020 restructuring, while the four countries arrived at this outcome through different earlier trajectories.

A second finding is that greater local sourcing does not necessarily mean greater domestic value creation. The distinction is especially clear in Czechia and Hungary. In both countries, purchases from domestically located suppliers rose over the second half of the sample period, but the domestic value-added intensity of those inputs did not keep pace: the additional local purchasing did not correspond to additional domestically generated value. In contrast, Slovakia and Poland show domestic sourcing declining rather than rising over the same period. These differences

reinforce the importance of separating the location of a transaction from the origin of the value embodied in it.

A third finding is that supplier diversification has occurred without a general shortening or Europeanisation of production networks. The strongest upstream diversification occurred after 2019. Yet cumulative production requirements expanded sharply during 2021–2022, with much of the elongation occurring in the foreign component of the production chain. Non-EU sourcing also rose, and China became a more important source of direct and indirect foreign intermediate inputs. The V4 therefore experienced broader international sourcing rather than a simple movement towards shorter or more regionally self-contained production networks.

Finally, the EV transition is common in technological direction but highly uneven in timing. Lithium-ion battery imports expanded dramatically in all four economies (by a factor of more than ten in every country and more than fifty in Czechia), but the dominant structural break occurs in Poland in 2019, Czechia in 2020, Hungary in 2022 and Slovakia in 2023. A formal panel test rejects the hypothesis that the four countries share a single common break date. The different dates are consistent with markedly different national investment histories and inherited automotive structures. They correspond more closely to the timing of individual battery and vehicle plant investments than to any EU- or national-level policy measure: firm investment decisions, not the regulatory calendar, are the more proximate correlate of when each country's transition became visible. This shows why a common European technological and regulatory shock need not generate a synchronized regional transition. The break dates identify changes in the trade series and are not interpreted as causal effects of particular investments or policies.

The paper makes three contributions. First, it provides a more precise measure of domestic embeddedness by separating purchases from domestically located suppliers from the domestic value added embodied in those purchases. This distinction is especially important in an FDI-led production system in which foreign-owned suppliers may locate close to assemblers while continuing to rely heavily on imported inputs.

Second, the paper distinguishes several forms of supply-chain adjustment that are often treated as if they were interchangeable. We look at geographical diversification separately from

production-chain length, regional sourcing and domestic value capture. This allows us to examine whether a less concentrated production network has also become shorter, more European or more domestically embedded.

Third, the paper connects these macro-level changes in GVC structure to the uneven transition towards electromobility, and tests that connection formally rather than asserting it. The monthly battery-import evidence identifies when the transition becomes statistically visible in each country. A panel common-break test then establishes that this timing is genuinely country-specific rather than a shared regional shock. Matching the resulting break dates against an independently documented chronology of policy and firm-level developments shows that investment timing, not the regulatory calendar, is the closer correlate. Together these let the analysis move beyond a regional aggregate to examine how a common technological transformation is filtered through different national structures within a group of dependent market economies.

The results point to a reconfiguration of V4 automotive integration rather than a retreat from international production. The region remains closely connected to the European automotive production system, but its upstream sourcing has become more geographically diversified and more exposed to China and other non-EU suppliers. At the same time, deeper GVC participation has not produced a comparable increase in domestic value capture. Most importantly, the green transition has not generated a single V4 trajectory. It has revealed, and in some respects widened, structural differences among four economies that developed from a broadly common model of FDI-led automotive integration: differentiated by country, but common in direction.

The remainder of the paper is organized as follows. Section 2 reviews the literature on FDI-led automotive development, GVC integration, supply-chain resilience and the transition to electric vehicles. Section 3 describes the data and empirical methods, and Section 4 presents the results. Section 5 discusses implications of the results against the reshoring/de-risking literature and the Dependent Market Economy framework. Section 6 notes the paper's contribution; Section 7 sets out its limitations; Section 8 concludes. Appendix A sets out the value-added accounting framework in full, including the construction and properties of the underlying FIGARO data. Appendix B gives the complete structural-break specification.

2. Literature Review and Conceptual Framework

2.1 FDI-led industrialization and dependent integration in the Visegrád 4 economies

FDI-led integration transformed the V4 economies into a major center of European automotive production. Since the 1990s, Czechia, Hungary, Poland and Slovakia have attracted large investments by Western European and other multinational vehicle manufacturers and component suppliers. Proximity to major European markets, EU integration, domestic skilled labor and lower production costs supported this development. Automotive output and exports expanded rapidly, and production capabilities became increasingly sophisticated.

The Dependent Market Economy (DME) framework explains how this industrialization combined economic modernization with continuing dependence on foreign capital. Nölke and Vliegenthart (2009) identify the V4 economies as systems in which foreign capital plays a central role in organizing production. Their comparative advantage in complex durable manufactures rests on skilled but relatively inexpensive labor, technology transfer within multinational enterprises, and capital supplied through FDI. The resulting model has in practice combined gains in productivity, exports, employment and production capabilities with persistent dependence on multinational firms. Bohle and Greskovits (2012) place this development within the broader diversity of post-socialist capitalism, emphasizing how inherited institutions and different strategies of integration produced variation even among the export-oriented economies of Central Europe.

The integrated-periphery approach draws attention more directly to the distribution of functions within this production system. Pavlínek (2016, 2018, 2020, 2023) emphasizes the combination of geographical proximity to the Western European industrial core and extensive foreign control of automotive production in Eastern Europe. Manufacturing capacity can expand rapidly while strategic functions remain concentrated elsewhere: including major R&D activities, product development, platform decisions and control over intangible assets. Firm-level evidence from Central Europe similarly shows that process and product upgrading need not be accompanied by an equivalent transfer of higher-value functions (Pavlínek and Ženka, 2011, 2016; Szalavetz, 2017, 2022).

The two perspectives are complementary. The DME framework explains the institutional basis of an FDI-led development model in which industrial modernization and external dependence coexist. The integrated-periphery approach examines how functions, control and value are distributed within the multinational production networks generated by that model. Together they provide the starting point for asking whether subsequent restructuring has altered the V4's position within European automotive production.

2.2 Global value chains (GVC), production networks (GPN) and functional upgrading

GVC and GPN research provides a closer view of how firms and regions are positioned within international production systems. GVC analysis examines the fragmentation and governance of production across firms and countries and the opportunities for upgrading within these structures (Gereffi et al., 2005; Gereffi, 2018). GPN research places greater emphasis on geography, power and the relationship between multinational production networks and the regions in which they operate (Coe and Yeung, 2015; Coe, 2021). These approaches provide a bridge between the political economy of FDI dependence and the organization of automotive production.

A central lesson from this literature is that industrial upgrading has several dimensions. Process upgrading improves the efficiency of production, while product upgrading involves movement towards more sophisticated products. Functional upgrading involves changes in the activities performed and the value associated with them (Humphrey and Schmitz, 2002; Gereffi et al., 2005). Foreign investment can produce substantial process and product upgrading without transferring R&D, design, branding or major corporate decision-making to the host economy: production of technologically advanced vehicles is not by itself evidence of functional upgrading.

This distinction also affects the interpretation of GVC participation. Backward participation captures foreign value added embodied in a country's exports, while forward participation captures domestic value added that subsequently enters other countries' exports. An increase in total participation can therefore arise from very different changes in a country's production position. Stronger forward participation may indicate a larger upstream contribution of domestic value added, but it should not by itself be interpreted as technological leadership or functional upgrading.

For FDI-dependent manufacturing economies, the composition of GVC participation is consequently as important as its level. Quantitative value-added measures complement firm- and industry-level research by showing whether deeper integration has increased the domestic contribution to downstream production or instead increased reliance on imported value added.

2.3 A common regional model with increasingly heterogeneous national production systems

The V4 economies entered the post-2010 period with a common FDI-dependent automotive model but distinctly different national production structures. Inherited industrial capacity, market size, timing of FDI, multinational specialization and the development of domestic suppliers already differed, and these differences became increasingly important as the industry moved towards electrification.

Slovakia developed an exceptionally assembly-intensive automotive sector around Volkswagen, PSA/Stellantis, Kia and, later, Jaguar Land Rover. A substantial supplier network emerged alongside these assemblers, and Slovak plants moved into increasingly sophisticated vehicle segments. Value-added evidence nevertheless shows strong reliance on imported intermediate inputs and high backward GVC integration (Pavlínek, 2016; Banerjee and Zeman, 2022).

Czechia entered the post-socialist period with a deeper industrial and engineering base. Škoda and an established supplier structure provided a stronger domestic foundation for subsequent integration into the Volkswagen Group. Its trajectory is also consistent with the broader argument of Bohle and Greskovits (2012) that inherited institutional and productive structures shaped different forms of post-socialist integration. In the automotive sector, modernization occurred within a relatively broad production system, although strategic functions remained embedded in multinational corporate structures (Pavlínek and Ženka, 2011, 2016).

Hungary developed around large foreign-owned operations such as Audi in Győr and Mercedes-Benz in Kecskemét. Research on Hungarian GVC participation documents substantial technological and subsidiary-level upgrading but also continuing foreign control over key strategic functions (Szalavetz, 2017). This structure later acquired a new dimension as Hungary attracted large Korean and Chinese investments in battery production. Szalavetz (2022) shows that electrification can create new upgrading opportunities for Hungarian subsidiaries without necessarily producing industrial upgrading at the level of the domestic economy.

Poland differs partly because of its larger domestic market and broader industrial base. Its automotive industry combines vehicle production with extensive component and commercial-vehicle manufacturing, producing a comparatively diverse supplier structure (Domanski et al., 2013; Guzik et al., 2020). This broader supplier base has nevertheless not eliminated functional asymmetries within the production network: indigenous firms remain disproportionately represented in less strategic and lower-tier activities, while foreign-controlled firms occupy many of the central positions in the automotive production system.

The significance of these differences extends beyond country description. The V4 began from a broadly shared model of FDI-led automotive integration, but that model did not produce a uniform regional structure. Differences in supplier depth, specialization and multinational investment created distinct capacities to respond to later technological change. Electrification therefore arrived in a region that was already structurally heterogeneous: a point the empirical analysis below (§4–§5) develops into a systematic, indicator-by-indicator finding rather than a qualitative characterization.

2.4 Follow-sourcing, domestic embeddedness and local value creation

Follow-sourcing is one of the principal mechanisms through which automotive FDI becomes locally embedded. When assemblers establish or expand production in a host economy, they often encourage established Tier-1 suppliers to locate nearby in order to preserve production relationships, satisfy quality requirements and support tightly coordinated delivery systems (Pavlínek, 2017, 2018). FDI by assemblers can therefore generate subsequent FDI by suppliers and a rapid increase in procurement from firms located within the host economy.

Localization of the transaction does not, however, establish localization of the value embodied in it. Foreign-owned suppliers operating near an assembler remain part of wider multinational production networks. They may import components, materials, machinery and services before supplying the local plant. National accounts record the sale as domestic sourcing, but part of the value contained in that transaction may have been generated abroad.

This distinction is particularly relevant in Central European automotive production. Research on supplier linkages shows that foreign-owned firms are strongly represented in the higher tiers of

automotive supplier networks, while domestic firms face greater difficulty entering technologically and strategically important positions (Pavlínek, 2017, 2018; Pavlínek and Ženka, 2016). Evidence for Slovakia likewise documents the high foreign-input content of automotive production despite the development of an extensive locally situated supplier network (Banerjee and Zeman, 2022).

The literature has established that the number or value of transactions with locally situated suppliers is an incomplete measure of domestic embeddedness. What has received less systematic attention is the distinction between the domestic-input share and the domestic value-added intensity of those same inputs within a common comparative accounting framework. An increase in local procurement may reflect deeper indigenous production, relocation of import-intensive multinational suppliers, or a mixture of both. This distinction becomes one of the empirical gaps addressed below.

2.5 Supply-chain resilience, reshoring and diversification after the pandemic

The resilience literature that expanded around the COVID-19 pandemic questioned whether internationally fragmented production had become excessively vulnerable to external shocks. Earlier disruptions had already exposed weaknesses in highly concentrated supplier networks. US–China trade tensions, pandemic shutdowns, semiconductor shortages and later geopolitical tensions then brought the location and organization of production chains to the center of policy debate (Strange, 2020; Miroudot, 2020).

One strand of this literature anticipated a significant geographical reorganization of international production. UNCTAD's World Investment Report 2020 identified reshoring, diversification, regionalization and replication as possible trajectories for international production. It expected shorter value chains and greater regionalization in a number of GVC-intensive industries, including automotive production (UNCTAD, 2020). Javorcik (2020) similarly argued that the pandemic would encourage firms to diversify their supplier bases and consider reshoring or alternative locations as they placed greater weight on resilience relative to pure cost efficiency.

Subsequent evidence has been more mixed. Jaax, Miroudot and van Lieshout (2023) find little evidence of a general retreat from GVCs in the period surrounding the pandemic. Alfaro and Chor (2023), by contrast, document a substantial reallocation of US sourcing after 2017: China's

direct share declined while Vietnam and Mexico gained, providing evidence of diversification, nearshoring and some reshoring of production stages. Importantly, they also caution that reduced direct sourcing from China does not necessarily eliminate indirect supply-chain dependence on China.

This literature points to reallocation rather than a simple binary choice between globalization and deglobalization. It also exposes an important measurement issue: evidence of nearshoring based on the physical location of production, bilateral gross trade or announced FDI does not by itself show where the value embodied in production originates. This limitation becomes especially important when geographical relocation occurs at the same time as a major technological change. If the new technology requires a different set of imported intermediate inputs, regionalization of final production can coexist with increasing foreign-value dependence further upstream. Gross trade and plant-location measures alone cannot identify that distinction.

A related but separate literature emphasizes diversification rather than chain shortening. Miroudot (2020) distinguishes resilience from self-sufficiency and argues that robustness may be improved through redundant suppliers and alternative production locations rather than complete localization. Subsequent OECD-related work similarly finds that high concentration of supplier countries and firms magnifies exposure to foreign disruptions (Grossman, Helpman and Lhuillier, 2023). Diversification can provide substantial protection, with partial onshoring adding relatively little in some simulations. The policy objective of reducing excessive dependence on a single supplier or country is therefore conceptually different from reducing the geographical length of the production chain.

Production-chain length and geographical concentration consequently need to be measured separately. Input-output measures of production length describe cumulative direct and indirect production requirements, or the distance through which production effects propagate (Dietzenbacher and Romero, 2007). Concentration measures describe how sourcing is distributed across countries. A production network can become geographically more diversified while remaining equally long or becoming longer. Treating diversification, nearshoring and chain shortening as interchangeable would therefore obscure different forms of supply-chain adjustment.

2.6 Regionalization and the vertical geography of automotive production

Automotive production has long combined strong regional organization at the assembly level with international linkages further upstream. Large assembly plants, tightly coordinated Tier-1 relationships and just-in-time production encourage firms to cluster around major final markets, while multinational production networks connect these regional clusters to suppliers and technologies elsewhere (Coe and Yeung, 2015; Pavlínek, 2018, 2020).

For the V4, this produced particularly dense integration with the Western European automotive core. EU membership, the Single Market and proximity to German and other Western European lead firms facilitated cross-border movements of vehicles and components and helped establish the region as an integrated European production platform (Pavlínek, 2018, 2020).

Regionalization at this level, however, does not establish that the value embodied in production is itself predominantly European.

GVC and GPN research stresses that the geography of a production network changes depending on the stage of production being observed (Coe and Yeung, 2015; Gereffi, 2018). A Tier-1 component delivered from Germany, Czechia or Hungary can contain electronics, materials and subcomponents produced elsewhere. The country of the immediate supplier is therefore not necessarily the country in which the underlying value was generated.

Electrification makes this vertical distinction still more important. Battery supply chains are highly concentrated geographically, particularly in processing, cathode and anode materials, and cell production. The IEA (2022) documents China's dominant position across much of this chain, alongside important Korean and Japanese capabilities. Europe has a substantial position in EV assembly but a much smaller presence in several upstream battery stages. European automotive regionalization can therefore coexist with substantial East Asian dependence further upstream.

Regionalization should consequently be assessed at more than one level of the production network. The location of assembly, the location of the direct supplier, and the geographical origin of the direct and indirect value embodied in an input are analytically distinct. This vertical geography is central to evaluating whether the restructuring of V4 automotive production has actually made its value chains more European.

2.7 Electromobility as a post-2015 transformation shock

The transition to electromobility introduced a second restructuring force into European automotive production from the middle of the 2010s. It combined a technological substitution away from the internal-combustion-engine powertrain with increasingly strong regulatory pressure to reduce vehicle emissions. The 2015 Dieselgate scandal exposed weaknesses in the existing European emissions regime and intensified scrutiny of conventional engine technologies, while progressively tighter EU CO₂ standards strengthened the incentive for manufacturers to shift towards electrified powertrains (Skeete, 2017; Pavlínek, 2023).

For the V4, this represented more than a change in the final product. EVs require a different input structure from ICE vehicles: batteries, power electronics, electric motors and associated materials acquire greater importance, while some traditional engine and transmission components lose weight. The technological transition can therefore change the structure and geography of intermediate demand even when final vehicle assembly remains in the same location.

The transformation creates substantial opportunities for Central European industry. Existing automotive capacity, manufacturing skills and proximity to European assembly operations make the V4 attractive locations for EV and battery investment. At the same time, the region's inherited FDI dependence shapes how these opportunities are captured. Pavlínek (2023) finds that foreign firms are driving the Eastern European transition and that its trajectory remains strongly conditioned by the region's integrated-periphery position. The EIB's regional assessment likewise emphasizes both the importance of electrification for Central and Eastern European automotive economies and their dependence on investment decisions taken by multinational lead firms (EIB, 2022).

The national investment patterns already documented in the literature are highly uneven. Poland and Hungary moved relatively early into large-scale battery production. Hungary subsequently attracted major Korean and Chinese battery producers, while Czechia's transition has been more closely associated with the electrification of its established vehicle and component base. Slovakia entered the transition from a particularly assembly-intensive position and initially developed battery capacity more slowly. Pavlínek (2023) documents these differences across Eastern Europe, while Szalavetz (2022) shows for Hungary that electrification can generate

subsidiary-level upgrading without necessarily changing the dependent position of the national automotive industry.

The new battery industry can itself generate new external dependencies. Battery materials, processing, cell components and technology are strongly connected to China, South Korea and Japan, with China occupying an especially dominant position in several upstream stages (IEA, 2022). Foreign-owned battery production located within Central Europe may therefore raise the technological sophistication of regional manufacturing while leaving ownership, technology and important upstream inputs outside the host economy: electrification can produce technological upgrading without technological autonomy.

This technological shift also complicates conventional measures of industrial success. Large battery investments, rapidly increasing battery imports and rising gross automotive trade indicate a substantial expansion of activity, but they do not reveal how much value is created domestically or how the underlying production chain has changed. Evaluating the EV transition therefore requires the trade and investment evidence to be considered together with value-added and production-network measures.

2.8 A common technological transition with heterogeneous national timing

Existing evidence already establishes that the EV transition has been uneven across the V4. Poland and Hungary attracted large battery investments relatively early. Czechia's adjustment was more closely tied to the electrification of its established vehicle and supplier system, while Slovakia remained more strongly oriented towards vehicle assembly during the earlier stages of the transition (Pavlínek, 2023; EIB, 2022; Szalavetz, 2022). The relevant question is therefore not whether national paths differ, but how and when those differences became visible in the restructuring of each country's production system.

Path dependence provides one explanation for this unevenness. The Eastern European EV transition is conditioned by positions established during the earlier phase of FDI-led automotive development (Pavlínek, 2023). Differences in supplier depth, multinational specialisation, assembly intensity and earlier investment influence the activities that each country is able to attract as the technology changes.

A common EU regulatory environment does not remove these national differences. The same tightening of vehicle-emission standards and the same shift in multinational EV strategies operate through production structures that were already heterogeneous. The green transition can consequently be common in technological direction while remaining staggered in investment, production and trade.

Existing studies document important elements of these national trajectories (Pavlínek, 2023; EIB, 2022; Szalavetz, 2022). But they do not establish whether structural changes became visible at the same time across the four national production systems, nor do they systematically connect the timing of the EV transition with simultaneous changes in foreign-value dependence, domestic sourcing, production-chain length and geographical concentration. This provides the basis for the high-frequency battery-import analysis used later in the paper.

2.9 Synthesis and empirical gap

The literature establishes three broad features of V4 automotive development. First, the region's industrial success emerged from an FDI-led model that combined modernization with persistent foreign control. Second, this common model produced heterogeneous national production structures rather than a uniform V4 automotive economy. Third, the post-2015 transition towards electromobility has introduced a technological and regulatory shock whose effects are filtered through these inherited structures.

What remains less well established is how the different dimensions of restructuring have moved together. Domestic sourcing may increase without a comparable rise in domestic value creation. Aggregate GVC participation can rise because of stronger backward dependence even while forward participation weakens. Supplier diversification may occur without shorter production chains, and European final assembly may coexist with increasing dependence on non-European inputs further upstream. The existing literature provides important evidence on each of these processes but rarely examines them within a common comparative accounting framework.

A further measurement issue arises from the EV transition itself. Much of the evidence on recent automotive restructuring relies on gross trade flows, production volumes, investment projects or announced FDI. These measures are informative about the scale and location of activity, but they cannot establish how much domestic value is captured or whether a new technology has altered the direct and indirect input structure underlying production. A large battery investment or a

rapid increase in battery trade can therefore coexist with increasing dependence on imported value added. The distinction is particularly important when geographical relocation and technological substitution occur simultaneously.

Our empirical framework addresses these gaps by linking five dimensions of restructuring. We distinguish domestic sourcing from the domestic value added embodied in that sourcing. We separate backward from forward GVC participation, compare production-chain length with geographical concentration, trace the regional and country composition of foreign inputs, and date the EV transition using monthly battery-import data. Sections 4 and 5 return to each of the possibilities raised above directly: whether domestic sourcing has grown without a commensurate rise in domestic value creation, whether GVC participation has deepened through backward rather than forward linkage, and whether supplier diversification has coincided with a lengthening, rather than a shortening, of production chains. The aim throughout is to establish which parts of the V4 production system changed, when they changed, and whether they moved in the same direction.

This framework also permits the four V4 economies to be compared as related but increasingly differentiated cases. Rather than treating the green transition as a common shock producing a common regional response, the analysis examines how a shared European technological and regulatory transformation interacted with distinct national production structures. The empirical strategy developed in the next section operationalizes these distinctions.

3. Empirical framework and methodology

3.1 Empirical strategy

The empirical strategy traces five dimensions of automotive restructuring across the four V4 economies. These are: (i) domestic sourcing and value creation; (ii) backward and forward GVC participation; (iii) production-chain length and its domestic and foreign components; (iv) the geographical concentration and regional composition of international linkages; and (v) structural breaks in lithium-ion battery imports. The annual analysis covers the period 2010–2023, while the monthly battery series begins in 2015.

The comparative design applies a common accounting framework while allowing the trajectories of the four countries to differ. The V4 economies share a broadly similar history of FDI-led automotive development, but differ in supplier depth, industrial scale, multinational specialization and the timing of EV- and battery-related investment. Rather than imposing a common path of adjustment, the empirical analysis therefore compares how the same dimensions of production-network restructuring evolved within four related but distinct national production systems.

3.2 Data and sectoral coverage

The analysis combines annual inter-country input-output data for automotive production with monthly lithium-ion battery imports that provide a higher-frequency indicator of the EV transition. The annual analysis uses FIGARO inter-country supply-use and input-output tables for the motor-vehicle industry, corresponding to NACE Rev. 2 division 29, over the period 2010–2023. The inter-country structure of FIGARO allows the direct and indirect inputs embodied in automotive production to be traced across industries and countries.

The value-added decomposition follows the sectoral-bilateral framework developed by Borin and Mancini (2023). Their approach permits domestic and foreign value added to be identified at the sectoral and bilateral levels, taking into account double counting generated by internationally fragmented production. The full accounting framework and construction of the indicators used in the paper are reported in Appendix A.

The annual FIGARO analysis is supplemented by monthly Eurostat COMEXT data on imports of lithium-ion accumulators, CN 85076000 excluding spent accumulators, from January 2015 to December 2023. These data provide a high-frequency indicator of the expansion of EV-battery-related activity and make it possible to identify structural shifts that cannot be dated precisely using annual input-output data.

3.3 Domestic sourcing and domestic value creation

Domestic embeddedness is measured by distinguishing how much the automotive sector purchases from domestically located suppliers from how much domestic value those purchases actually contain. Four indicators are used.

Backward GVC participation (or backward linkage) measures the foreign value added embodied in automotive exports relative to gross automotive exports:

$$BWD_{it} = FVA_{it} / EX_{it}$$

where FVA_{it} is foreign value added embodied in the automotive exports of country i in year t , and EX_{it} denotes gross automotive exports.

Backward linkage is considered alongside three domestic indicators. The first is the direct value-added share generated within NACE 29 relative to gross automotive output. The second is the share of intermediate inputs purchased from suppliers located in the domestic economy (the domestic-input share). The third is the domestic value-added content of those domestically sourced intermediate inputs (domestic value-added intensity).

The latter two indicators distinguish domestic sourcing from domestic value creation. The domestic-input share measures the extent to which transactions take place with suppliers located within the country, whereas domestic value-added intensity measures how much of the value embodied in those inputs was actually generated domestically. Domestic sourcing can therefore increase without a corresponding increase in domestic value creation when locally located suppliers themselves rely heavily on imported inputs. As the findings below show, the two can move in opposite directions.

3.4 GVC participation and position

The direction of GVC integration is identified by separating reliance on foreign value added from the contribution of domestic automotive value added to production elsewhere. Backward linkage, defined above, captures the first dimension. Forward linkage captures the second and is defined as domestic value added generated by the automotive sector and subsequently embodied in other countries' exports:

$$FWD_{it} = DVX_{it} / EX_{it}$$

where DVX_{it} denotes domestic automotive value added that enters foreign exports.

Total GVC participation is defined as the sum of the two:

$$GVC_{it} = BWD_{it} + FWD_{it}$$

The decomposition matters because the same increase in aggregate GVC participation can represent different changes in a country's position within international production. Higher backward linkage indicates greater foreign value added embodied in domestic automotive exports. Higher forward linkage indicates a larger contribution of domestic automotive value added to exports produced elsewhere. We therefore examine the two components separately (§4.1 and §4.3) before considering movements in aggregate GVC participation.

3.5 Measuring production chain length: two complementary metrics

We measure production chain length in two complementary ways, both built on the same underlying input-output structure (Appendix A gives the formal derivation). *Leontief chain length*, following Wang, Wei, Yu and Zhu (2017), is a sum: it is best understood as an index of production fragmentation, counting how many upstream stages (domestic or foreign) a unit of output has passed through on its way to final use. Being a sum, it rises whenever upstream activity increases at any stage, however far removed, and it decomposes exactly into a domestic and a foreign component that sum to the total. *Average propagation length (APL)*, following Dietzenbacher and Romero (2007), is instead a weighted average: rather than the volume of upstream activity, it captures how far away, on average, that activity occurs: the expected number of stages a shock originating deep in the chain would have to propagate before reaching final demand. Like the Leontief chain length, APL also decomposes exactly into domestic and foreign components.

The sum-versus-average distinction is what makes the two measures complementary rather than duplicates. The Leontief chain length tracks the scale of vertical fragmentation embodied in output, whereas APL tracks its structural reach. A country can draw on more upstream production (a rising Leontief chain length) without that production coming from any farther away, in which case APL stays flat or falls. Where the two measures diverge in the results below, that divergence is informative: it identifies whether volume or distance is the margin driving the change.

3.6 Measuring geographical concentration and regional composition

Geographical concentration is measured using country-level Herfindahl-Hirschman indices (HHIs) for both upstream sourcing and downstream destinations. For country j in year t ,

$$HHI_{jt} = \sum_i (s_{ijt})^2 \times 10,000$$

where s_{ijt} is country i 's share of the relevant sourcing or destination distribution for country j in year t . The index is placed on the conventional 0–10,000 scale, where full concentration in a single partner country equals 10,000 and complete dispersion across many partners approaches zero.

The backward HHI measures the geographical concentration of the foreign intermediate inputs embodied, directly and indirectly, in automotive production. A high value indicates that foreign sourcing is concentrated in a relatively small number of source countries; a decline indicates greater upstream geographical diversification.

The forward HHI applies the same concentration principle to the foreign destinations of automotive exports. It measures how concentrated the sector's downstream international relationships are across destination countries. A decline indicates that exports are distributed across a broader set of foreign destinations.

The two indices consequently distinguish source-country diversification upstream from destination-country diversification downstream: a country can diversify on one margin while remaining, or becoming, more concentrated on the other.

Regional composition answers a different question. Rather than asking how concentrated foreign sourcing is across individual countries, it identifies where those foreign inputs originate. Sources of foreign intermediate inputs are divided among the euro area, non-euro-area EU economies and non-EU economies; the data additionally identify China, South Korea and Japan separately within these totals.

A production network can become more geographically diversified while simultaneously shifting toward or away from particular regions. In particular, a declining backward HHI does not by

itself imply Europeanisation: sourcing may become less concentrated across countries while the non-EU share, and within it China's share, increases. Examining concentration and regional composition together allows these two forms of geographical restructuring, how spread out sourcing is and where it is spread to, to be distinguished. Trend statistics for both dimensions are reported in Tables 3 and 4 below and discussed in turn in §4.5 and §4.6.

3.7 Identifying structural shifts in the EV transition

Monthly lithium-ion battery imports are used to identify when statistically significant shifts in EV-related activity became visible in each V4 economy. Annual input-output data provide a detailed picture of changes in production structure but cannot date relatively rapid changes within a year. The monthly battery series therefore provides a complementary high-frequency indicator.

Monthly lithium-ion accumulator imports are seasonally adjusted and log-transformed. Structural breaks in each country series are then examined using four complementary procedures. Full specification (including the seasonal-adjustment procedure, minimum segment length, and bootstrap replication counts) is given in Appendix B.

The first procedure is the Bai–Perron multiple-break framework (Bai and Perron, 1998, 2003), which allows several unknown changes in the intercept and trend of the series and estimates their dates jointly, subject to a minimum segment length. This method is useful when the transition consists of several successive regime changes rather than a single discontinuity.

The second is the Quandt–Andrews sup-F test for an unknown single break (Andrews, 1993), which evaluates candidate dates over the admissible sample and identifies the date generating the largest test statistic: the dominant single break in each country series.

The third is the Brown–Durbin–Evans CUSUM test (Brown, Durbin and Evans, 1975). CUSUM provides an independent diagnostic of parameter stability and identifies when the estimated relationship first departs persistently from its previous path.

The fourth procedure asks a different kind of question: not when a break occurs within a country, but whether the four countries share the same break date. A panel test, adapted from Bai (2010)

for a small four-country cross-section, compares a model that imposes one common break date on all four series against a model that allows each country its own date, and asks whether allowing country-specific dates reduces the total residual sum of squares by more than what sampling variation alone would produce. This test is the formal counterpart to the country-by-country comparison that follows: it establishes whether the V4 pattern is better described as one regional shock with local timing noise, or as four genuinely distinct national trajectories.

The procedures are complementary because they identify different features of structural change. Bai–Perron identifies a sequence of statistically distinct regimes; the sup-F test identifies the largest single discontinuity; CUSUM indicates the first persistent departure from the previous relationship; and the panel test asks whether these country-specific dynamics amount to one shared regional break or four separate national ones. The first sign of change therefore need not coincide with the dominant break, and neither individual-country result determines whether the region as a whole moved together.

Finally, EV battery growth is mapped against backward linkage growth, and the estimated break dates are compared with the timing of major battery investments, changes in EV production and relevant EU and national policy developments. This comparison is chronological rather than causal. Temporal proximity between an estimated break and an investment or policy event can help interpret the sequence of the EV transition, but the structural-break tests do not identify individual investments or policies as causes of the observed changes.

4. Empirical results

The restructuring of V4 automotive production between 2010 and 2023 was not a single linear transition: the timing and direction of change differed across indicators and countries, although a number of common shifts became increasingly visible after 2020. Three broad phases help organize the evidence. Up to around 2015, the production structure largely reflects the mature ICE-based automotive system. Between 2015 and 2019, national trajectories become more differentiated as electrification begins to alter the industry's input structure and investment pattern. From 2020 onward, the pandemic shock, semiconductor shortages, accelerating EU climate policy and rapidly expanding battery-related activity coincide with more pronounced changes in foreign-value dependence, production-chain structure and the geography of sourcing.

The analysis therefore follows the annual evolution of the indicators rather than relying primarily on comparisons between 2010 and 2023. We first examine backward linkage together with domestic sourcing and domestic value creation; then turn to forward linkage and the composition of overall GVC participation; and finally examine production-chain length, geographical concentration and the regional composition of foreign sourcing. The battery evidence considered subsequently provides the higher-frequency counterpart to these annual changes.

Throughout Section 4, country-specific and pooled linear trends are estimated by ordinary least squares from the annual indicator series. For indicator y in country i and year t , the country-specific trend is

$$y_{it} = \alpha_i + \beta_i t + \varepsilon_{it},$$

estimated separately for each of the four countries, with β_i the reported country-level slope. The pooled row reported alongside each country in Tables 2–4 restricts the slope to be common across countries while allowing country-specific intercepts (country fixed effects):

$$y_{it} = \alpha_i + \beta t + \varepsilon_{it},$$

estimated on the within-country (country-demeaned) panel of all four countries, with β the single pooled slope reported. Both specifications are estimated by OLS with standard errors clustered by country; the p-values reported throughout Tables 2–4 correspond to this slope coefficient.

4.1 Backward linkage rises in waves rather than along a linear path

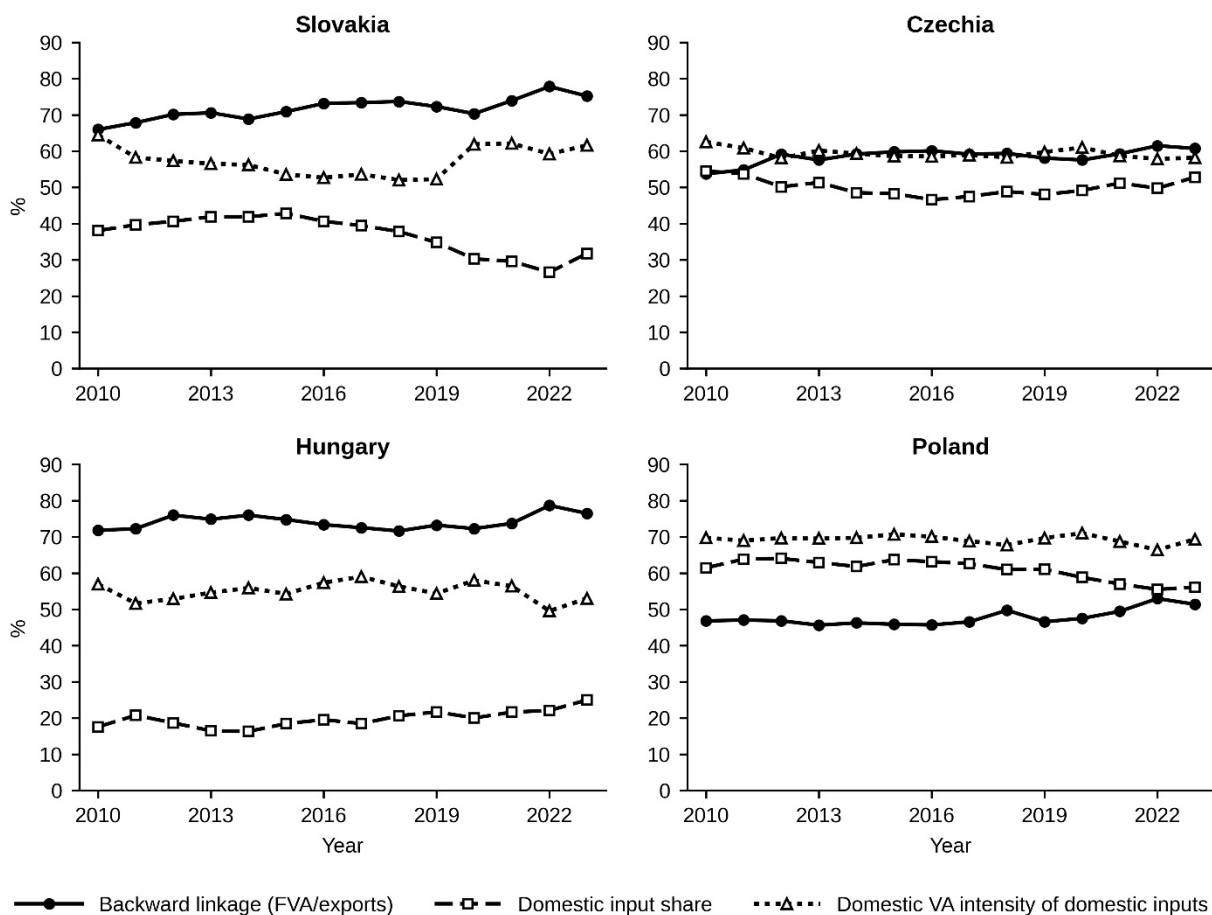
Backward linkage increased over the full period in all four economies, but the annual series reveal markedly different national trajectories followed by a common rise during 2021–2022 and a partial reversal in 2023.

The differences are apparent both in levels and in timing (Table 1). Hungary entered the period with the highest backward linkage, followed by Slovakia. Czechia occupied an intermediate position and Poland was substantially less dependent on foreign value added. By 2023, Slovakia had almost caught up with Hungary, reflecting the largest increase over the full period, whereas Poland remained the least backward-integrated of the four economies.

Table 1. Backward linkage and domestic sourcing: levels and changes, 2010–2023 (%)

Country	Backward linkage			Domestic input share			Domestic VA intensity		
	2010	2023	Chg.	2010	2023	Chg.	2010	2023	Chg.
Slovakia	66.0	75.2	+9.2	38.1	31.8	-6.3	64.5	61.6	-2.9
Czechia	53.7	60.7	+7.0	54.5	52.8	-1.7	62.5	58.2	-4.4
Hungary	71.8	76.5	+4.7	17.6	25.0	+7.4	57.0	53.0	-3.9
Poland	46.8	51.4	+4.6	61.5	56.1	-5.3	69.8	69.4	-0.4

Notes: Backward linkage = foreign value added / gross automotive exports; domestic input share = share of intermediate inputs sourced domestically; domestic VA intensity = domestic value-added content of domestically sourced intermediate inputs. Levels are percentages; "Chg." columns are percentage-point changes, 2010–2023. Source: authors' calculations from FIGARO

**Figure 1. Backward linkage, domestic sourcing and domestic value-added intensity by country, 2010–2023**

The paths towards these endpoints were quite different (Figure 1). Slovakia and Czechia display broadly similar early patterns, with backward linkage rising during the first half of the sample period before levelling off and subsequently weakening before the pandemic. Hungary's already-

high backward linkage also rose initially, but turned down earlier. Poland stands apart: its backward linkage remained comparatively stable during the first half of the decade and only subsequently began to move more decisively upwards. The increase in foreign-value dependence was therefore already underway in parts of the V4 before electrification accelerated, but it was neither continuous nor regionally synchronized.

A much clearer common pattern appears after 2020. Backward linkage increased in all four economies during 2021–2022 and reached a local or sample peak in 2022. All four then recorded some reversal in 2023, though levels remained above those of 2015. The end-of-period increase in foreign-value dependence therefore reflects a particularly strong post-pandemic upswing superimposed on quite different earlier national trajectories.

4.2 Domestic sourcing and domestic value creation follow different national paths

The domestic side of the production network is considerably more heterogeneous than the common increase in backward linkage. The four economies differ sharply both in the depth of domestic sourcing and in the domestic value embodied in that sourcing (Figure 1).

Poland has the deepest domestic supplier base throughout most of the period. Its domestic-input share is substantially above that of Slovakia and especially Hungary, although it declines after the middle of the decade. Poland also consistently records the highest domestic value-added intensity of domestic inputs. This narrowing of the domestic-input share points to some erosion of Poland's domestic supplier base, but it is not matched by any comparable loss of domestic value added in the inputs still sourced at home.

Czechia follows a different trajectory. Domestic sourcing weakens from the early 2010s to a trough around 2016. It then partially recovers, particularly after 2020, but not enough to regain the 2010 level: the domestic-input share in 2023 remains slightly below where it started. Its domestic value-added intensity, meanwhile, fluctuates around a broadly horizontal to mildly declining path. Domestic sourcing in Czechia therefore ends the period lower than it began, and the post-2020 rebound in purchases from domestic suppliers is not matched by any strengthening in the domestic value those purchases embody.

Slovakia presents almost the reverse configuration. Its domestic-input share rises initially but then declines persistently from around 2015 through 2022, before recovering somewhat in 2023.

Its domestic value-added intensity initially declines as well, but turns sharply upwards around 2019–2020 and remains considerably stronger thereafter. A shrinking share of inputs was being purchased domestically for much of the later period, while the domestic value content of those locally purchased inputs increased: the two dimensions of domestic embeddedness moved in opposite directions.

Hungary provides the clearest example of why the distinction between supplier location and value creation matters. Its domestic-input share rises more strongly than in any of the other three economies, particularly from the latter half of the decade. Yet the domestic value-added intensity of those inputs does not rise with it and follows a broadly declining path from around 2017, with a particularly sharp fall in 2022. Hungary therefore combines increasing localization of transactions with no corresponding increase in the domestic value embodied in those transactions.

Taken together, the four trajectories show why the increase in backward linkage cannot be read simply as the inverse of domestic supplier development. Domestic sourcing itself moves differently across the four economies, and changes in its domestic value-added intensity add a further layer of differentiation. What is common is that none of the countries displays a sustained combination of rising domestic sourcing and rising domestic value-added intensity sufficient to offset the broader increase in foreign-value dependence.

4.3 Forward linkage contracts as GVC participation becomes increasingly backward-oriented

Forward linkage generally weakened in all the V4 economies, while total GVC participation increased, producing a progressively more backward-oriented form of international integration (Figure 2).

The decline in forward linkage is much smaller in absolute magnitude than the movement in backward linkage, but its direction is revealing. Slovakia begins with an already-low forward linkage and experiences a further substantial contraction. Czechia and Hungary start from appreciably higher levels, fluctuate during the pre-pandemic period and then decline markedly after 2020. Poland is again distinctive: forward linkage is both more resilient and more variable, and by 2023 it has the highest forward linkage among the four countries.

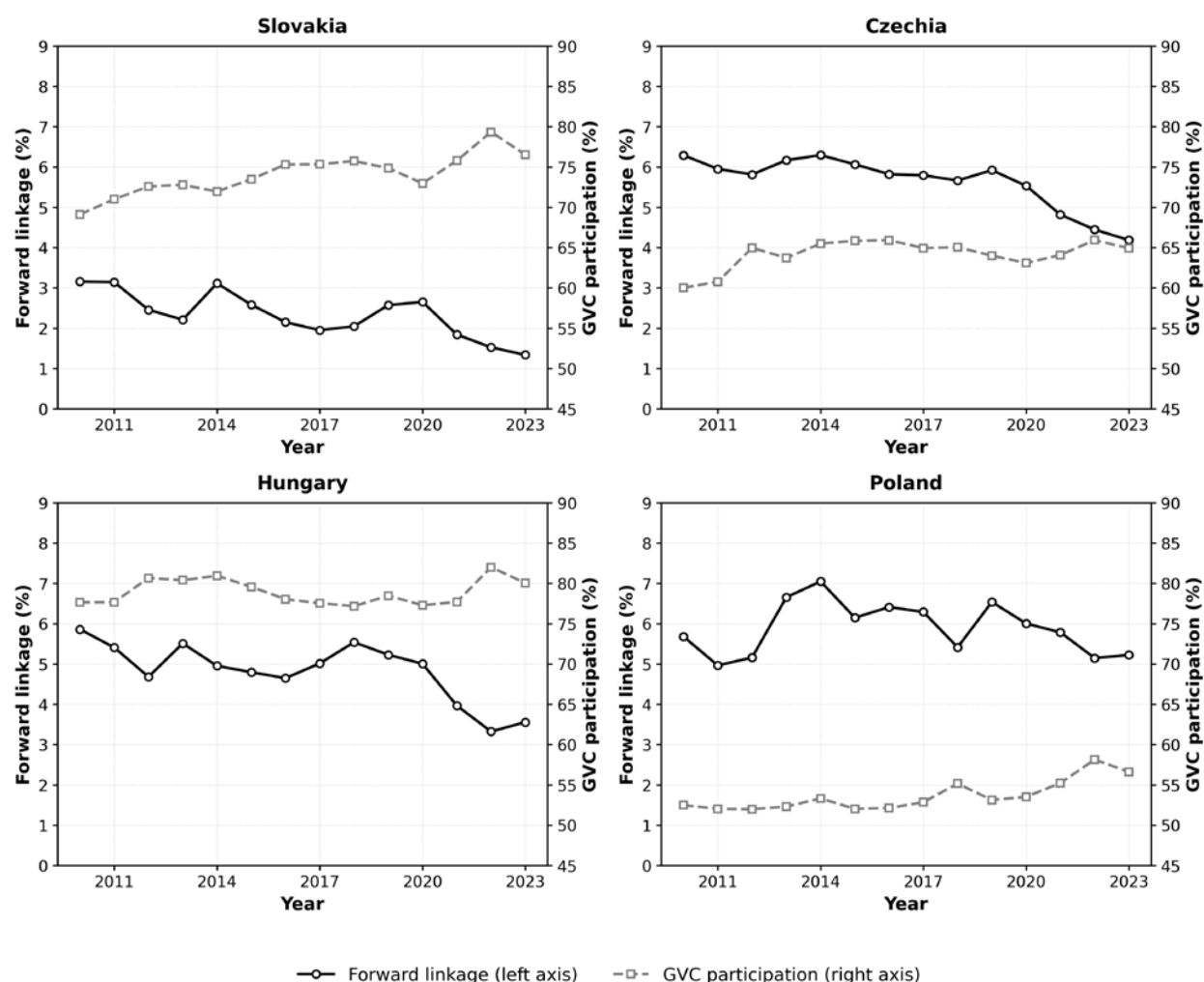


Figure 2. Forward linkage (left axis) and total GVC participation (right axis) by country, 2010–2023. Note the different vertical-axis scales: GVC participation values are much larger than forward linkage values

The post-2020 movement is particularly striking. Forward linkage falls in all four economies between 2020 and 2022, at precisely the time when backward linkage is rising strongly (§4.1). The partial recovery or stabilization in 2023 does little to alter the broader shift in composition.

Total GVC participation consequently follows the movement in backward linkage increasingly closely. It rises over the full sample period in all four economies and reaches a peak in 2022, before easing in 2023. But the increase does not reflect a larger contribution of V4 automotive value added to subsequent foreign exports. It is overwhelmingly associated with greater foreign value added embodied in the V4's own automotive exports. Aggregate participation therefore conceals an important change in the direction of integration: what looks, in the single summary

statistic, like deepening GVC integration is in fact a shift towards a more one-sided, backward-oriented form of it.

4.4 Production chain length: Country-by-country evidence

Figure 3 plots total chain length by country over 2010–2023 for both measures. Table 2 reports the corresponding linear trends (stages per year) and their domestic/foreign components, by country and pooled across the panel with country fixed effects. The pooled results reproduce the pattern visible in Figure 3: Leontief total chain length rises significantly (panel A), while total APL shows no significant trend (panel B). Given the mechanics set out in §3.5, this divergence is consistent with growth concentrated in the volume of upstream activity rather than in its average distance.

Table 2. Country-by-country and pooled trends in production chain length (Leontief-based) and average propagation length (APL), 2010–2023 (OLS slope, stages/year; p-value in parentheses)

Country	Chain length			APL		
	Total	Domestic	Foreign	Total	Domestic	Foreign
Slovakia	+0.0030 (0.662)	−0.0150*** (0.004)	+0.0180*** (0.003)	−0.0008 (0.754)	−0.0055*** (0.000)	−0.0100** (0.023)
Czechia	+0.0077 (0.165)	−0.0014 (0.704)	+0.0091* (0.053)	+0.0000 (0.991)	−0.0046* (0.092)	−0.0011 (0.756)
Hungary	+0.0107 (0.109)	+0.0058*** (0.002)	+0.0049 (0.404)	+0.0018 (0.479)	−0.0009 (0.624)	+0.0053* (0.083)
Poland	+0.0020 (0.649)	−0.0090*** (0.002)	+0.0111** (0.013)	+0.0016 (0.471)	−0.0018* (0.079)	−0.0061** (0.036)
Pooled (country FE)	+0.0059** (0.036)	−0.0049*** (0.009)	+0.0108*** (0.000)	+0.0007 (0.549)	−0.0032*** (0.000)	−0.0030* (0.087)

Notes: OLS trend slope in stages per year, 2010–2023 (T = 14); p-values in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10.

The pooled row reports a within-country (country fixed-effects) demeaned panel regression across all four countries.

Source: authors' calculations

The domestic components move in the same direction on average, but not uniformly, and the two measures of production chain length diverge in an instructive way here too. The pooled decline in Leontief domestic chain length is driven by Slovakia and Poland; Czechia's is essentially flat, and Hungary is the only country where it rises. Domestic APL is more consistent across countries, negative in sign everywhere though not always significantly. The pooled agreement between the two measures therefore conceals a real difference in cross-country pattern: the

Leontief chain length is polarized, rising in Hungary as it falls elsewhere. APL, in contrast, points the same way everywhere, just with varying statistical precision. This anticipates the Hungary discussion below.

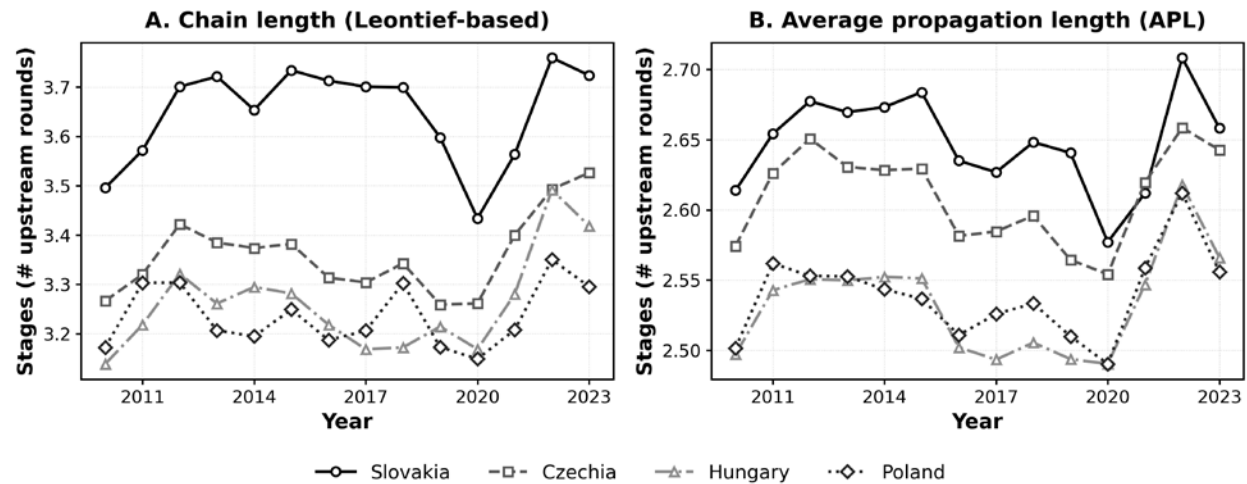


Figure 3. Total chain length by country, 2010–2023: Leontief-based measure (panel A) versus average propagation length (panel B).

The foreign components tell a more nuanced story than a simple "both measures show internationalization" would suggest. The foreign component of Leontief chain length rises sharply and is the main driver of the total-length trend: V4 automotive output increasingly embodies foreign-sourced inputs, in volume. The foreign component of APL, however, does not move the same way: its pooled trend is small and only marginally significant, and at the country level three of four countries (Slovakia, Czechia, Poland) show flat-to-declining APL-foreign values; only Hungary shows an insignificant increase. In other words, V4 producers are sourcing substantially more from abroad, but that additional foreign sourcing is not, on average, occurring at a systematically greater remove than before. If anything, the average distance of foreign sourcing has mildly compressed in three of the four countries. This is precisely the sum-versus-average distinction set out in §3.5: a rising volume of international linkages need not raise their average distance, and here it largely does not.

Country patterns reinforce this reading. Slovakia shows the clearest and most consistent internationalizing pattern: domestic components decline significantly under both measures, while the chain-length foreign component rises significantly even as APL-foreign falls significantly: more foreign input value is being sourced, on average, slightly closer rather than farther away.

Poland follows a similar pattern, with a significant decline in domestic share under both measures alongside a significant rise in the foreign component of chain length. Czechia shows the same direction throughout but with weaker statistical power. Hungary is the outlier. Its domestic chain-length component is the only one in the panel to rise significantly, its foreign chain-length component does not rise significantly, and it is the sole country with a positive, if statistically insignificant, APL-foreign trend. This is consistent with the country typology developed earlier, in which Hungary's electronics- and battery-led FDI wave has broadened rather than narrowed its domestic input base over this period.

The domestic share of chain length (the domestic component as a percentage of the total) declines significantly in Slovakia and Poland, falls only marginally in Czechia, and is flat in Hungary. The APL-based domestic share shows the same ranking, generally with smaller magnitudes, confirming that the shift toward foreign sourcing is a genuine structural pattern rather than an artefact of either metric alone.

4.5 Concentration of upstream sourcing and downstream destinations, 2010–2023

Figure 4 plots the backward and forward HHI for all four countries, and Table 3 reports the corresponding linear trends (2010–2023, OLS, HHI points/year). Pooled across the panel with country fixed effects, the backward HHI falls significantly ($p < 0.001$): upstream sourcing has broadly diversified across the V4. The decline, however, is concentrated in two countries: it is sharp and significant in Slovakia and Poland, only directional in Hungary, and essentially flat in Czechia, which begins the period as the second-most-concentrated source and ends it as the most concentrated of the four, having diversified the least. Slovakia moves in the opposite direction, ending the period as the most diversified source in the group.

The forward HHI tells a different story on two counts. First, its levels (roughly 2,700–3,600) are far higher throughout than the backward HHI's (roughly 900–1,450): export destinations are inherently much more geographically concentrated than input sources, reflecting the sector's continued reliance on a small number of core European final-assembly and OEM markets. Second, the pooled trend runs in the opposite direction to the backward HHI: destinations became significantly more concentrated, not less, driven by Czechia, Hungary and, marginally, Slovakia. Poland is the sole exception, with export destinations significantly diversifying.

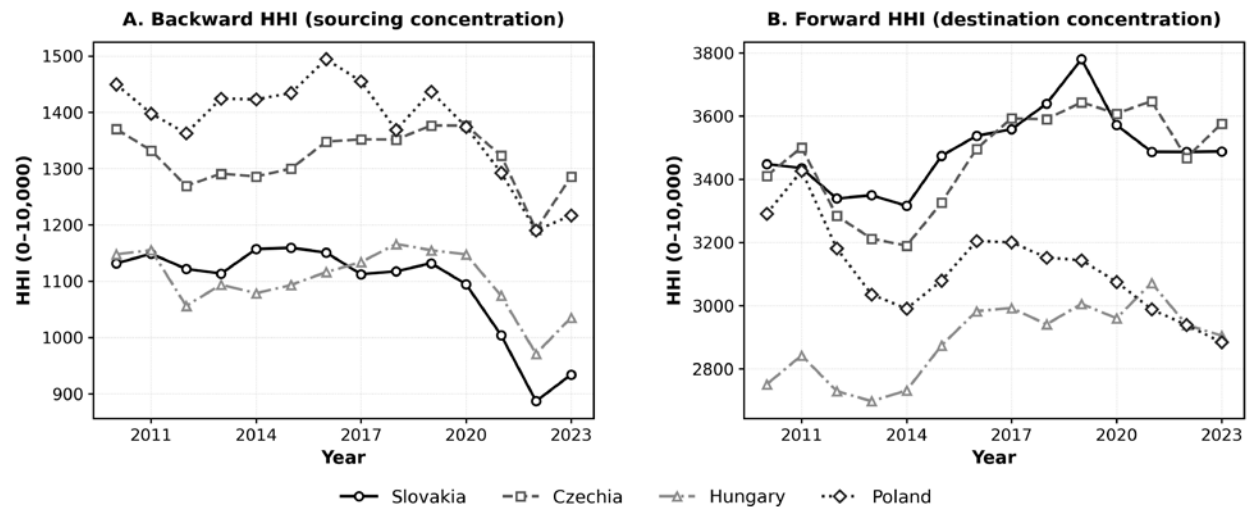


Figure 4. Geographical concentration of upstream sourcing (panel A, backward HHI) and downstream destinations (panel B, forward HHI) by country, 2010–2023.

Table 3. Trends in geographical concentration, 2010–2023 (OLS slope, HHI points/year; p-value in parentheses)

Country	Backward HHI (sourcing)	Forward HHI (destinations)
Slovakia	−15.24*** (0.002)	+14.97* (0.064)
Czechia	−2.10 (0.560)	+24.13** (0.014)
Hungary	−5.12 (0.175)	+21.03*** (0.003)
Poland	−14.20*** (0.010)	−24.47*** (0.005)
Pooled (country FE)	−9.16*** (<0.001)	+8.91** (0.043)

Notes: OLS trend slope in HHI points per year, 2010–2023 (T = 14), on the 0–10,000 scale; p-values in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10. The pooled row reports a within-country (country fixed-effects) demeaned panel regression.

Source: authors' calculations from FIGARO

Together, Table 3 and Figure 4 point to an asymmetric pattern of geographical restructuring: upstream sourcing networks have broadened (most clearly in Slovakia and Poland), while downstream export markets have, for three of the four countries, narrowed rather than diversified. Poland is the outlier on both margins: it is the only country diversifying its export destinations as well as its input sourcing, consistent with its structurally deeper domestic base identified elsewhere in this paper.

4.6 Changing geography of foreign intermediate sourcing

The diversification documented in §4.5 is not, in general, a Europeanisation of sourcing. Pooled across the panel (Table 4), the euro area's share of foreign intermediate inputs falls significantly, the non-euro-area EU share rises modestly, and the non-EU share rises significantly. China's share, specifically, rises consistently and by a similar magnitude in every country. At the same time that upstream sourcing was becoming less concentrated across countries (§4.5), it was also, on average, becoming less anchored in the euro area and more oriented toward non-EU suppliers, with China acquiring materially greater weight within the upstream production network.

Table 4. Trends in the regional composition of foreign intermediate sourcing, 2010–2023 (OLS slope, percentage points/year; p-value in parentheses)

Country	Broad region			Selected non-EU partners		
	Euro area	Non-euro EU	Non-EU	China	South Korea	Japan
Slovakia	−0.399*** (0.006)	+0.243* (0.083)	+0.147 (0.397)	+0.540*** (<0.001)	−0.118*** (0.003)	−0.193*** (<0.001)
Czechia	−0.574*** (0.001)	+0.186*** (<0.001)	+0.368** (0.025)	+0.500*** (<0.001)	+0.006 (0.875)	−0.051* (0.078)
Hungary	−0.630*** (<0.001)	+0.132** (0.037)	+0.495*** (0.003)	+0.448*** (<0.001)	+0.156*** (<0.001)	−0.101*** (0.004)
Poland	−0.681*** (<0.001)	−0.021 (0.343)	+0.704*** (<0.001)	+0.612*** (<0.001)	+0.084*** (<0.001)	+0.001 (0.980)
Pooled (country FE)	−0.571*** (<0.001)	+0.135*** (0.001)	+0.429*** (<0.001)	+0.525*** (<0.001)	+0.032 (0.105)	−0.086*** (<0.001)

Notes: OLS trend slope in percentage points of the country's total foreign intermediate sourcing per year, 2010–2023 (T = 14); p-values in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10. Euro area, non-euro EU and non-EU shares sum to 100%; China, South Korea and Japan are sub-components of the non-EU total. The pooled row reports a within-country (country fixed-effects) demeaned panel regression. Source: authors' calculations from FIGARO.

This pooled average, however, conceals two different kinds of heterogeneity that point in opposite directions. On the broad non-EU aggregate, the four countries genuinely diverge: the share rises significantly in Czechia, Hungary and Poland, but not in Slovakia, whose non-EU share is statistically flat across the period despite its euro-area share falling by more than any other country's. On China specifically, by contrast, the four countries move together to a striking degree: China's share of foreign intermediate sourcing rises significantly, and at a similar pace, in all four economies. The V4's reorientation toward China is close to a shared regional pattern; its reorientation toward non-EU suppliers more broadly is not.

Poland shows the strongest and most consistent broadening: the largest and most significant rise in the non-EU share of the four, together with a substantial rise in its China share. Both moves are part of the same steady widening rather than offsetting one another. Czechia and Hungary follow a similar pattern at a more moderate pace: both show a significant rise in the non-EU share (Table 4) alongside a significant, closely comparable rise in China's share. Hungary's China-sourcing trend is, in fact, one of the strongest in percentage-point terms of the four: the opposite of an outlier on this measure.

Slovakia is the country that stands apart, but not in the direction the raw euro-area decline might suggest. Its euro-area sourcing share falls the most sharply of the four, yet the released share does not flow mainly into the broader non-EU category, which is statistically unchanged. Instead, a meaningful part of what Slovakia loses from the euro area moves into non-euro-area EU sourcing, which rises at the 10% level. Within its non-EU sourcing, however, Slovakia's China share still rises significantly and substantially, comparable in magnitude to the other three countries, while its South Korea and Japan shares both fall significantly. This is consistent with the country's automotive-FDI-linked sourcing from North-East Asia partly rotating toward China specifically rather than the region as a whole.

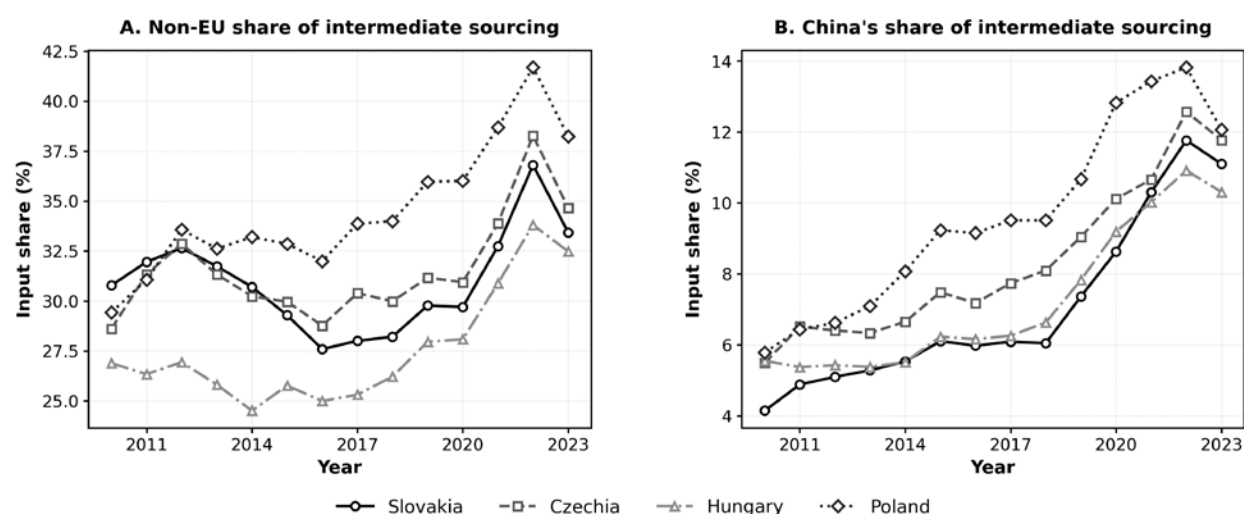


Figure 5. Changing geography of foreign intermediate sourcing by country, 2010–2023: non-EU share (panel A) and China's share (panel B).

Figure 5 illustrates the two patterns side by side. Panel A shows the non-EU share diverging across the four countries: rising clearly in Poland, Czechia and Hungary, essentially flat and

more volatile in Slovakia. Panel B shows the opposite: China's share rises in all four countries along closely parallel paths, with Poland consistently highest and Hungary consistently lowest in level but all four moving together in direction and pace. Read together, the two panels make the point Table 4 makes numerically: geographical diversification away from the euro area and a specific reorientation toward China are related but distinct phenomena, and it is the China-specific shift, not the broader non-EU shift, that comes closest to a uniform V4-wide pattern.

4.7 EV battery imports: levels, breaks and policy correspondence

4.7.1 Battery-import levels and growth, 2015–2023

Table 5 reports annual lithium-ion accumulator imports for each V4 country and the resulting 2015–2023 growth multiple. The picture is informative even before any break is estimated.

Table 5. Lithium-ion accumulator imports, all partners, 2015–2023 (€ million)

Country	2015	2016	2017	2018	2019	2020	2021	2022	2023	2023/2015
Slovakia	34.9	53.4	68.9	135.8	283.7	826.8	1,255.7	1,921.6	1,415.7	40.5×
Czechia	95.5	110.3	126.0	151.1	238.9	682.1	1,445.1	3,543.3	4,805.2	50.3×
Hungary	78.2	117.1	235.8	285.1	395.3	372.6	608.8	1,666.1	1,740.7	22.3×
Poland	156.5	169.8	219.4	345.7	808.9	902.2	1,256.3	1,934.7	1,828.3	11.7×

Source: Eurostat Comext, CN 85076000, all partners

The starting point matters as much as the endpoint. In 2015, Poland imported more than four times what Slovakia imported and roughly twice what Czechia or Hungary imported: it entered the sample as the region's established battery importer, consistent with LG Chem's Wrocław plant already under construction. By 2019 Poland's own imports had grown roughly fivefold, and it remained the largest importer in absolute terms through most of the sample. But the other three countries closed the gap from far behind and did so much faster: Slovak and Czech imports each rose more than forty-fold over the full period, overtaking Poland in absolute terms by 2021–2022, while Hungary's growth, though still substantial, was markedly slower than Slovakia's or Czechia's. Poland is therefore best described as an early mover whose growth then moderated relative to its neighbors, not as a country that came late to electrification. This is the opposite of what the raw growth multiples alone would suggest if read without the corresponding levels.

4.7.2 Structural breaks in monthly imports

The pattern visible in the annual totals (different starting levels, sharply different growth rates, and in Poland's case, an earlier acceleration than the other three) points toward the countries

having undergone their transitions on different timetables. Table 6 reports the dates identified by each of the three country-level procedures applied to the seasonally adjusted, log monthly import series.

All four series reject a single stable trend: each country supports at least four statistically distinct Bai–Perron regimes rather than one continuous growth path, confirming that the acceleration visible in Table 5 did not occur smoothly but in discrete jumps. The dominant single break identified by the sup-F test lines up with an early Bai–Perron break in Poland (January 2019, its second break) but with the final, 2023 break in Slovakia: the country whose sup-F break is latest of the four is also the country whose CUSUM instability is detected earliest (January 2020), indicating that Slovakia's series began drifting from its initial path well before its single largest discontinuity arrived. Czechia and Hungary sit between these two patterns: their dominant breaks fall in 2020 and 2022 respectively, each roughly a year after their CUSUM-detected instability. Read together with Table 5, the four countries' import paths diverge not only in magnitude but in shape: Poland's transition front-loaded into 2017–2019, Slovakia's and Czechia's back-loaded into 2020–2023, and Hungary's spread across an intermediate, more gradual path anchored by the 2022 ramp-up of its main domestic battery plant.

Table 6. Structural changes in monthly lithium-ion accumulator imports: three complementary methods

Country	Bai–Perron multiple breaks				Quandt–Andrews	CUSUM
	Break 1	Break 2	Break 3	Break 4	Dominant sup-F break	First crossing
Slovakia	Jun. 2016	Oct. 2018	Aug. 2021	Jan. 2023	Jan. 2023	Jan. 2020
Czechia	Jan. 2019	Jan. 2020	Aug. 2021	Jan. 2023	Jan. 2020	Nov. 2020
Hungary	Dec. 2016	Oct. 2019	Jan. 2022	Jan. 2023	Jan. 2022	Sep. 2020
Poland	Jan. 2017	Jan. 2019	Oct. 2021	Nov. 2022	Jan. 2019	Feb. 2019

Notes: Bai–Perron dates are the four reported multiple-break dates. The dominant sup-F break is the date maximizing the Quandt–Andrews statistic over the admissible sample. CUSUM reports the first persistent crossing of the Brown–Durbin–Evans stability boundary. All procedures use the seasonally adjusted log monthly import series; full estimation details and sequential-test results are reported in Appendix B. *Source:* authors' calculations from Eurostat Comext.

A panel test of whether the four countries share a single common break date, adapted from Bai (2010) for a small cross-section (full derivation and estimation detail in Appendix B), formally rejects the common-break null: the best common break date, if imposed on all four countries, is November 2019, a compromise that fits poorly for Slovakia and Hungary in particular, and letting each country choose its own date reduces the total residual sum of squares significantly

(bootstrap $p < 0.003$). The four countries' import trajectories are therefore better described as four distinct, country-specific regime shifts than as one shared regional shock, formally corroborating the country-by-country reading above.

4.7.3 Battery-import growth and backward linkage

If the electrification of V4 automotive production simply added another category of imported input, battery-import growth and backward linkage should move together. They do, but not to the same degree in every country, and the country ranking on one measure is not the country ranking on the other. Over 2015–2023, backward linkage rose furthest in Poland and least in Czechia: the reverse of the ranking on battery-import growth, where Czechia's increase was the largest of the four and Poland's the smallest.

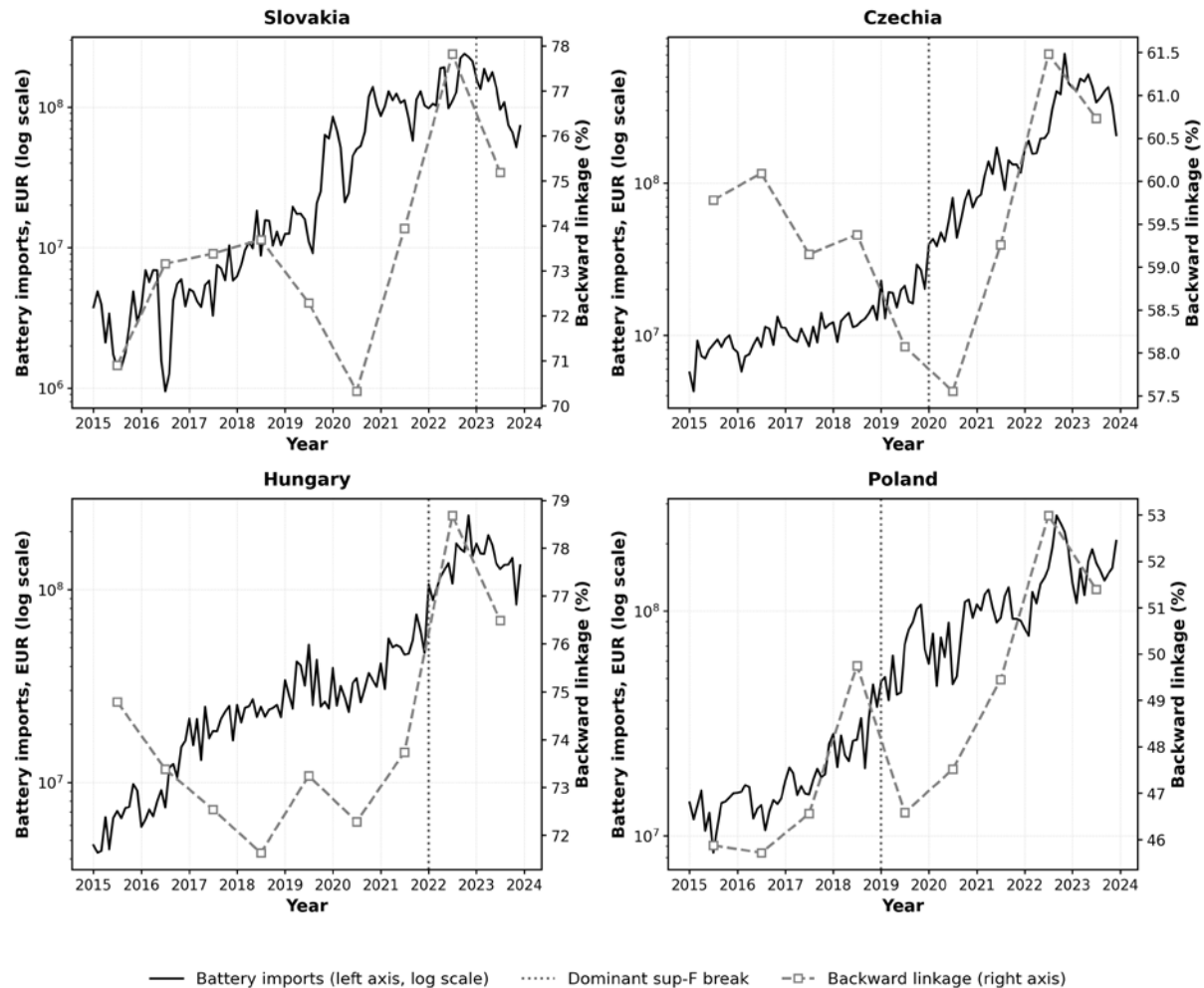


Figure 6. Monthly battery imports (log scale, left axis) and annual backward linkage (right axis), 2015–2023, with the dominant sup-F break date marked by a dotted vertical line

Figure 6 and Table 7 use the battery-import series at two different frequencies, deliberately rather than incidentally, and the distinction matters for how each should be read. The figure plots battery imports at their native monthly frequency, so that the shape of the series and the timing of the sup-F break remain visible; backward linkage is only ever measured annually, so it necessarily appears as nine yearly points joined by a line, not as a monthly series of its own. The correlation in Table 7, by contrast, is computed after aggregating battery imports up to annual totals (the same annual figures reported in Table 5), so that both series being correlated are measured at the same, annual frequency. The coefficients therefore describe how the annual pattern of battery-import growth relates to the annual pattern of backward linkage; they are not a monthly correlation, and Figure 6's monthly detail should be read as illustrative context for the break dates and the shape of each country's import path, not as the basis for the correlation itself.

Table 7. Correlation between annual battery-import levels and backward linkage, 2015–2023

Country	r (annual battery imports, annual backward linkage)	p -value	N
Slovakia	0.513	0.158	9
Czechia	0.408	0.275	9
Hungary	0.603	0.085	9
Poland	0.788	0.012	9

Notes: Pearson correlation between the log of annually aggregated battery imports (Table 5) and the level of backward linkage, both measured annually, 2015–2023. With only nine annual observations per country, these should be read as descriptive rather than formally tested associations; only Poland's correlation is significant at conventional levels ($p < 0.05$), and Hungary's is marginal ($p < 0.10$). *Source:* authors' calculations from Eurostat Comext and FIGARO

The correlations confirm what the ranking comparison suggested: year-on-year co-movement between battery imports and backward linkage is strongest in Poland and weakest in Czechia, with Slovakia and Hungary in between, the reverse of the ranking on battery-import growth. Figure 6's monthly detail is broadly consistent with this annual pattern, though it is a visual illustration of it rather than the series the correlation is computed from. In Slovakia and Czechia, the monthly battery-import line climbs in a long, fairly steady ascent that owes little to the shorter-run swings in annual backward linkage, including the dip that all four countries show around 2019–2020; the dominant sup-F break in both countries arrives well after backward linkage has already turned back upward. In Hungary and especially Poland, the two series track each other more closely in shape, including the shared mid-sample trough, and in Poland's case

the sup-F break (January 2019, the earliest of the four) sits right at the point where both series begin climbing together.

This is not a contradiction: battery imports are a small part of a much larger import trajectory need not track its aggregate backward linkage one-for-one. But the pattern is informative in its own right. Slovakia and Czechia, the two countries that built no domestic battery-cell manufacturing capacity within the sample window, show the fastest, most abrupt battery-import growth and a comparatively loose association with the slower-moving backward-linkage aggregate: the battery transition arrived there as a sharp, largely self-contained import shock. Poland, which had the region's earliest and largest existing battery-manufacturing presence, shows the closest year-by-year correspondence between the two series, consistent with battery-related trade there being more gradually absorbed into, rather than superimposed on, the broader pattern of import dependence. Hungary, whose domestic capacity arrived later in the sample, sits in between on both measures. With only nine annual observations per country, these associations are descriptive rather than formally established, but the comparison reinforces rather than qualifies the paper's central finding: electrification did not add a uniform increment to import dependence across the V4, but was absorbed differently depending on each country's existing production structure.

4.7.4 Breaks and policy / firm-level developments

Table 8 matches each country's identified break dates directly against the closest independently documented policy or firm-level event (full chronology, with legal references, in Appendix B, Table B1).

Reading Table 8 as a whole, two patterns stand out. First, the clearest matches are firm-specific rather than policy-specific: of the eleven breaks with any identified counterpart, six correspond most closely to the opening, ramp-up or announcement of a named battery or vehicle plant (Jaguar Land Rover Nitra, Samsung SDI Göd [twice], CATL Debrecen, LG Chem Wrocław, and Gotion-InoBat), while EU- or national-level policy measures (the IPCEI approvals, the Czech incentive-legislation amendment, WLTP) appear mainly as secondary or concurrent factors alongside a firm event, rather than as the closest match on their own. Investment decisions by individual battery and vehicle producers, not the broader EU regulatory timetable, are the more

Table 8. Structural breaks and policy/firm-level developments

Country	Break date	Closest policy / firm-level event	Approx. lag
Slovakia	Jun. 2016	No clear single trigger identified; falls within general pre-WLTP EU market expansion	—
	Oct. 2018	Jaguar Land Rover Nitra begins vehicle production	Same month
	Aug. 2021	EU EuBatIn (2nd battery IPCEI) approval (Jan 2021, incl. InoBat); chip-shortage escalation	~7 months after IPCEI approval
	Jan. 2023	Precedes Gotion–InoBat JV negotiations (2023–24)	Leading indicator
Czechia	Jan. 2019	Precedes Sep 2019 amendment to Act 72/2000 redirecting incentives to advanced automotive/R&D	~8 months leading
	Jan. 2020	COVID-19 onset; start of tightened EU CO ₂ fleet-emission phase-in	Same month/quarter
	Aug. 2021	Chip-shortage escalation (regional, shared with Slovakia)	Concurrent
	Jan. 2023	Continued post-shortage EV-component ramp (no single Czech domestic-capacity milestone in window)	—
Hungary	Dec. 2016	Precedes Samsung SDI Göd construction/ramp-up (production from 2018)	Leading indicator
	Oct. 2019	No single confirmed trigger; falls within general pre-COVID EU EV-policy tightening	—
	Jan. 2022	Samsung SDI Göd reaches full production capacity	Same month
	Jan. 2023	Follows CATL Debrecen announcement (Aug 2022, €7.3bn)	~5 months after announcement
Poland	Jan. 2017	Follows LG Chem Wrocław production start (H2 2017)	Concurrent / leading
	Jan. 2019	Precedes Dec 2019 first battery IPCEI approval (Poland a participant); follows a further LG expansion stage	Concurrent with LG expansion
	Oct. 2021	Chip-shortage / energy-crisis period (regional, shared)	Concurrent
	Nov. 2022	Continued post-shortage adjustment; no single further Polish milestone identified in window	—

Notes: Structural breaks are the Bai–Perron dates from Table 6 (Appendix B, Table B1), matched to the closest independently documented policy or firm-level event. Entries marked “—” have no single confirmed trigger identified and are left deliberately unmatched rather than force-fitted; this correspondence is a timing-consistent narrative, not a causally identified relationship.

proximate correlate of when each country's import trajectory shifted. Second, the countries divide by mechanism rather than by timing alone: Hungary's and Poland's breaks cluster around their own domestic capacity coming online (Göd, Wrocław), consistent with the closer battery-linkage correspondence found in Section 4.7.3 above, whereas Slovakia's and Czechia's breaks cluster around regional shocks shared with each other (the 2021 chip shortage and the 2023 post-shortage adjustment) and around external capacity commitments (InoBat's foreign partners) rather than any completed domestic plant within the sample window. The four countries were not

simply at different points on one shared electrification timeline; they were pulled onto that timeline by different kinds of events.

5. Discussion

The country-by-country evidence assembled in Section 4 speaks directly to two competing accounts of what has been happening to Central European automotive production since 2010, and to a live transformation — electrification — that has unfolded inside that period. This section brings the five empirical dimensions together against, in turn, the reshoring/de-risking literature (§5.1), the Dependent Market Economy framework (§5.2), and the specific case of electrification (§5.3), before drawing out the finding that cuts across all three: heterogeneity across the four countries is pervasive, not incidental, and it is itself part of what needs to be explained (§5.4).

5.1 The reshoring and de-risking literature is not supported

The post-2018 reshoring, nearshoring and de-risking literature predicts, in its various forms, some combination of three things: a shift of intermediate sourcing back toward the domestic economy or nearby partners; a shortening of production chains, as firms trade efficiency for resilience by cutting the number of intermediating stages; and a reduction in value-chain dependence on foreign, and specifically distant, suppliers. None of these predictions is borne out by the V4 automotive evidence over 2010–2023. Three specific empirical contrasts make the mismatch precise rather than impressionistic.

First, on sourcing. If post-pandemic adjustment had primarily involved shifting supply lines closer to the point of production, a systematic increase in domestic intermediate sourcing would be the most direct signature to look for. This is not, in general, what happened, and where it did happen it did not do what reshoring is supposed to do. Over the most recent years of the sample, the domestic-input share declined in Slovakia and Poland, while it rose noticeably in Czechia and, to a lesser extent, in Hungary, so on this measure alone two of the four countries look like they reshored. Backward linkage, however, the trade-based measure of foreign value embodied in exports, rose in all four countries over exactly the same window, including in the two countries where gross domestic purchasing increased. The reconciliation is in §4.2: domestic value-added intensity of domestically sourced inputs was flat-to-declining in Czechia and

Hungary over the same period, so the additional purchasing from domestically located suppliers did not correspond to additional domestically generated value — those suppliers were themselves more import-intensive. Buying more from local firms is not the same thing as reducing import dependence, and nowhere in the V4 automotive sector did actual import dependence, measured correctly, fall.

Second, on chain length. A genuine shortening of production chains should show up as a decline in the number and depth of upstream production relationships embodied in output. Chain length moved in exactly the opposite direction. Total chain length rose, in level terms, in all four countries between 2010 and 2023, and so did its international component — the part attributable to foreign rather than domestic upstream rounds — most strongly in Slovakia and more modestly in Hungary and Poland. Pooled across the panel with country fixed effects, both increases are statistically significant. Taken country by country, the rise in the international component is clearly significant in Slovakia and Poland, only marginally so in Czechia, and directional but not statistically distinguishable from noise in Hungary. No country shows chain-shortening on this measure, whether assessed at the pooled or the country level.

Third, on value capture. Total GVC participation, the sum of backward and forward linkage, rose over the full sample in all four economies and is often read, in isolation, as evidence of deepening integration into global production. It is not evidence of the kind of integration reshoring rhetoric has in mind. Backward linkage rose significantly in Slovakia, Czechia and Poland, and directionally but not significantly in Hungary, between 2010 and 2023. Forward linkage — the domestic value added that V4 automotive production contributes to other countries' exports — fell significantly in Slovakia, Czechia and Hungary over the same period, and was flat in Poland. The rise in aggregate participation is therefore not a story of V4 producers capturing more value that then moves on to further production elsewhere; it is almost entirely a story of V4 exports absorbing more foreign value added. The headline statistic of "deepening GVC integration" conceals a composition that is the opposite of what a value-capture narrative would require.

Taken together, these three contrasts do not describe a region trading efficiency for resilience, or migrating value chains closer to the point of final assembly. They describe production chains that

lengthened, internationalized further, and became more, not less, reliant on foreign value, with whatever domestic-sourcing adjustment did occur failing to translate into reduced dependence once its value content is accounted for.

5.2 Dependent integration under technological change

The Dependent Market Economy (DME) framework (Nölke and Vliegenthart 2009) predicts that Central European automotive integration reproduces dependency at each new technological frontier, rather than resolving it through upgrading. The evidence here is broadly consistent with that prediction for Slovakia, Czechia and Hungary. Backward linkage rose; the domestic input base generally weakened or, where it strengthened, remained value-shallow; and chains lengthened and became increasingly international. Together these point toward continued or deepening assembly-platform specialisation rather than functional upgrading. This pattern holds across a genuine technological discontinuity (electrification), rather than only in the steady state the original DME literature was built to describe: the mechanism generalizes across the specific inputs through which dependency is expressed, which is a stronger test of the framework than a stable-technology period would provide.

Poland complicates a simple reading of the DME thesis without refuting it. It retains the deepest domestic supplier base, the highest domestic value-added intensity, and the least concentrated forward-linkage destinations of the four countries throughout the sample: the clearest structural outlier on level. Yet Poland's own trajectory is not a story of escaping dependency: its backward linkage rose faster over the most recent years of the sample than in any of the other three countries, its domestic input share fell over the full period, and its chain length internationalized on the same margin as its neighbors, simply from a deeper starting point and at a more moderate pace. Poland is a variant within the DME pattern, a later-arriving, more diversified node of the same kind of transnationally organized production, rather than a counter-example to it.

5.3 Electrification as a transformation, not a resolution, of dependence

Electrification did not create an opportunity for the V4 to reduce automotive import dependence; it changed the input structure through which that dependence is expressed. The lithium-ion battery import series (Section 4.6) shows import volumes rising many times over between 2015 and 2023, with growth steepest in Czechia and Slovakia and Poland showing the smallest, though still substantial, increase. That ranking is not four countries running the same race at

different speeds. Poland entered the period as the region's established battery importer and accelerated earliest, on the strength of capacity already under construction; Slovakia and Czechia started from far behind and only began their own acceleration once Poland's had already moderated, then overtook it. Each country's series rejects a single stable trend in favor of several distinct regimes, and formal testing finds no shared common break date across the panel, confirming that the countries' experiences of the transition genuinely diverged rather than following one shared timeline. The ranking on battery-import growth (Czechia and Slovakia fastest and most abrupt, Hungary intermediate, Poland slowest) matches the ranking on backward linkage, domestic input erosion and chain-length internationalization established across §4.1, §4.2 and §4.4: the same two countries that were deepening fastest on every conventional GVC measure also show the sharpest, most abrupt increases in battery-specific import dependence.

What differs by country is not whether dependence deepened under electrification, but the institutional form it took. Slovakia and Czechia built no domestic battery-cell manufacturing capacity within the sample window and absorbed the transition entirely through import growth. Hungary and Poland did gain domestic battery-cell capacity, but that capacity arrived through foreign investment rather than indigenous development: Hungarian capacity came through Korean and Chinese direct investment under domestic investment-incentive legislation, and Polish capacity through a wholly foreign-owned plant (LG Energy Solution, Wrocław). In neither case does the presence of domestic manufacturing capacity indicate domestic technological autonomy; it indicates a different node, one stage further upstream, of the same transnationally organized production network. The dated breaks bear this out: matched against an independently documented policy and firm chronology, most of the four countries' shifts line up more closely with the opening, ramp-up or announcement of a named battery or vehicle plant than with any EU- or national-level policy measure, which suggests that firm investment decisions, not the regulatory timetable, are the proximate driver of when each country's dependence took its new form.

The same divide shows up in how closely battery imports track the broader pattern of import dependence. In Poland, and to a lesser extent Hungary, battery-import growth and backward linkage move together year by year; in Slovakia and, most starkly, Czechia, the two series largely

decouple, with battery imports climbing on a path of their own regardless of the shorter-run movements in backward linkage. Domestic battery capacity, in other words, does not buy a country independence from the wider pattern of dependence: it changes how that dependence is expressed, folding battery trade into the same slower-moving aggregate that already captures the rest of automotive production, rather than leaving it to arrive as a separate, faster-moving shock. Electrification is therefore best read as a transformation of dependence, a new product category and a new set of source countries (Section 4.4's China and non-EU sourcing results are the general-equilibrium counterpart of this battery-specific finding), rather than as a disruption to the underlying DME pattern.

5.4 Heterogeneity as the central empirical fact

A theme recurs across §5.1–§5.3 that is worth stating as a finding in its own right rather than treating as noise around a single V4 story: on almost every dimension examined in this paper, the four countries follow different paths, and the differences are not confined to one or two indicators. Table 9 summarizes the direction and statistical significance of the country-level trend, 2010–2023, across eleven indicators spanning chain length, geographical concentration and composition, and backward/forward linkage; the EV-battery evidence in §5.3, evaluated separately because it rests on a different data source and frequency, tells the same story on a twelfth dimension the table does not cover: different starting levels, different growth paths, different break timing, and a different relationship to the broader pattern of import dependence depending on whether domestic battery capacity exists.

Three patterns stand out. First, no two countries share the same significant-trend profile across all eleven rows. Even Slovakia and Czechia, often treated as the most similar pair on stylized level comparisons since both are pure-play, non-battery-manufacturing assembly platforms, diverge sharply on domestic input share, where the decline is significant in Slovakia but Czechia is essentially flat, and on forward-destination concentration, where the rise is only marginal in Slovakia but clearly significant in Czechia. Second, Hungary is the country most often out of step with the pooled V4 direction. It is the only country where domestic chain length and domestic input share rise rather than fall, and the only one where the foreign chain-length component fails to rise significantly. Yet Hungary shows some of the deepest backward linkage

Table 9. Direction and significance of country-level trends across eleven dimensions, 2010–2023

Dimension	Slovakia	Czechia	Hungary	Poland
Chain length, total (Leontief)	↑	↑	↑	↑
Chain length, foreign component	↑***	↑*	↑	↑**
Backward sourcing concentration (HHI)	↓***	↓	↓	↓***
Forward destination concentration (HHI)	↑*	↑**	↑***	↓***
Non-EU sourcing share	↑	↑**	↑***	↑***
China sourcing share	↑***	↑***	↑***	↑***
Backward linkage	↑***	↑***	↑	↑***
Domestic input share	↓***	↓	↑***	↓***
Domestic VA intensity of domestic inputs	↑	↓*	↓	↓
Forward linkage	↓***	↓***	↓***	↓
GVC participation (backward + forward)	↑***	↑*	↑	↑***

Notes: Arrows show the sign of the OLS trend slope from a country-level regression on year, 2010–2023 (T = 14). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; no stars = not significant at the 10% level. Source: authors' calculations from FIGARO.

and GVC participation levels of the four throughout. China's sourcing share is a rare exception to Hungary's outlier status: there, Hungary tracks the other three countries almost exactly, with one of the strongest and most significant rises of the four, a reminder that Hungary's divergence from the pooled pattern is not universal across every indicator. Third, Poland is the most consistent outlier on level, with the deepest domestic base, the most diversified forward linkage, and the slowest battery-import growth of the four, but it is not exempt from the pooled direction of travel on the indicators that matter most for the reshoring critique in §5.1: its backward linkage rose faster than in any of the other three countries over the most recent years of the sample, and its chain length internationalized on the same margin as its neighbors.

The theoretical implication is that the DME framework, as applied here, describes a shared structural exposure (assembly-platform specialisation financed and technologically driven by foreign capital) rather than a shared trajectory. Bohle and Greskovits's (2009) caution against treating the Visegrád political economies as a homogenizing bloc is borne out directly by the granular, indicator-by-indicator evidence assembled here: the countries differ not only in level, which a typology can accommodate, but increasingly in the direction and pace of change on indicators as fundamental as domestic sourcing, chain length and destination concentration. A DME account of this sector going forward needs to explain why the shared exposure produces diverging, not converging, national trajectories: a question this paper's evidence base is well suited to pursue but does not, on its own, resolve.

6. Contribution

The paper's contribution follows the three claims set out in the Introduction, each of which the empirical results substantiate directly.

First, the paper provides a more precise measure of domestic embeddedness by separating the location of a transaction from the origin of the value it embodies. This distinction is not a technical refinement: the results in §4.2 show that domestic sourcing and domestic value-added intensity can and do move in opposite directions within the same country and period, a divergence that a single domestic-input-share indicator would conceal entirely.

Second, the paper distinguishes several forms of supply-chain adjustment that the reshoring and diversification literature often treats as interchangeable: geographical concentration, production-chain length, regional sourcing composition and domestic value capture. The findings in §4.4–§4.6 show why this separation matters empirically: geographical diversification away from the euro area coincided with longer, not shorter, production chains, and a decline in backward-HHI concentration did not amount to a Europeanisation of sourcing. Treating these as a single shortening/lengthening or reshoring/offshoring axis, as much of the post-2018 literature does, would have obscured exactly the pattern that turns out to be central to the V4 case.

Third, the paper connects these macro-level structural changes to the uneven transition toward electromobility and tests that connection formally rather than asserting it. The monthly battery-import evidence in §4.7 identifies country-specific structural breaks, the panel common-break test rejects a shared regional timing, and the resulting dates correspond more closely to individual firm investment decisions than to the EU or national regulatory calendar.

These three contributions support the more general point developed in Section 5: a shared institutional starting point (FDI-led automotive integration under broadly similar conditions across all four V4 economies) does not imply a shared trajectory. Slovakia, Czechia and Hungary have moved further toward deeper, more internationalized assembly-platform integration, while Poland's structurally deeper domestic base narrows relative to the other three only gradually. Treating the V4 as a single regional production platform, as much of the existing literature implicitly does, obscures this differentiated pattern of dependence.

7. Limitations

Five limitations qualify the interpretation of the results.

The correspondence between structural breaks and policy or firm-level events, documented in §4.7.4, is a timing-consistent narrative rather than a causal claim. No identification strategy (for example, a difference-in-differences design exploiting the staggered timing of battery-plant openings) has been used to establish that these events caused the observed breaks, as opposed to being coincident with other unobserved drivers.

With only four countries, the panel-level tests reported in §4.5 and Appendix B rely on bootstrap rather than asymptotic inference, and any description of "the V4 pattern" necessarily generalizes from a small, non-random sample of countries.

The battery-import evidence used to date the EV transition (§4.7) covers a single product code, lithium-ion accumulators (CN 85076000). Other EV-relevant components (power electronics, electric motors, battery management systems) are not covered and could show different timing or magnitude.

The analysis is conducted at the level of NACE Rev. 2 division 29, which aggregates final assembly, component manufacturing and engine production. The paper's indicators cannot distinguish how much of the observed cross-country heterogeneity reflects differences in the sub-sectoral composition of each country's automotive industry, as opposed to differences in GVC integration within a broadly similar sub-sectoral mix.

Finally, the Bai–Perron sequential procedure did not always terminate cleanly for Hungary and Poland, with additional marginal breaks appearing as segment lengths approached the 12-month trimming floor (Appendix B.2). Results are therefore capped at four breaks per country for comparability; any break beyond that cap should be treated as indicative rather than robustly identified.

8. Conclusion

This paper asked a simple question. Did Central European automotive integration change shape between 2010 and 2023, a period spanning both the post-2018 debate on reshoring and de-risking and the accelerating shift to electromobility? Or did the older pattern persist (the foreign-dependent, FDI-led model described by Nölke and Vliegenthart (2009), Bohle and Greskovits (2012) and Pavlínek's integrated-periphery research) just under a new technological surface?

The answer is clear on one count and more qualified on the other. The reshoring and de-risking literature's predictions do not hold for this sector. The dependent-market pattern persists, and if anything deepens through the EV transition. But it does not persist as a single regional story. It plays out along four national paths that are related to each other but increasingly distinct.

On reshoring and de-risking, three contrasts make the case, and each was checked independently against the FIGARO data (§5.1). First, domestic sourcing did not systematically increase across the V4. Only Hungary shows a net increase in domestic sourcing over the full period. Czechia's domestic-input share partially recovered after a mid-decade trough but still ended 2023 slightly below its 2010 level. In both countries, the domestic sourcing that did occur (Hungary's net rise, Czechia's partial recovery) was not matched by extra domestically generated value. Backward linkage rose regardless. Second, production-chain length lengthened, not shortened, in every country between 2010 and 2023. The growth came specifically from the internationally sourced component of the chain. Third, the headline rise in aggregate GVC participation is not what it looks like. Decomposed into its two parts, it is almost everywhere a rise in backward linkage combined with a fall in forward linkage: deepening reliance on foreign value, not a bigger domestic contribution to production elsewhere. None of the three predictions behind the post-pandemic resilience literature (nearshoring, shorter chains, reduced foreign dependence) is supported by this sector's value-added evidence, whatever gross trade and investment announcements might suggest.

On the Dependent Market Economy framework, the evidence points the same way for three of the four countries. Slovakia, Czechia and Hungary show rising backward linkage, a domestic input base that is either eroding or adding little value, and a production chain that is becoming more international. Together these point to continued assembly-platform specialisation, not

functional upgrading. This pattern holds even across a genuine technological break (electrification), not only in the stable conditions the framework was originally built to describe. Poland qualifies this picture rather than contradicting it. Its deeper domestic base and more diversified linkages reflect an earlier-arriving, differently positioned node within the same transnationally organized production system. It is not an escape from that system. This is exactly what the literature review anticipated in its account of Poland's larger domestic market and broader industrial base (§2.3).

Electrification, on this evidence, transforms dependence rather than resolving it. The lithium-ion battery import series shows import volumes rising more than tenfold in every V4 country between 2015 and 2023, and more than fifty-fold in Czechia. Each country's series rejects a single stable trend, and the four countries do not share a common break date. Where domestic battery-cell capacity did emerge, in Hungary and Poland, it arrived through Korean, Chinese or other foreign direct investment, not through indigenous technological development. That capacity is a new upstream node of the same kind of foreign-controlled production network the DME and integrated-periphery literatures describe, not a departure from it. Matched against an independently documented chronology, the timing of each country's shift tracks individual battery and vehicle plants more closely than it tracks EU or national policy measures, pointing to firm investment, not regulatory design, as the proximate driver of when dependence took its new form. And where that domestic capacity exists, battery imports move together with the wider pattern of import dependence; where it does not, they arrive as a separate, faster-moving shock of their own. This confirms, now with product-specific, monthly evidence, what §2.7–§2.8 anticipated conceptually: a shared technological and regulatory shock, filtered through inherited and already-heterogeneous national structures, produces new dependencies rather than new autonomy.

The paper's most consequential finding, though, cuts across all of the above: heterogeneity across the four countries is pervasive, not incidental. Across eleven indicators (spanning chain length, sourcing concentration, regional composition, and backward and forward linkage), no two countries share the same significant-trend profile. Hungary stands out in particular. It has among the deepest backward-linkage and GVC-participation levels of the four throughout the period, yet it is repeatedly the outlier on the direction of change, not just its pace. This is exactly the

caution Bohle and Greskovits (2009, 2012) raised against treating the Visegrád economies as a single, homogeneous bloc: now given granular, indicator-by-indicator support rather than asserted in general terms. Read this way, the DME framework describes a shared structural exposure: assembly-platform specialisation financed and technologically driven by foreign capital. It does not describe a shared trajectory. Explaining why that shared exposure produces diverging, rather than converging, national paths is the question this sector's future study now needs to take up.

Two things follow for how this evidence should be used. First, we should be cautious of aggregate, V4-wide statements about "the region's" automotive dependence, reshoring exposure or EV readiness. They risk obscuring the very heterogeneity this paper's country-by-country approach was designed to surface. Policy and firm-level analysis pitched at the regional level should carry that caveat. Second, this paper has drawn a distinction throughout: between the location of a transaction and the origin of the value it embodies, and between the volume of upstream activity and its average distance. That distinction is not a methodological nicety. It is the difference between two opposite readings of the same headline statistics. Gross trade, investment announcements and even nominal domestic-sourcing shares can tell a story of reshoring and resilience. The value-added accounting used here tells a different one: lengthening, internationalising and increasingly backward-oriented dependence, differentiated by country but common in direction.

That is the paper's central claim, and it is a claim about direction as much as about level. The V4 automotive sector did not step back from global value chains after 2018, and electrification has not given it a way out. It has deepened its dependence, changed what that dependence is made of, and done so on four separate national timetables rather than one regional one. Any account of this sector's future (its exposure to further supply-chain shocks, its capacity to upgrade, its role in Europe's automotive transition) has to start from that plural reality, not from a single V4 story that the evidence no longer supports.

Appendix A. GVC accounting framework and construction of indicators

A.1 Inter-country input-output framework

The empirical analysis is based on the FIGARO inter-country input-output (ICIO) system. Let x denote the vector of gross output, A the global matrix of technical input coefficients and y final demand. The accounting identity is

$$x = Ax + y,$$

which yields

$$x = (I - A)^{-1} y = Ly,$$

where

$$L = (I - A)^{-1}$$

is the global Leontief inverse (denoted B where it recurs in Section 3.5 of the main text). An element of L measures the total direct and indirect output required from a particular country-industry pair to satisfy one unit of final demand elsewhere in the system.

Let v denote the vector of direct value-added coefficients, with each element defined as value added per unit of gross output. Writing $\hat{v}$ for the diagonal matrix of these coefficients,

$$\hat{v} L$$

traces the country-industry origin of value added embodied in production and final demand. This provides the accounting basis for the domestic- and foreign-value-added indicators used in the paper.

The empirical analysis focuses on NACE Rev. 2 division 29, manufacture of motor vehicles, trailers and semi-trailers, for Czechia, Hungary, Poland and Slovakia over 2010–2023.

A.2 Sectoral-bilateral value-added decomposition

Gross trade statistics record the value of an intermediate product each time it crosses an international boundary. In production networks involving repeated processing and re-exporting,

the same underlying value added can therefore enter gross trade more than once. A decomposition that distinguishes domestic and foreign value added from double counting is required when analyzing internationally fragmented production.

We follow the sectoral-bilateral approach of Borin and Mancini (2023). The relevant accounting boundary is the export flow from automotive sector s in exporting country r to partner country n . For each sectoral-bilateral flow, the procedure constructs a modified technical-coefficient matrix $A(sr,n)$ in which the relevant intermediate-export linkage is removed. The associated Leontief inverse is

$$B(sr,n) = (I - A(sr,n))^{-1}.$$

Removing the export linkage prevents value that crosses the same sectoral-bilateral boundary repeatedly from being attributed incorrectly to net value-added exports.

For expositional purposes, the resulting decomposition of gross sectoral-bilateral exports can be written compactly as

$$u(sr,n) = DVA(sr,n) + DDC(sr,n) + FVA(sr,n) + FDC(sr,n),$$

where $u(sr,n)$ denotes gross bilateral sectoral exports from automotive sector s in country r to partner country n , DVA domestic value added embodied in exports, DDC domestic double counting, FVA foreign value added embodied in exports, and FDC foreign double counting. The empirical implementation follows the complete Borin–Mancini sectoral-bilateral decomposition, including the distinction between intermediate and final exports and the subsequent absorption or re-export of intermediate trade.

The bilateral-sectoral components are subsequently aggregated across partner countries to construct the country-level automotive indicators used in the paper.

A.3 Backward and forward GVC participation

Backward GVC participation measures foreign value added embodied in automotive exports relative to gross automotive exports:

$$BWD_{it} = FVA_{it} / EX_{it} \times 100,$$

where FVA_{it} is foreign value added embodied in the automotive exports of country i in year t , and EX_{it} denotes gross automotive exports.

Forward participation measures domestic automotive value added that enters foreign production and is subsequently embodied in other countries' exports:

$$FWD_{it} = DVX_{it} / EX_{it} \times 100,$$

where DVX_{it} denotes domestic automotive value added embodied in subsequent foreign exports.

Aggregate GVC participation is

$$GVC_{it} = BWD_{it} + FWD_{it}.$$

The decomposition is important because a given level of aggregate participation can represent very different positions within an international production network. Backward participation captures the use of foreign value added in domestic exports, whereas forward participation captures the contribution of domestic value added to subsequent foreign production and exports.

A.4 Domestic sourcing and domestic value capture

Three indicators are used to distinguish different dimensions of domestic embeddedness.

The direct value-added share is

$$DVA_{it}^{direct} = VA_{it}^{NACE29} / GO_{it}^{NACE29} \times 100.$$

The domestic-input share is

$$DIS_{it} = DI_{it} / TI_{it} \times 100,$$

where DI_{it} denotes intermediate inputs purchased from suppliers located in the domestic economy and TI_{it} total intermediate inputs used in automotive production.

The domestic value-added intensity of domestic inputs is

$$DVAI_{it} = DVA_{it}^{DI} / DI_{it} \times 100,$$

where DVA_{it}^{DI} denotes domestic value added embodied in domestically purchased intermediate inputs.

The distinction between *DIS* and *DVAI* separates the location of the immediate supplier from the origin of the value embodied in that supplier's output. Domestic sourcing can therefore increase even if the domestic value-added intensity of those inputs declines.

A.5 Production length and its domestic/foreign decomposition

Chain length answers a different question from A.2–A.4: not how much value added crosses a border, but how many processing stages (domestic or foreign) a unit of final demand passes through before it is satisfied. Following Wang, Wei, Yu and Zhu (2017) for the chain-length indicator itself, and Dietzenbacher and Romero (2007), building on Dietzenbacher, Romero Luna and Bosma (2005), for its normalized (average propagation length) form, the question is addressed by expanding the Leontief inverse as an infinite power series in A :

$$L = I + A + A^2 + A^3 + \dots = \sum_{k=0 \text{ to } \infty} A^k.$$

The k -th term, A^k , captures deliveries that have passed through k successive processing stages before being absorbed. Weighting each term by the number of stages it represents and summing gives the cumulative, stage-weighted production-length matrix H , following Wang, Wei, Yu and Zhu (2017); H is used directly to construct the Leontief chain-length indicator reported in Table A1:

$$H = \sum_{k=1 \text{ to } \infty} k \cdot A^k.$$

Because H sums directly over the underlying A^k terms, it partitions exactly into a domestic component, aggregating only A^k terms whose entire path stays within country i , and a foreign component, aggregating every path that crosses at least one border at any stage; the two add up to the total chain length by construction:

$$H_{total} = H_{domestic} + H_{foreign}.$$

Normalising H by the corresponding element of the Leontief inverse, net of the direct (zero-stage) term, yields the average propagation length (APL):

$$APL_{ij} = H_{ij} / (L_{ij} - \delta_{ij}),$$

where δ_{ij} is the Kronecker delta ($\delta_{ij} = 1$ if $i = j$, 0 otherwise), which removes the direct, single-stage delivery from the base against which the average is taken. APL_{ij} is the expected number of production stages a unit of output from i passes through before being absorbed as value added embodied in the delivery to j .

For the automotive sector of country i , the paper reports the sector's own element, restricted to paths that both originate and terminate in country i 's NACE29 final demand, and partitions it into a domestic and a foreign component:

$$APL_{total} = APL_{domestic} + APL_{foreign},$$

where $APL_{domestic}$ aggregates only those A^k terms whose entire path stays within country i , and $APL_{foreign}$ aggregates every path that crosses at least one border at any stage. The two sum to the total by construction, since every path does one or the other. The domestic share, $APL_{domestic} / APL_{total}$, is the paper's primary indicator of how much of the automotive production process (not only final assembly) is retained on domestic soil once every intermediate stage is taken into account.

A.6 Geographical concentration of destination and sourcing structure

Two further indicators summarize how concentrated a country's automotive trade is geographically, on the export side (forward exposure) and the sourcing side (backward exposure). Both are constructed as Herfindahl–Hirschman indices over a common partition of partner geography w , most coarsely {euro area, non-euro-area EU, non-EU}:

$$HHI(k)_{it} = \sum w (share(k)_{wit})^2, \quad k \in \{backward, forward\}.$$

For $k = forward$, $share(k)_{wit}$ is the share of country i 's gross automotive exports absorbed by destination region w in year t ; for $k = backward$, $share(k)_{wit}$ is the share of country i 's foreign intermediate inputs (A.4) sourced from region w in year t . Both sets of shares sum to one over w by construction, so each HHI ranges from a lower bound set by the number of categories in the partition (an even split across all categories, maximal diversification) to 1 (complete concentration in a single region). A falling HHI over time indicates diversification away from whichever region previously dominated; on its own, it does not indicate which region gains share or why: that is the role of the compositional indicator in A.7.

A.7 Sourcing composition

The regional partition in A.6 treats non-EU sourcing as a single category, which is convenient for the concentration index but does not identify which external partners account for it. Where the underlying FIGARO breakdown permits, the non-EU component of backward-linkage sourcing is further disaggregated into named partners p (e.g. China, South Korea, Japan, the United States):

$$Source_share(p,it) = FVA^{input}(p,it) / \sum_w FVA^{input}(w,it).$$

Each named-partner share is expressed, as in A.4, as a share of total foreign intermediate inputs rather than of the non-EU total alone, so that it is directly comparable to the regional shares underlying A.6. This decomposition is purely compositional: it does not itself enter the HHI in A.6, which retains the coarser regional partition throughout, but it is what allows the paper to distinguish a change in the geographical concentration of sourcing (A.6) from a change in its underlying country composition. A given non-EU HHI can rise for reasons ranging from broad-based diversification across many non-EU partners to concentration in a single new one, and only the partner-level shares in this section separate those two possibilities empirically. Coverage of the named-partner breakdown is not uniform in the underlying FIGARO release; where a given partner's element is reported as uniformly and implausibly zero across the whole panel, this is treated as a coverage gap in that breakdown rather than as evidence of an absence of trade, and that partner is not read as informative.

A.8 Relationship between the value-added, length and concentration measures

The three groups of indicators in this appendix answer distinct questions on the same underlying input-output system and are not substitutes for one another. The value-added decomposition (A.2–A.4) asks how much value added crosses a border, and in which direction. Production length (A.5) asks how many processing stages, domestic or international, a unit of final demand passes through, irrespective of how much value is created at each stage. Geographical concentration and sourcing composition (A.6–A.7) ask, conditional on a border being crossed, how many partners and which ones are involved. A sector can therefore combine high backward linkage with either a short or a long international chain, and a long international chain can be sourced from either a concentrated or a diversified set of partners. Reporting all three groups

together, rather than any one in isolation, avoids collapsing these distinct dimensions of GVC integration into one another.

Table A1. Definitions and interpretation of principal indicators

Indicator	Definition	Interpretation
Backward linkage	Foreign VA embodied in automotive exports / gross automotive exports	Reliance of domestic automotive exports on foreign value added
Forward linkage	Domestic automotive VA entering subsequent foreign exports / gross automotive exports	Contribution of domestic automotive VA to downstream foreign exports
GVC participation	Backward + forward linkage	Overall participation in internationally fragmented production
Direct VA share	Direct NACE 29 VA / gross NACE 29 output	Direct domestic value created within the automotive industry
Domestic-input share	Domestically purchased intermediates / total intermediate inputs	Physical or transactional localization of sourcing
Domestic VA intensity of domestic inputs	Domestic VA embodied in domestic inputs / domestic inputs	Domestic value captured within locally sourced inputs
Leontief production length	Cumulative direct and indirect production requirements, weighted by stage (H, A.5)	Accounting depth of the production network
APL	Average propagation distance through the input-output network, decomposed into domestic and foreign components (A.5)	Alternative, normalized measure of production distance
Backward HHI	Sum of squared regional shares in upstream sourcing (A.6)	Geographical concentration of foreign sourcing
Forward HHI	Sum of squared regional shares in downstream exposure (A.6)	Geographical concentration of downstream foreign linkages
Sourcing composition (named partners)	Named-partner share of total foreign intermediate inputs, e.g. China, South Korea, Japan (A.7)	Identifies which specific external partners drive a change in backward-linkage sourcing

Appendix B. Structural-break analysis of lithium-ion battery imports

B.1 Data and transformation

The structural-break analysis uses monthly Eurostat Comext imports from all trading partners of lithium-ion accumulators, excluding spent accumulators (CN 85076000), for Czechia, Hungary, Poland and Slovakia. The sample extends from January 2015 through December 2023, providing 108 monthly observations for each country.

Let M_{it} denote nominal battery imports of country i in month t . The dependent variable is

$$mit = \ln(Mit).$$

The logarithmic transformation reduces the influence of the large increase in nominal import values towards the end of the sample and permits changes in trend to be interpreted proportionately.

Monthly seasonality is controlled for using eleven calendar-month indicators. The resulting seasonally adjusted series is modelled as a piecewise linear function of time.

B.2 Bai–Perron multiple-break procedure

The principal procedure follows Bai and Perron (1998, 2003) and allows the number and timing of structural changes to be determined endogenously. Within regime j ,

$$mt = \alpha_j + \beta_j t + \varepsilon t, \quad T(j-1) < t \leq Tj,$$

so that both the intercept and trend slope may change across regimes.

Conditional on a specified number of breaks, the break dates are selected by dynamic programming to minimize the global residual sum of squares over all admissible partitions.

A minimum segment length of 12 months is imposed. With 108 observations, this prevents the algorithm from identifying regimes consisting of only a small number of monthly observations.

The number of breaks is evaluated sequentially. Because of the relatively short monthly sample, inference for the sequential tests is based on a residual bootstrap: residuals from the restricted specification are resampled with replacement, and the distribution of the relevant F-statistic is generated from 299 bootstrap replications.

For Hungary and Poland, the sequential procedure continued to identify additional marginal breaks as regime lengths approached the 12-month trimming constraint. To avoid treating short-lived variation as separate economically meaningful regimes and to preserve comparability across countries, the reported specifications (Table 3, main text) are capped at four breaks per country.

B.3 Quandt–Andrews dominant-break test

The multiple-break analysis is complemented by a single unknown-break test following Andrews (1993). For every admissible break date, separate pre- and post-break linear-trend regressions are estimated and a Chow-type F-statistic is calculated. The test statistic is

$$Sup F = \max (\tau \in T) F(\tau),$$

where T denotes the trimmed set of admissible dates. Candidate dates are restricted to months 13–96, applying the same 12-month minimum-segment rule as in the Bai–Perron analysis. The date producing the largest statistic is reported in the main text (Table 3) as the dominant single break; it need not be the first structural change in the series.

B.4 CUSUM parameter-stability test

The Brown–Durbin–Evans CUSUM procedure provides an independent diagnostic of parameter instability. Unlike the sup-F procedure, which searches for the date producing the largest discrete improvement in model fit, CUSUM accumulates recursive residuals and identifies when the maintained relationship first departs persistently from parameter stability.

The first CUSUM crossing, reported alongside the other break dates in Table 6 of the main text, can therefore precede the dominant sup-F break. Differences among the Bai–Perron, sup-F and CUSUM dates are not necessarily contradictory, because the procedures identify different aspects of instability.

B.5 Supplementary test statistics

The break and crossing dates identified by each procedure, together with a brief interpretation, are reported in Table 6 of the main text and are not reproduced here. This section reports the test statistics and bootstrap p-values underlying those dates, which the main text does not give in full.

Table B1. Supplementary structural-break test statistics

Country	Dominant single break		Bai–Perron 3 → 4 breaks	
	Sup-F statistic	p-value	F-statistic	Bootstrap p-value
Slovakia	29.44	<0.001	6.58	0.030
Czechia	112.42	<0.001	8.61	<0.001
Hungary	21.28	<0.001	9.65	<0.001
Poland	29.30	<0.001	8.86	<0.001

Notes: The sup-F statistic and p-value test the dominant single break reported in Table 6 against a stable-trend null. The Bai–Perron 3 → 4-break statistic and bootstrap p-value test whether a fourth break improves significantly on the three-break specification, using the residual bootstrap described in B.2 (299 replications); four-break specifications are reported throughout for comparability across countries.

Source: authors' calculations from Eurostat Comext.

B.6 Cross-country synchronization: test specification

Sections B.2–B.4 treat each country's series separately. A further question, in the spirit of Bai (2010), is whether the four countries in fact share a single common break date once country-specific levels and trends are allowed for, or whether the country-specific dates preferred above are statistically distinguishable from a single shared regional date. Because Bai's (2010) original asymptotic theory is derived for panels with a large number of cross-sectional units, and this panel has only four, the test is implemented as a bootstrap comparison of nested models rather than by relying on Bai's large- N asymptotic distribution, which would not be well justified here.

Two models are compared, both restricted to a single break per country for tractability, matching the Quandt–Andrews specification in B.3: a restricted model (H_0) in which all four countries share one common break date τ , with country-specific intercepts and trends estimated separately before and after τ ; and an unrestricted model (H_1) in which each country's break date is estimated separately, as in Table 6 of the main text. H_1 nests H_0 as a special case, so its total residual sum of squares can never exceed H_0 's; the test asks whether the gap between them is larger than sampling variation alone would produce, again assessed by residual bootstrap.

The resulting best common break date, the associated bootstrap p -value, and the conclusion drawn from it are reported in §4.7.2 of the main text and are not repeated here.

B.7 Interpretation and identification limits

The general case against reading these breaks, or their correspondence with policy and firm-level events, as causally identified is set out in the paper's Limitations (Section 7) and is not repeated here. One reporting convention specific to this appendix and to Table 8 of the main text is worth stating explicitly: temporal proximity between an estimated break and an independently documented event is described only as consistent with, corresponding to, or coinciding with that event, never as an estimated treatment effect. This wording is deliberate throughout the paper and should be read literally.

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