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The Generics Revolution and the New Economic Geography of the Global Pesticide Industry

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ABSTRACT

The global pesticide industry transformed from one dominated by patented products and legacy multinationals with strong manufacturing bases in the United States and EU to one dominated by generic products produced in India and China. We use proprietary market research data, data from regulatory filings, industry press and bilateral trade data to map how the 'generics revolution' transformed production and trade in pesticides. Tracing significant changes in sourcing over two decades, we show the emergence of major agribusiness multinationals focused on the generics market as producers, exporters or both. Industrial policy and firm strategy among Chinese firms, which now dominate the generics market, have had a global impact on the industry. Legacy R&D companies maintain dominance through strong positions in the production and marketing of generics as well, blurring the traditional distinctions between these two sectors. Overall, our analysis raises serious questions for regulation and efforts to reduce pesticide dependence.

1 | Introduction

The global pesticide industry seems to be heading into a new, promising future. Innovation in the industry is celebrated for more targeted application, less substance use and 'biological' pest control, signalling a departure from the dark era of agrochemical[1] overuse (Bronson and Sengers 2022). Behind this optimistic narrative lurks a wholesale transformation of the industry that has seen cheaper generic agrochemicals driving increases in pesticide use in much of the world, above all in lower income countries (Shattuck 2021; Shattuck et al. 2023; Werner et al. 2022). This transformation both facilitated and reflected what agricultural economists dubbed the 'herbicide revolution in developing countries', where low-cost herbicides transformed supply and agricultural use in countries as diverse as Mali, India, China and Eastern Europe (Aga 2018; Haggblade et al. 2017). We refer to this overall shift as the 'generics revolution' to highlight the changing industry structure that is responsible for this transformation and to analyse its main lineaments and their implications in what follows.

In the 1990s, generics firms were primarily smaller, domestic outfits that benefited from import-substitution policies. The distance between R&D firms and generics companies in terms of revenue and market reach at the time cannot be overstated. The combined annual sales of the top 100 generics companies were $5 billion dollars in 1997, around 15% of the world pesticide market (Hicks 1998). With the success of pharmaceutical firms in setting the global intellectual property (IP) agenda and the rollback of trade barriers under the WTO (Baker 2008; Chang 2001), one could have expected these local generics companies to flounder. The new global IP regime made it much easier for R&D firms to enforce their patents in global South markets, and the emerging neoliberal trade regime exposed local companies to heightened foreign competition (Agrow 2007). Yet the outcomes of 1990s market regulatory reforms did not conform to such predictions, and in the rest of this paper, we offer an initial explanation as to why this was the case. Despite significant consolidation among legacy R&D firms, generic agrochemical companies increased their market share the world over. In 2000, generic products made up less than a third of the global market in value terms, while 70% of pesticides were either under patent or off-patent but still controlled by the patent-holding company (or its successor). By 2021, these ratios had flipped, and more than three quarters of the market was made up of generics (S&P Global 2023a).

Our approach draws upon debates in geography and beyond on the development implications of the restructuring of global production networks and value chains and their decentring from a north–south orientation to a polycentric production and trade pattern (Gereffi et al. 2021; Horner 2016a; Horner and Nadvi 2018). Pharmaceuticals offer an important parallel given an analogous supply chain based on active ingredient and formulation, the centrality of IP rights (IPR) and product-specific registrations for market access, and the outsized role that generics firms have played in emerging markets (Horner 2016b). Particular to pesticides, however, has been a dearth of innovation in new chemistries, which exceeds similar problems in the pharmaceutical industry and, we argue below, is transforming the general understanding of the generics and R&D firm categories in themselves. Finally, ecological feedback loops are an additional consideration in our discussion, dimensions that are generally given short shrift in global production network and value chain literatures (Campling and Havice 2019).

The pesticide industry is notoriously opaque. In order to trace its transformation through the generics revolution, we rely upon a mix of sources. Global trade data include formulated products—pesticides ready for application—but trade in bulk active ingredients, which have become increasingly important for pesticide supply chain restructuring, is invisible in public trade statistics (Shattuck et al. 2023). The industry itself relies on proprietary data collected by market research firms, the most prominent of which has been Phillips McDougall now owned by S&P Global.[2] Here, we use a combination of proprietary market research data we accessed under an academic use licence with S&P Global, including active ingredient production plants, global market value by product and parent company information for producers. We triangulate data from S&P Global with extensive analysis of public data from company reports, regulatory filings, industry press sources (e.g., Agropages) and investor reports, as well as trade data from UN COMTRADE.[3]

We begin with an overview of the industry and a geography of the major shifts in global trade over the last 20 years. We map active ingredient production by plant location, ownership and pesticide class in the first academic analysis of this function in the supply chain. Turning to an analysis of changing trade flows of formulated product, we trace significant changes in sourcing over two decades. We then unpack these observed changes in active ingredient and formulation geographies through two principal lenses. First, we focus on new actors: The emergence of major agribusiness multinationals focused on the generics market as producers, exporters or both. We look at both industrial policy and firm strategy among Chinese firms, which now dominate the generics market. Second, we examine the significance of R&D companies to the generics market. We offer evidence on firm-level production, sales, markets and strategic relationships to demonstrate that these firms' dominance is maintained through strong positions in the production and marketing of generics. While IPR continue to be an important terrain upon which the distinction between generics and R&D firms is reproduced, the emergence of new generics actors along with the supply chain strategies of R&D firms blurs the lines between these two sectors. Overall, our analysis of the generics revolution in pesticides highlights the contested outcomes of the global market regulatory reforms of the 1990s. Efforts to shift the needle on conventional agriculture away from intensive pesticide use will have to contend with the industry's new structure and changing landscape of corporate actors and interests.

2 | Uneven Geographies of Pesticide Production, Trade and Use

Pesticides and fertilizers are typically grouped into the life science segment of the chemical industry, which includes pharmaceuticals and veterinary chemicals. While the pesticide industry shares the same customer base as fertilizers, research and development (R&D) spending and regulatory environments are more similar to those of the pharmaceuticals industry with regard to product discovery and development (Swanton et al. 2011).

In terms of the extended production network, pesticide production involves activities associated with the production of commodity chemicals (highly standardized, low-price and produced in dedicated plants on large scale), fine chemicals (complex, pure, high-value chemicals, such as intermediaries and selective active ingredients, produced in lower volume in multi-purpose plants) and specialty chemicals (final formulations of chemicals, containing one or more active ingredients, typically sold under brand name by distributors for user application) (Pollak 2011). Further, companies may own facilities involved in different R&D activities such as novel formulations, the discovery of new active ingredients or new seeds engineered to be resistant to proprietary formulations.

The supply chain for pesticides begins with extraction of core minerals and hydrocarbons, from which chemical inputs are manufactured or by-products from refining processes are fed into the supply chain (Hanieh 2021; Romero 2022). Active ingredients—the component of herbicides, insecticides and fungicides that limit or kill the target pest or weed—are synthesized from these raw inputs. Active ingredients are then mixed with surfactants, adjuvants and inert ingredients to make the final product spray, stick and generally perform more effectively. Final formulated products are then labelled, marketed and distributed. Similar to pharmaceuticals, all active ingredients and formulations must be registered with the competent authority in the countries where they are sold.

Global trade can occur at any stage in this value chain (Figure 1). Only 39 countries currently manufacture active ingredients. A

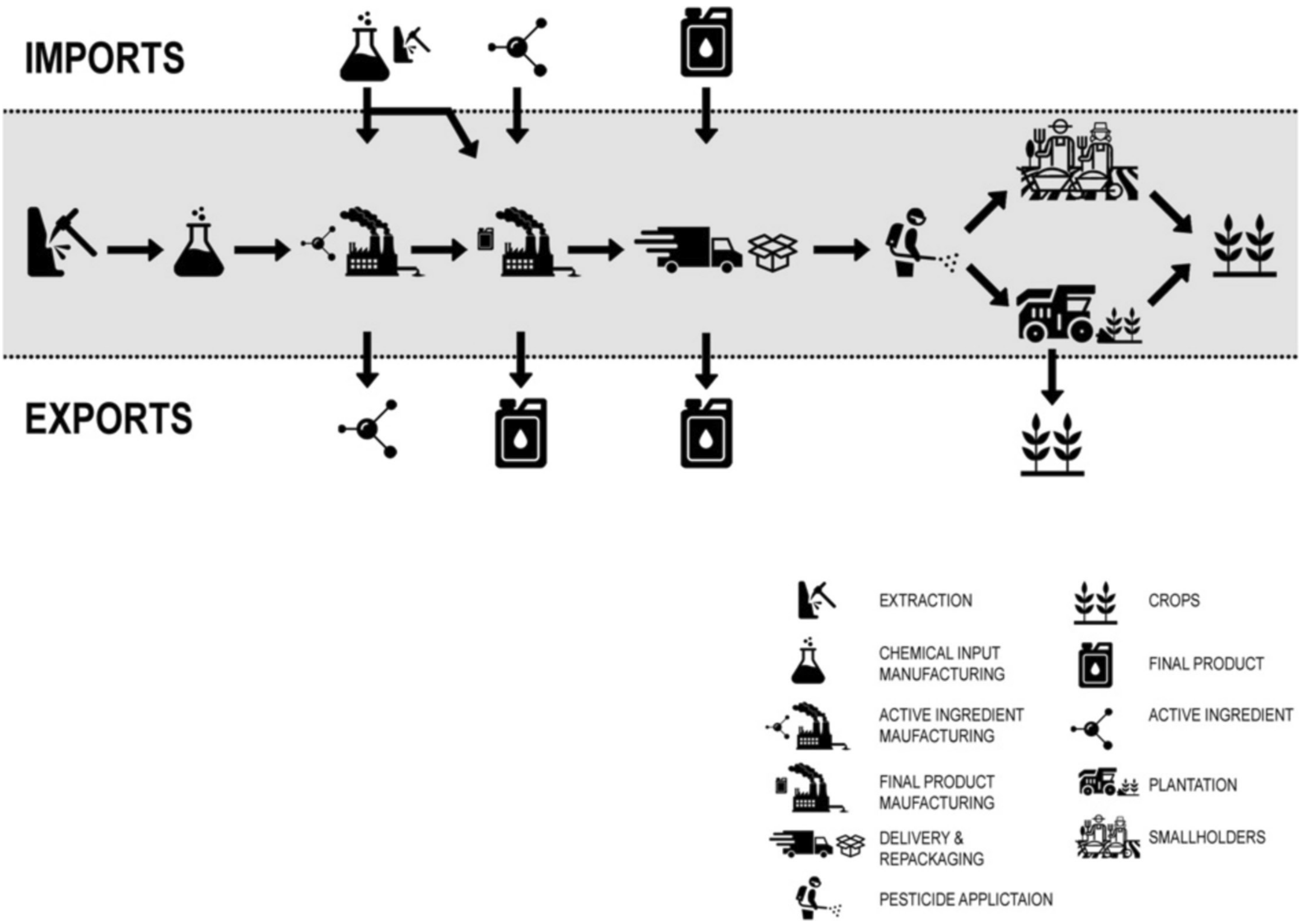

FIGURE 1 | Schematic representation of the pesticide supply chain. *Source:* Illustration by Aishwarya Suresh Vyawahare, University at Buffalo, SUNY Food Lab, 2021 based on authors' research. *Note:* Grey area represents domestic activity.

total of 102 countries have some form of pesticide manufacturing, either producing formulated products locally from imported active ingredients, manufacturing active ingredient or both.[4] Countries without a domestic formulation industry or active ingredient synthesis capabilities depend on the import of formulated products from legacy R&D firms or generics traders, which may be sold under a variety of brands.

2.1 | Active Ingredients—Markets and Global Production

Compared to formulated products, the dynamics of global active ingredient production and trade are even more difficult to map, as there are no publicly available datasets for such purpose. Dynamics in the production and trade of active ingredients can be approximated through data provided by industry actors and industry research services, however. Here, we rely on a proprietary dataset, the S&P Global Directory of Chemical Producers (DCP), listing the location of chemical plants synthesizing individual active ingredients. The dataset is the most complete one available for the industry and does not provide information on production volume and value. As is typical for the fine chemistry segment, individual plants are typically multi-purpose and often synthesize a number of different active ingredients and other substances in one location. Still, this analysis provides a first step in mapping an industry that has received little attention in the social sciences to date (Mansfield et al. 2023).

The DCP lists a total of 527 individual plants that produce active ingredients for pesticides. These plants have licences to produce anywhere between 1 and 41 different substances on site (5.7 on average) and may produce other chemicals. Figure 2 maps the distribution of plant locations by country. The top 10 countries in terms of plant locations includes those related to legacy producers (e.g., the United States, Germany, Japan and the United Kingdom) and other companies outside traditional location centres, in particular China (191 plants) and India (95) (S&P Global 2023b). When considering the distribution of plants according to the location of parent company headquarters (see Figure 2, lower panel), China and India remain dominant, but the role of core countries becomes more important. This holds for Germany, in particular, but also for Japan and the United States.[5]

Figure 3 illustrates the distribution of active ingredient production facilities for the top 5 agrochemical companies as measured by sales in 2023. Of these, two are headquartered in Germany and one each in the United States, China and India. The spatial distribution observed clearly attests to the globalized nature of intrafirm geographies in active ingredient production. Through nested networks of subsidiaries, these companies tend to have synthesis plants in Europe (all except Corteva), the United States

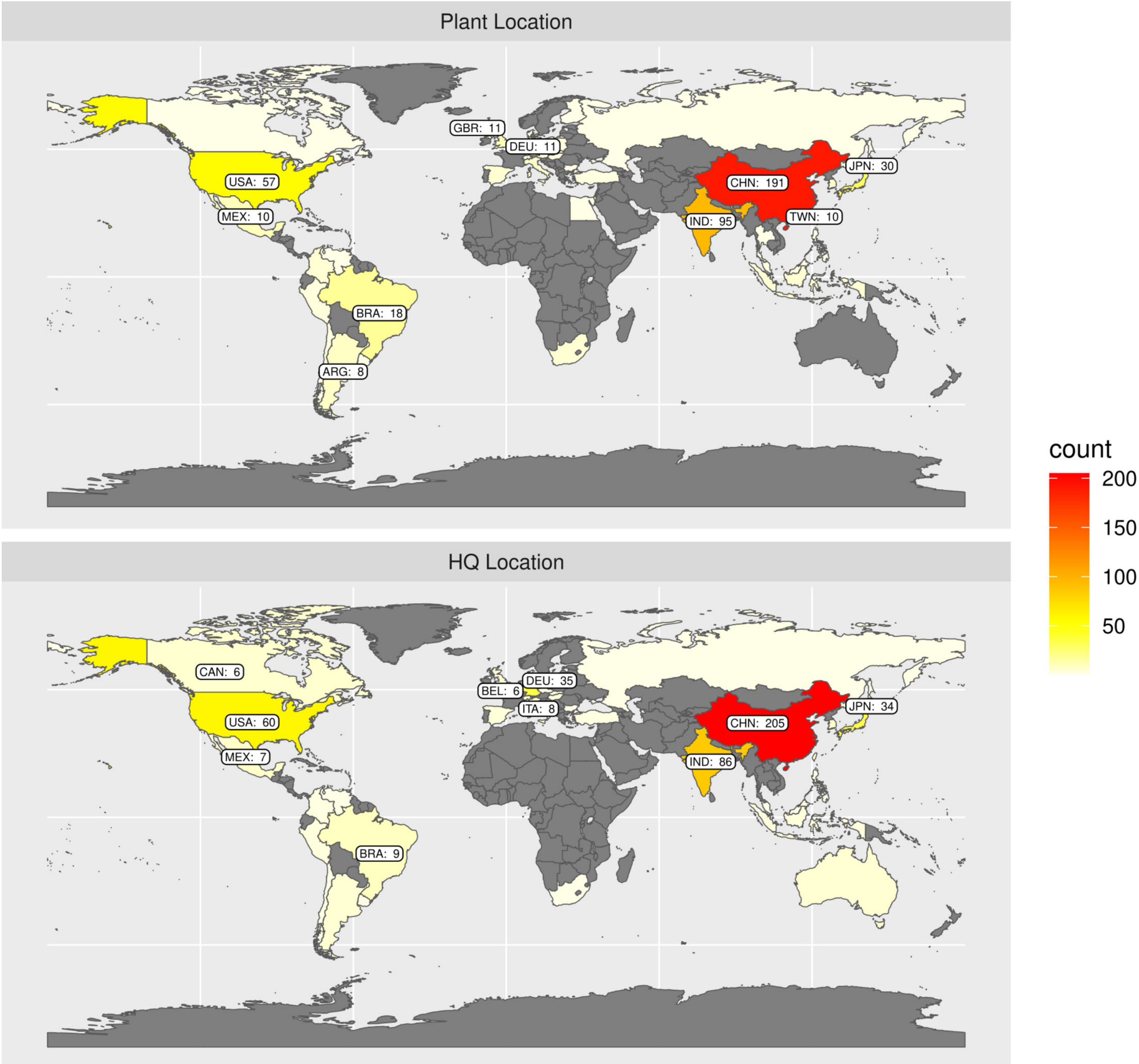

FIGURE 2 | Global active ingredient production. Upper: Distribution of plant locations. Lower: Distribution of plant (ultimate) parent company headquarters. The top 10 countries are labelled (ISO 3166 country codes). *Source:* S&P Global (2023b); elaboration by Finn Mempel.

(all except UPL), Brazil/Argentina (all), India (all) and China (all except BASF and UPL).

Countries specialize in the production of certain pesticide classes (Figure 4). The United States is more relevant as a site for herbicide production, while India hosts many plants producing insecticides. Indonesia is among the top 10 herbicide producing locations, while Colombia and South Korea are top 10 locations for fungicides.

2.2 | Formulated Products—Markets and Trade Patterns

While trade in formulated products remains a crucial source of pesticides for the majority of countries in the world, the geography of production has shifted dramatically over the past 20 years. In this section, we use UNCOMTRADE data (Code 3808) to analyse changes from two perspectives. The first looks at 13 deductively defined regions and asks how the origins of pesticide imports have changed over time. We examine changes in regional market share from the mid-1990s to the mid-2010s. This refers to intraregional and global contributions to the pesticide trade in formulated product across the 13 regions, comparing averages for the two time periods 1995–1999 and 2014–2018. The data are limited to countries/region pairs where the country accounts for at least 5% of the region's imports in either period. Overall, we identify a relative decline in pesticide exports originating in North America and Western Europe and a corresponding increase in exports from China. For a more detailed picture, we focus on the United States and Germany, key headquarter countries for R&D legacy companies, and on China and India, key emerging production centres. Both the United

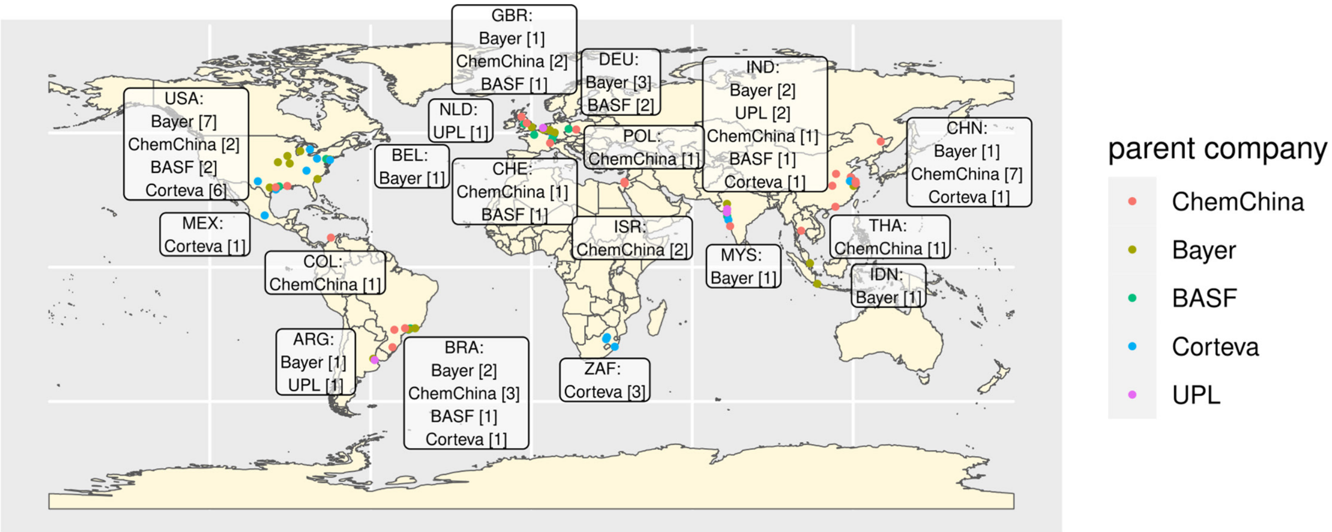

FIGURE 3 | Active ingredient production plants of global top 5 pesticide companies. *Source:* S&P Global (2023b); elaboration by Finn Mempel.

States and Germany witnessed an overall decline in their export shares. If there is evidence for increasing trade, this is mainly with neighbouring countries. The United States reports significant increases for neighbouring Canada and also for Central America (primarily Mexico), and Germany has growing export shares with Western Europe, Eastern Europe and also North Africa. Both the United States and Germany saw significant declines for some key global South markets. US regional export shares fell from 22.8% to 7.6% for South America, from 15.6% to 1.7% for South-East Asia and from 5.1% to 1.1% for sub-Saharan Africa. Germany witnessed significant declines in Central Asia (32.1%–7.3%), Central America (18.4%–6.8%), South America (7.5%–1.9%) and sub-Saharan Africa (6.7%–2.3%). The picture for China is a mirror image of these trends. Overall, China's export shares grew enormously between the two time periods, with remarkable increases in sub-Saharan Africa (from 2.7% to 51.1%), Southern Asia (mainly India; 8.2%–45.6%) and South America (1.0%–42.7%). China also expanded its market share in higher income countries: Export growth to Oceania (1.0%–43.8%) is mainly attributed to Australia, the principal market. Overshadowed by China, India's had noteworthy increases in Northern Africa (1.2%–9.5%), sub-Saharan Africa (2.3%–10.1%) and South America (0.1%–6.1%).

In addition to China and India, there are a number of global South countries that play a role as second-tier exporters above all in their respective regions. Argentina offers an example of a country that has slightly increased its position in the midst of the wider shift towards China. Argentina's share of South American imports increased from 11.8% to 13.3% over the period. Other countries with increases are Kazakhstan (exports to Central Asia), Thailand (East and South-East Asia) and Indonesia (East Asia). At the same time, South Africa, an important intraregional source for pesticides in the 1990s, saw its market share diminished in sub-Saharan Africa (19.1%–16.4%) and Brazil's share of exports to South America decreased from 8.2% to 3.0%. Other countries have managed to keep their positions overall. For instance, Malaysia's industry lost its role as an important intraregional player in South-East Asia but increased its exports to Oceania (see also Sears 2023).

In a second step, we focus on China and provide a long-term overview of how the profile of Chinese exports in formulated product has shifted from 2003 to 2023, confirming the geographical expansion to the global South. Figure 5 illustrates that China was largely a regional player in 2003, exporting about 15% of the global trade volume, with over half of that volume remaining within Asia. As of 2023, China has risen to global dominance, exporting 46% of the global trade volume, with Latin America (30%) and Africa (24%) becoming increasingly important trade partner regions. In the same period, however, the gap between China's share of traded net weight and value has increased significantly. In value terms, China exports only 21% of the global pesticide trade, highlighting the profile of off-patent herbicides.

Our analysis clearly illustrates that the role of traditional producer countries in the global North has diminished since the mid-1990s. There is evidence that North–South trade is being replaced by South–South trade, but this does not happen uniformly, not least because of the outsized role of China. There are also obvious limits to a such a territorial analysis of formulated pesticide trade flows; the ongoing global reorganization of pesticide supply chains increasingly depends upon the formulation of products from imported active ingredient, largely originating from China.

3 | Making the Generics Revolution: New Actors, New Supply Chain Strategies

3.1 | Generics Versus Proprietary Firms: Definitions and New Corporate Actors

To unpack the generics revolution that has reshaped these active ingredient and formulation production and export geographies, we first discuss how these sectors are defined and look at the significance of generic products to regional markets. Firms specialized in generics are normally defined as those that manufacture off-patent active ingredients and/or formulations and/or attribute most of their sales to these products. The designation

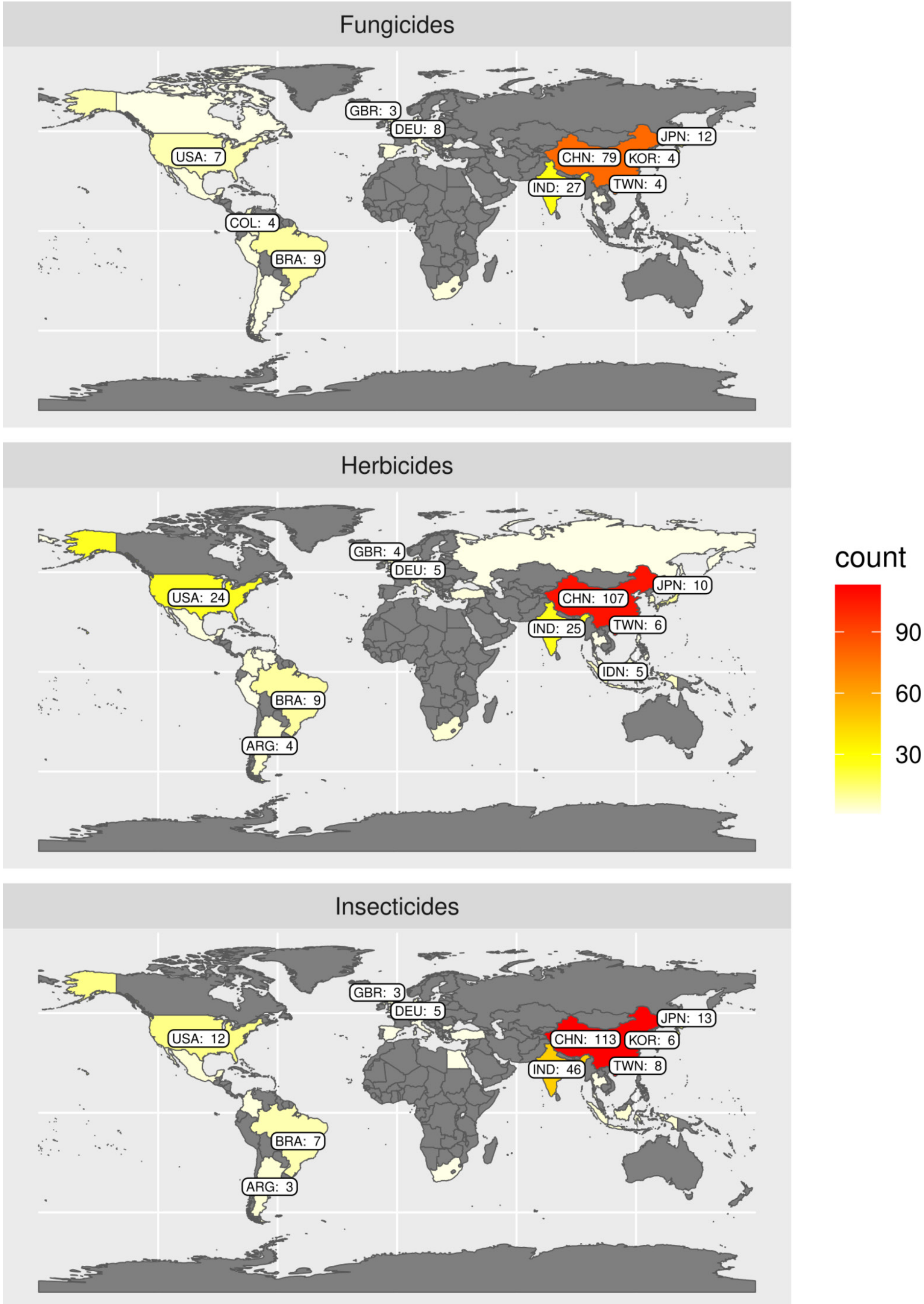

FIGURE 4 | Global active ingredient production. Distribution of plant location by pesticide class. *Source:* S&P Global (2023b); elaboration by Finn Mempel; the top 10 countries are labelled.

of a substance as 'generic' or 'off-patent' generally refers to composition-of-matter patents for the active ingredient. When composition-of-matter patents expire, generics firms often find it difficult to register and produce the active ingredient or formulation because R&D firms find ways to extend IPR-based monopolies through additional patents (Schwartz 2022). Other patents may protect variants of the active ingredient (e.g., chiral forms) or synthesis and formulation processes. Finally, a host of other instruments in the IPR arsenal, such as brands, trademarks and, crucially for pesticides, registration data protections, also muddy the waters (Jansen 2017). Competitors can only navigate what the industry refers to as 'the IP space' of multiple, sometimes interlocking protections with significant resources and expertise. In this way, R&D firms prolong their monopolies on key products and markets for several years after the original patent has expired. For instance, even though its original patent from 1971 had expired, Monsanto managed to extend its grip on glyphosate until the early 2000s, as the patent for a popular commercial form, a cationic water-soluble salt, did not expire until then (Franz et al. 1997).

When a company that first held the composition-of-matter patent on a compound extends its near-monopoly position, this compound is designated as 'proprietary off-patent' (Uttley 2009). S&P Global defines this category as a market segment where the patent-holding firm (or its successor in the case of M&As)

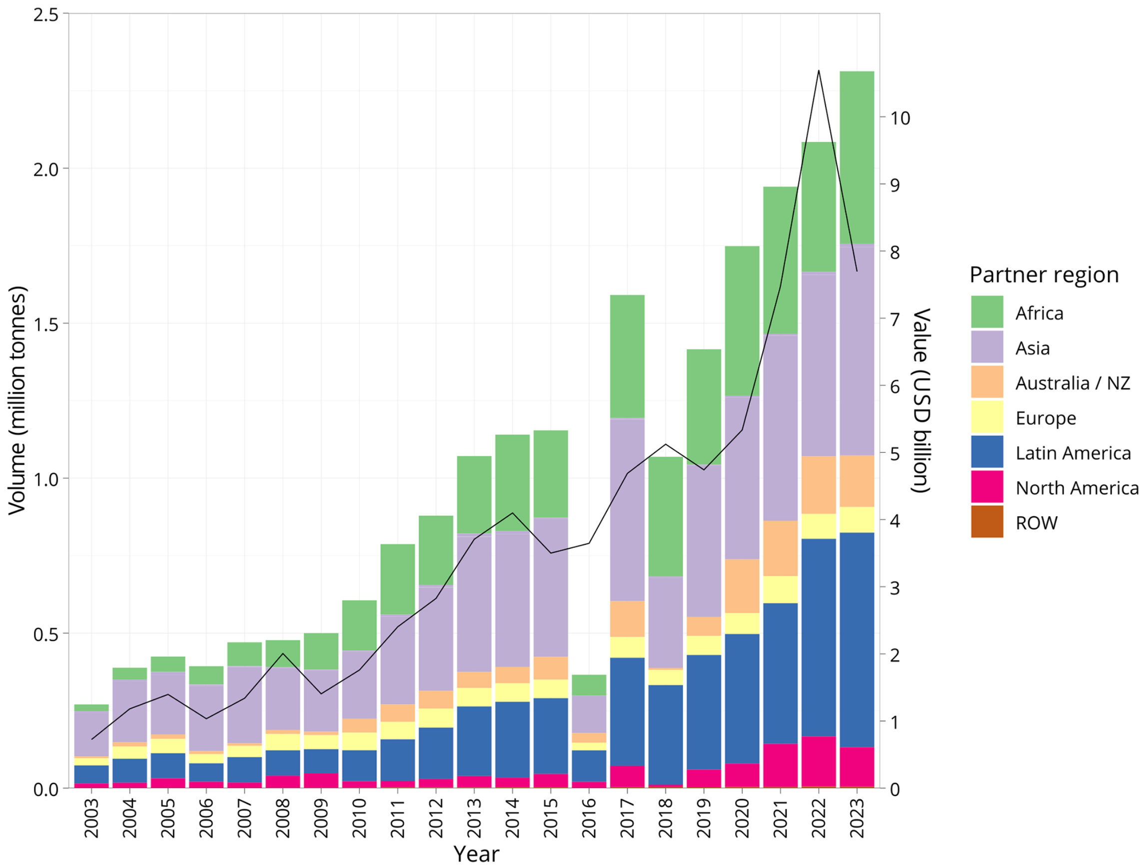

FIGURE 5 | Chinese pesticide exports (formulated products) by target region, 2003–2023. *Source:* UN COMTRADE; HS Code 3808 for China, mainland; elaboration by Finn Mempel; disinfectants were excluded from results; barplot refers to volume, lineplot refers to value.

accounts for greater than 90% of sales. Under this arbitrary definition, generics products are those where 'the company that first introduced the molecule has a market share of less than 90% of global sales' (S&P Global 2023a, 1).

The expiry of the last major patent on glyphosate in 2000 has been a crucial driver of the generics revolution. However, patents had already started to expire in the 1980s, and there has been a growing share of off-patent substances in the wake of declining innovation into new active ingredients. In 2000, only 30.5% of the global market was still accounted for by patented substances in value terms (36% were in the proprietary off-patent and 33.5% in the generics categories; S&P Global 2023a). Despite the limitations of the industry definition to capture the blurring of boundaries between generics and IP firm activities, an acceleration of the generics revolution is clearly discernible in the industry since the early 2000s. The market share of patented substances declined further to 23.5% by 2010 and to 8.3% by 2021, due to the increasing number of off-patent substances relative to patented chemistries. Within the off-patent sector, this shift has been accompanied by a gradual decline in control of products by legacy firms. Using the S&P Global definition, proprietary off-patent products still accounted for 36% of the global market in 2000. By 2021, this number had fallen to 15.3% (using S&P Global's 90% threshold).

Generic products can be an order of magnitude less expensive than proprietary ones: Thus, measured in value (as opposed to volume where we would expect the proportion of generics to be higher), generic products are clearly dominant. In the past 20 years, scholars have attributed the turn to biotech innovations through genetic engineering of seeds as largely driven by the dearth of new discoveries, in addition to high costs to pass regulatory hurdles in the EU for commercial pesticide development (Clapp 2021; Shattuck 2021). While the top active ingredient in a market varies by region, older, off-patent substances clearly predominate in most markets for the three main pesticide classes (Figure 6).

Within the industry, the generics revolution has led to a dual transformation. On the one hand, as we have demonstrated, there has been a geographical shift in production towards the global South. One industry report noted around 3000 companies worldwide that produced generic pesticides in the year 2000 centred on two countries, China and India. Reflecting the difficult data situation, estimates for China ranged between 500 and 1500 factories, predominantly small-scale operations producing for the growing domestic market. Although nearly half of the 100 pesticide active ingredient producers analysed were based in China and India, none of these firms was amongst the top 20 in terms of market sales in 1999 (Hicks 2001).

On the other hand, there was a parallel process of concentration as a new class of large, multinational firms formed through the supply of generic pesticides. Initially, these were mainly companies from higher income countries, for instance, Albaugh (the United States), AMVAC (the United States), Israel's Makhteshim Agan Industries (MAI) or Nufarm (Australia).

FIGURE 6 | Active ingredients, top 10 by target market and class, all crops aggregated. *Source:* S&P Global (2023b); elaboration by Finn Mempel; MEA = Middle East and Africa; active ingredients coloured blue still under patent (as of 2024).

But generic multinational companies would soon reflect the production geographies we have sketched out above, as major corporate players in this sector emerged, based in China and India. By 2021, seven billion dollar plus companies focused on generic agrochemicals had consolidated. Only one firm in this list was headquartered in a legacy producer country: US-based Albaugh, with the Chinese generics firm Nutrichem as a minority (20%) shareholder. Led by the Indian company UPL, the list also included four Chinese companies, Adama and Yangong (both part of Syngenta Group), as well as Rainbow and Wynca (Table 1).

India's rise to importance globally is noteworthy, given that the country became the world's second-largest agrochemical exporter by value after China in 2022, surpassing the United States (Mehta 2024). This rise was clearly driven by United Phosphorous Limited (UPL). Founded in 1969 with an initial focus on the production of red phosphorus for fertilizer, UPL established an agrochemical division in 1975 to supply intermediates to organophosphorus insecticide producers. The company began producing organophosphate and pyrethroid insecticides in the late 1980s and early 1990s and pursued a strategy of internationalization by the 1990s, primarily through acquisitions in key markets. Already

TABLE 1 | Leading generic companies, 2021.

	Company	Ownership	Sales (m $)
1	UPL	India	5239
2	Adama	China	4349
3	Nufarm	Australia	2123
4	Yangnong Chemical	China	1816
5	Albaugh	United States	1663
6	Rainbow Chemical	China	1519
7	Wynca Chemical	China	1185

Source: Banerjee (2023).

the 11th largest pesticide company by market sales in 2015, UPL moved up to fifth place in 2021 (Hicks 2001; S&P Global 2021a).

As impressive as UPL's trajectory has been, Indian generic multinational corporate development has been dwarfed by the booming Chinese industry. In 2023, the top 20 firms in this sector included 11 Chinese and two Indian companies, clearly demonstrating the outsized role of China (L. Huang 2024). This is also visible in our data. China's annual pesticide production volume exceeds India's by a factor of 10 (average of 2017–2020; National Bureau of Statistics of China via Statista and Agropages 2021). Average export volumes have been 3.5 times higher for formulated products in the period from 2019 to 2023 (UN COMTRADE 2024). We therefore focus on China in the remainder of this section. We discuss the state policies that spurred the sector's development and unpack supply chain strategies, taking herbicides as our focus.

3.2 | The State-Led Emergence of the Chinese Pesticide Industry

The development of China's remarkable pesticide sector reveals an important mix of facilitative and restrictive state roles. These oscillate between measures to supply domestic farmers and large-scale producers in the context of massive agrarian change, efforts to regulate environmental harms of production and end use, pressures to address related food safety concerns and interventions to upgrade production to end-user formulations and brands and to increase exports of these formulations (J. Huang et al. 2017; Werner et al. 2022; Zhang and Qi 2019). We focus on the three most prevalent areas of intervention: export promotion, environmental regulation and industry consolidation and upgrading.

Starting with exports, there was a decisive change as the neoliberal free trade agenda became hegemonic globally during the 1990s. While pesticide production capacity had been mainly oriented towards the domestic market, the government incentivized active ingredient exports following China's accession to the WTO in 2001 (ChinaAG 2018; Xu and Chen 2024). This marked a first phase in the growth of the generics sector. The principal policy instrument was a generous export tax rebate programme. Introduced in 2005 for pesticides, the programme was applied to 40 pesticide active ingredients and subsequently expanded (Lu et al. 2023). By the end of the 2000s, China had become the leading exporter of pesticide active ingredients globally, making inroads in key markets, such as the United States, Brazil and Argentina (de Oliveira et al. 2020; Werner et al. 2022).

Despite curtailing some export tax rebates around 2008 to mitigate pollution and lower energy demand (see below), the policy tool remained robust. In 2015, rebates for several pesticide active ingredients were increased further, including a number of older herbicides, such as 2,4-D (first launched in 1945) and dicamba (1965). As we discuss below, demand for these and other herbicides was increasing on the heels of glyphosate's (i.e., Roundup) waning effectiveness due to weed resistance and growing controversy over the compound's health effects (Poupard 2015a; see also Werner et al. 2022).

Export promotion received further support as the government began to curb domestic pesticide use (see below). A principal tool for this purpose was an 'export-only' registration, which the government reinstated in 2020. These registrations also allow the export of pesticide active ingredient that have been banned domestically, effectively permitting continued production of these substances. Given that official regulations have lower information requirements for the chemical properties of 'non-novel' vis-à-vis 'novel' active ingredient registrations, the export-only registration of banned substances appears to be relatively easy. In 2021 and 2022, more than 400 export-only registrations were granted, which corresponded to about 10% of total registrations. They have increased strongly in recent years, accounting for 27% and 40% of the annual growth in exports by volume and value respectively in 2020 (Agropages 2020a; Cao 2021; Wong 2023).

Second, bans and restrictions on domestic use were part of a broader policy toolkit to address environmental and health concerns. Triggered by international attempts to ban highly polluting substances (e.g., the Stockholm Convention on Persistent Organic Pollutants), the government cancelled export tax rebates for 21 pesticides in 2008 and another 50 pesticides in 2010 (Lu et al. 2023). The latter included glyphosate; 70% of its production was for export at that time (Poupard 2008, 2010). Concurrently, government policy sought to regulate pesticide firms that had concentrated in the coastal centres of export manufacturing (i.e., Jiangsu and Zhejiang provinces). While some firms relocated to western regions with less restrictive environmental regulations, others leveraged their international linkages to transform and upgrade their production (de Oliveira et al. 2020; Zhao and Rogers 2024). In 2015, the government launched an 'Action Program for Zero Growth of Pesticide Utilization by 2020', curbing domestic demand for pesticides (ChinaAG 2018, 9). Other measures were implemented to meet energy caps, which led to decreases in raw material extraction for pesticide production. These regulatory measures had a stifling effect on production volumes as per their objective. Pesticide output declined significantly from its peak of 3.7m metric tons (MT) in 2014 to 2.1m MT in 2019 and slowly increased again to 2.7m MT in 2023 but well below the 2014 peak (Figure 7; see also Xu and Chen 2024).

Environmental regulations and increasing barriers to entry dovetailed with the government's efforts to consolidate a

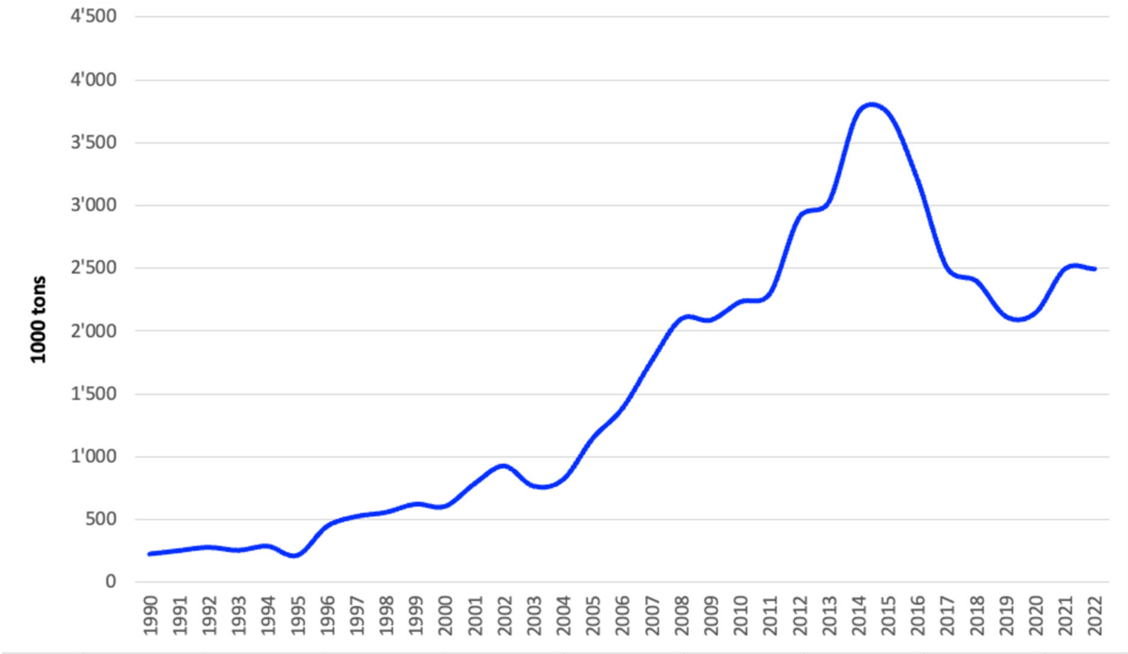

FIGURE 7 | Production of chemical pesticides in China from 1990 to 2022 (in 1000 metric tons). *Source:* National Bureau of Statistics of China via Statista.

fragmented industry and to upgrade to higher value segments. The government issued several ambitious policies towards these goals, including targets to reduce the number of pesticide companies and to consolidate the industry into a two-tiered structure (ChinaAG 2018). In 2017, and again in 2020, export rebates were redeployed as an upgrading policy. To incentivize companies to export formulations instead of bulk active ingredients, more generous rebates were applied to the former. This policy change did away with a long-standing gap in rebates in favour of active ingredients (Agropages 2020b; Poupard 2015b; Pucci 2017).

By the beginning of the 2020s, consolidation aims were all but achieved. Government sources reported a decline in the total number of pesticide manufacturers (active ingredient synthesizers and formulators) from more than 2600 in the mid-2010s to—still considerable—1700 companies (Cao 2021; Han 2016). More importantly, a new hierarchy emerged led by the state-owned enterprise (SOE) China National Chemical Corporation or ChemChina. Originally operating as a chemical processing and petrochemical refining enterprise, ChemChina rapidly expanded its pesticide portfolio through a series of international mergers and acquisitions (M&A) beginning in 2011. A key development in this context was the acquisition of a 60% stake in MAI via its agrochemical subsidiary CNAC. This was the first step towards the creation of Chinese multinational companies in the sector. MAI was subsequently renamed Adama after merging with ChemChina's Hubei Sanonda and developed into the leading pesticide producer in China. In 2015, ChemChina made an offer to acquire the Swiss legacy company Syngenta, which was completed in 2017. The government subsequently formed Syngenta Group by combining ChemChina's agricultural businesses with those of Sinochem. With Syngenta Group, China finally had its leading multinational player, ranking number one globally when combining the sales numbers of Syngenta, Adama and Jiangsu Yangnong Chemical (where Syngenta Group has a controlling share). More M&A activities domestically consolidated a robust set of firms with international pretensions beyond Syngenta. By 2022, 29 of the top 50 agrochemical firms in terms of sales value were located in mainland China, accounting for 42% of total sales of this group of companies. This figure is reduced to 27.6%, if the old legacy Syngenta is excluded from the new Syngenta Group (S&P Global 2022a, 2022b).

Supported by the export-friendly regulations described above and efforts to curb consumption domestically, Chinese pesticide exports rose steadily in value and volume terms over the last decade. When calculating the export numbers in terms of 100% active ingredient, that is, only counting the active ingredient content in formulated products and considering that active ingredients are also not 100% pure, exports reached 74% of the overall production volume in 2020 (Agropages 2022b). Throughout the 2010s, direct active ingredient exports, sold as inputs for formulation elsewhere, played a more prominent role than the export of formulated products; the direct active ingredient export share in volume terms was 58.3% in 2020 a decrease from 66.7% in 2011, indicating a slow rise of the share of formulation exports (Cao 2021, 2024; Zhao and Rogers 2024). Bulk generic substances continue to dominate in both segments, suggesting limits to upgrading for now.

3.3 | Chinese Pesticide Company Strategies

If the state created both facilitative conditions and constraints to promote and shape the pesticide sector, what strategies were adopted by Chinese pesticide manufacturers? Given only spurious innovation either for new active ingredient products or sophisticated formulations, two key strategic trajectories stand out. First, principal Chinese companies used a mix of product specialization in bulk commodity active ingredients, capacity increases and backward integration to gain powerful positions in global supply chains. Second, select firms expanded their downstream market reach internationally through the registration of pesticide products in key target markets. In what follows, we briefly discuss both trajectories with a focus on herbicides for empirical and conceptual reasons. Herbicides are drivers of the generics revolution as the fastest growing segment of the pesticide market. Within that segment, as mentioned, glyphosate has played an outsized role in the consolidation of the Chinese generics industry (Werner et al. 2022) and remains the principal herbicide in all regional markets, with margins that exceed any other compound in any pesticide class (Figure 6, top left panel). Furthermore, firms are developing positions in chemical alternatives to glyphosate, as the latter faces waning effectiveness due to weed resistance. The supply chain strategies driven by declines in susceptibility to herbicides offer a potent example for socio-ecological feedback shaping firm strategies.

The consolidation of glyphosate production in China has depended upon the backward integration of supply chains for intermediates and raw materials. The global production capacity for glyphosate was estimated at around 1.2m tons for 2022, with two-thirds synthesized in China (Agropages 2022a). While Bayer-Monsanto is still the leading single producer globally (380,000 t, see discussion below), the largest producer in China, Xingfa, is not too far behind (230,000 t in 2023 up from 180,000 t in 2018), accounting for over 25% of the country's glyphosate production capacity (Agropages 2022a; Rana 2021a). Xingfa's dominant position was facilitated by the Chinese state. The temporary suspension of glyphosate production of several competitors (including Fuhua and Jiangshan) due to environmental non-compliance in 2019 allowed Xingfa to fill the gap. The company's position was strengthened further with a strategic cooperation deal with Syngenta Group involving the production of pesticides and phosphate fertilizers (Agropages 2022a; Rana 2021a, 2021b, 2020; S&P Global 2021b).

As weed resistance to glyphosate has spread, other generic herbicides have seen increasing market demand globally because no new significant modes of action have been introduced. While glyphosate remains by far the largest exported active ingredient, industry observers reported investments to increase production capacities in other herbicides, exceeding those for glyphosate: 197,000 MT for glufosinate, 159,000 MT for 2,4-D, 110,000 MT for atrazine and 93,000 MT for the paraquat substitute diquat. The corresponding number for glyphosate was 27,000 t, occupying a distant ninth place in a list that contained almost exclusively herbicides (Cao 2021; Wang 2024).[6]

These changes in production capacity are also reflected in a specialized industry landscape. The Chinese firm Lier, for example, focuses on products for GM crops and on alternatives to glyphosate such as glufosinate, for which it recently expanded production capacity. Established by the China Academy of Engineering Physics in 1993, Lier was already an important domestic manufacturer of other herbicide subclasses including pyridines and sulfonylureas. With an estimated production capacity around 15,400 MT annually, Lier claims to be the largest producer of glufosinate worldwide. Upstream supply of important raw materials was secured through mergers, strategic equity investments and long-term cooperation agreements, while Lier developed production inhouse for a number of key intermediates (Agropages 2022b; Malhan 2022; Shan 2018; Shi 2018).

The resurrection of the export-only registration vehicle has played an important role in firm strategies. This includes banned active ingredients. When the acutely toxic bipyridyl herbicide paraquat was prohibited for use in China in 2016, export-only registrations enabled Luba to continue its production through an integrated production chain. Luba is among the top three paraquat producers globally. The company is also the largest manufacturer of the related bipyridyl compound, diquat, in China (Agropages 2022b; Malhan 2023; Shan 2018; Shi 2018).

Overall, recent aggregate data for the period 2021–2023 demonstrate increases in production capacities across different active ingredients in contrast to government policies promoting higher value activities. From January 2021 to September 2023, active ingredient production capacities are reported to have increased by 560,000 MT, well above increases for formulated products (240,000 MT). By far the largest reported increases, however, are for intermediate chemicals, which grew by 1.14m MT (Shan and Huang 2024). This supports our finding that the consolidated industry is comprised of companies that engage in backward integration of their supply chains (Shan 2018).

Looking at the downstream end of production networks and supply chains, while most Chinese producers continue to have a significant domestic market presence, there is compelling evidence that firms are increasingly turning to exports. The following table lists those companies for which domestic/export figures are available. There are a number of companies that generate the majority of their sales from exports, most notably Rainbow, but also Lianhe, Wynca, Nutrichem, Jiangshan and Changqing (Table 2).

While Rainbow is a clear outlier, the firm offers an important example of downstream internationalization that other Chinese firms have since aimed to replicate. Founded in 2001, the same year as WTO accession, Rainbow has always focused on export markets (de Oliveira et al. 2020). The company developed at breathtaking speed. Ranked 11 among the top 100 pesticide companies in China in 2011, it moved to Number 3 in 2023 behind ChemChina-owned Adama and Yangnong. Annual sales increased 12-fold during this period to almost 15bn yuan (currently over 2bn USD). Globally, Rainbow was the 12th largest pesticide producer in 2021; in 2015, it was not even in the top 35.

Our findings from research on the downstream end of supply chains in Latin America show that Rainbow adopted an innovative approach based on a regulatory strategy. While other suppliers were exclusively relying on brokers to sell active ingredients to domestic formulators in the region, Rainbow accessed the knowhow to register products—formulations and active ingredients—under its name in foreign markets, including its factories as the listed suppliers on the registrations. This strategy allowed the company to aggressively increase market presence in the region.

Other Chinese companies have internationalized by increasing investment in global product integration. Limin, for

TABLE 2 | Top Chinese agrochemical firms by sales share (domestic/export).

Global rank	Company	Domestic	Export	Total	Domestic share
10	Jiangsu Yangnong[a]	1399	417	1816	77%
12	Rainbow	48	1471	1519	3%
13	Wynca	524	661	1185	44%
16	Beijing Nutrichem	508	621	1130	45%
18	Lier Chemical	497	433	930	53%
19	Sichuan Hebang Biotechnology	720	94	814	88%
22	Nanjing Redsun	615	109	724	85%
26	Lianhe Chemical Technology	200	463	663	30%
27	Limin Chemical	385	272	657	59%
28	Nantong Jiangshan Agrochemical & Chemicals	272	334	606	45%
33	Jiangsu Changqing Agrochemical	256	315	571	45%
34	Hailir Pesticides and Chemicals Group	358	201	559	64%
37	Anhui Guangxin Agrochemical	359	162	521	69%
39	Shenzhen Noposion Agrochemicals	497	7	504	99%

[a]Control by Syngenta Group following merger with Sinochem, which owned prior controlling 40% stake.
Source: S&P Global (2022a, 2022b).

instance, managed to register active ingredient synthesis, single formulation and combined formulation for the fungicide mancozeb in the EU, the United States, Brazil, Argentina and in smaller global south markets (e.g., Tanzania, Kenya, Vietnam, Myanmar). The company also developed brands, holding trademarks in key export markets. These efforts were complemented by the establishment of distribution channels, involving own sales outlets and representative offices. A route in this context taken by many firms was the acquisition of local distributors and/or formulators, providing access to distribution channels and registrations, as illustrated, for instance, by Red Sun and Rainbow in Argentina; Zhongshan in Argentina, Bolivia and Indonesia; and Wynca in Ghana (Agropages 2019, 2022b; Han 2018).

4 | The Place of Legacy Firms in the Generics Revolution

In the preceding discussion of the emergence of a global generics industry, we have highlighted a geographically uneven corporate landscape, dominated by Chinese actors. We now revisit the strategies and positions of legacy R&D firms and highlight further layers of complexity in the global pesticide complex, above all the blurring of lines between generic and R&D capital.

While the generics revolution has shifted the geographies of production, trade and ownership, legacy firms still appear dominant in the traditional domain of patented chemistries and new areas of apparent innovation. In 2022, the top four ‘legacy’ firms—Syngenta Group, Bayer (acquisition of Monsanto), BASF and Corteva (merger of the agrochemical activities of Dow and DuPont)—accounted for 65% of all market sales (excluding Adama from Syngenta's contribution).

Market introduction of new active ingredients has slowed progressively and is reflected in R&D firms' focus on new GM seeds packaged with existing compounds. There is a continuing dominance of this part of the market by companies from the United States, Germany and Japan, but also a noticeable presence of Chinese companies, a materialization of the upgrading process stimulated by the Chinese government (S&P Global new active ingredient data; various years).

Industry and scholarly literatures on R&D firms focus on product and process innovations at the heart of their industry leadership, such as digital agriculture, precision applications and low-dose applications for maintaining profitability with the promise of environmental stewardship. R&D firms have also sought to innovate in biologicals, often through joint ventures with, or acquisitions of, smaller firms. The industry's enthusiasm has not yet transformed the sector, however, which remains strongly dependent upon traditional synthetic pesticides: By 2019, global sales of biologicals accounted for about 4.5% of the market, or about 3bn USD, up just 1% since 2012 (Rana 2022a, 2022b).

What this industry narrative (and some scholarly work) largely ignores is the continuing reliance of many R&D firms on off-patent chemicals and their sourcing practices for them, which overlap with generic supply chains. Not unlike other sectors, a key strategic move to maintain competitivity has been to shift production and supply to the global South, particularly China. Our analysis in Section 2 of the location of active ingredient synthesis plants gave evidence for this offshoring process. Again, a lack of precise data complicates the analysis. There is no information on production volume in the DCP data on active ingredient synthesis sites, and continuing M&A activities complicate systematic comparison further. Having seen more stability since the early 2000s than other legacy multinationals, BASF allows at least an approximation. With all due caution (especially given the possibility to add and remove products in its chemical manufacturing facilities), BASF seems to have concentrated own active ingredient production in Germany, the United States, Brazil and India since the early 2000s. There is evidence of a shift away from traditional production centres, above all in Germany, where BASF has recently terminated the production of glufosinate-ammonium in two legacy production sites. While BASF led the global glufosinate market jointly with the Chinese company Lier in 2020, there is no evidence of own synthesis, suggesting sourcing of all its glufosinate supply from third parties for formulation. There is evidence of increased formulation activities in China, while active ingredient synthesis in the company's Nanjing factory seems to have ended (Birkett 2024; Rana 2013).

What the BASF example demonstrates is an emerging bifurcated structure, with dominance of companies based in the global North that maintain vertically integrated production of a limited number of patented chemistries, and third-party supply in the global South for their branded, off-patent products in parallel with growing involvement of generics producers, particularly in China. A look at key off-patent herbicides supports this claim. While precise company-level data on the weight of specific product sales in overall revenues are unavailable, we analyse proprietary herbicide data that provide product value and product volume numbers for a sizeable part of the global market in 2019 and allow for a breakdown according to companies, active ingredient and countries.[7] For 2019, these detailed herbicide data account for 61% of global herbicide sales reported by IHS Markit (now S&P Global) for the same year, itself not the entire herbicide market given that proprietary datasets are not robust for small markets.

When looking at global market data and plant locations from the perspective of the key herbicides glyphosate, 2,4-D, atrazine and dicamba, the predominance of outsourced supply is evident (Tables 3 and 4). Bayer, for example, leads the glyphosate market, accounting for 39% of global sales in 2019. We identify four active ingredient production sites in Belgium, the United States, Malaysia and Argentina. Of the total of 77 plants globally, 39 are located in China and an additional 9 in India, demonstrating the geographical shift towards these countries with the generics revolution (S&P Global 2023b). When probing further, there is evidence for sourcing from smaller producers and contract manufacturing. In China, there are three plants controlled by Syngenta Group/ChemChina (Adama and Jiangsu Jangnong) and additional plants owned by the leading glyphosate producers Xingfa (1) and Wynca (2). Further, five plants can be traced back to other top 50 Chinese companies, for instance, Lier or CAC Nantong. With 28 plants, the majority of Chinese production sites for glyphosate active ingredient are owned by smaller companies, which very likely have supply chain relations with the larger glyphosate players in China. In short, while Bayer's glyphosate brands represent the majority of sales in major markets by volume and value (noting, again, that this universe is partial, see Footnote 6), in these major markets, a significant proportion of this supply is outsourced to third-party suppliers. The situation for dicamba and atrazine is broadly similar. Just as in the case of glyphosate, albeit at a smaller scale, China hosts more than half of the plants for each dicamba and atrazine globally, with India and other Asian country accounting for the majority of additional production capacity in third-party facilities.

One interesting exception to this trend is 2,4-D. Among the top-tier companies, Corteva is the main individual seller of 2,4-D products (23.5%), producing in its own plants in the United States, Italy, South Africa and Colombia; it is notable that China's role is much less prominent. There are as many plants in South and Central America as there are in China (7). 2,4-D synthesis has a longer history in Argentina, and the strong presence

TABLE 3 | Market data on key herbicides, 2019.

	Top markets	Top companies	Volume (t)	Value (m $)	Volume (t)	Value (m $)
2,4-D	1. Argentina	1. 'Various'	44,970.12	158.60	45,041.83	53.56
	2. Brazil	2. Corteva	42,660.24	111.57	18,630.46	59.16
	3. Thailand	3. Albaugh[a]	28,243.74	19.29	14,600.53	34.64
Atrazine	1. Brazil	1. 'Various'	85,663.62	232.92	76,867.62	206.71
	2. United States	2. Syngenta[b]	73,422.52	422.25	64,398.01	317.95
	3. China	3. 'Local source'	38,664.92	155.06	38,664.92	155.06
Dicamba	1. United States	1. Bayer	10,684.28	130.05	22,375.81	333.91
	2. Poland	2. BASF	8845.08	174.59	2369.34	9.11
	3. Argentina	3. 'Various'	3585.33	19.98	1147.47	12.91
Glyphosate	1. Brazil	1. Bayer	409,506.70	1594.84	347,443.51	1174.48
	2. Argentina	2. 'Various'	233,744.20	692.69	221,159.92	634.97
	3. United States	3. Syngenta[b]	100,421.99	379.45	159,008.75	562.59

Note: 'Top company' listed refers to the company that held the registration for the final product in the country market.
[a]Including Atanor.
[b]Including Adama.
Source: Phillips McDougall (2020); own calculations.

TABLE 4 | Geographical distribution of key generic herbicide active ingredient synthesis plants 2023.

	Glyphosate		2,4-D		Dicamba		Atrazine	
	Plants	%	Plants	%	Plants	%	Plants	%
United States	2	2.6	3	**9.4**	1	**25.0**	3	**12.5**
Western Europe	5	6.5	3	**9.4**	—	—	1	4.2
Japan	—	—	1	3.1	—	—	—	—
China	39	**50.6**	7	**21.9**	2	**50.0**	13	**54.2**
India	9	**11.7**	2	6.3	1	**25.0**	1	4.2
Rest Asia	12	**15.6**	6	**18.8**	—	—	3	**12.5**
South and Central America	8	**10.4**	7	**21.9**	—	—	2	8.3
Eastern Europe	1	1.3	2	6.3	—	—	—	—
South Africa	1	1.3	1	3.1	—	—	1	4.2
	77		32		4		24	

Note: Bold and shaded values refer to the most important geographical production locations for each substance. Percentages may not total 100 due to rounding.
Source: S&P Global (2023b).

in Argentina and Brazil may be linked with the key role played by 2,4-D in soybean production, as a stand-alone product or as a complement for herbicide mixtures (for a discussion of China's role in the soybean expansion, see Giraudo 2020).

For all four herbicides, we find sales by legacy companies sourced in part to third-party producers and substantial participation of generics company sales (listed as 'various' in the data, referring to 'no name' or 'house brands' marketed by generics formulators). Generic company sales play a very prominent role, ranked Number 1 for 2,4-D, Number 2 for glyphosate and atrazine and Number 3 in the case of dicamba. When compared with the location of production sites according to DCP, the declining role of traditional producer countries (Western Europe, the United States and Japan) becomes obvious again with the overall share of plants in legacy countries ranging between 25% for dicamba to 9.1% in the case of glyphosate (Tables 3 and 4).

In the light of the preceding discussion of the evolving landscape of new generics producers, mainly from China, our analysis complicates widespread dualist representations of the industry. The R&D and generics categories are increasingly blurred in at least three ways. First, as we have seen in the analysis above, the generics revolution has led to the emergence of large, multinational companies that are commonly represented as 'generic' ones (see Table 1).

Second, and related, no company embodies this blurring between R&D and generics firms better than Syngenta Group. Owned by Chinese state capital, Syngenta Group combines advanced R&D activities with aggressive synthesis, formulation and marketing of bulk generic substances through acquisition of both a leading legacy firm and the largest generics manufacturer. Third, although Syngenta Group may be exceptional in terms of its trajectory and structure, all legacy companies today are clearly responsible for a considerable share of off-patent substances and are integrated to a considerable degree with the extensive production networks that source nonbranded, generic products. As we have shown, companies both produce these bulk commodities in their own factories located strategically in most major regional markets and outsource production—of active ingredients and formulations—through the considerable production capacity of generics firms with secure backward linkages in China and elsewhere. In this context, Syngenta Group appears to use its hybrid structure to reduce exposure to contested substances. For instance, it has recently started to terminate the sale of Syngenta-branded paraquat products in many global South countries, for instance, in Argentina. However, the company still offers Argentinian farmers paraquat formulations under the name of Adama (*Source:* Argentina company websites; Gross 2024).

5 | Conclusion

The transformation of the global pesticide industry offers a unique window into actually existing restructuring in the global economy. First, the consolidation of active ingredient production suggests new hierarchies in the industry, rather than distributed multipolarity. Even as trade in formulated product appears more multipolar, active ingredient manufacturing consolidated in China and India. While a few important regional exporters have sprung up, for instance, Argentina, Indonesia and Thailand, these countries are also tied into supply chains originating in China and to a lesser degree, India. Such consolidation on the back end of the supply chain suggests regional dominance, rather than genuine multipolarity. Second, significant consolidation within the Chinese pesticide sector has occurred with mergers and contractual relationships to secure supplies for raw materials and to access markets through generic registrations. The Chinese pesticide industry, despite significant domestic market presence, is increasingly turning to exports due to the Chinese government's zero increase in pesticide use policy and support for upgrading. Third, while the generics revolution has transformed production geographies, it has yet to upend the role of legacy firms and their dominant market share. The strategy of the big four multinationals to maintain profits through innovations like stacked-trait GM packages and platform agriculture, however, is inseparable from their significant subcontracting relationships with smaller generics firms, in addition to the production of their own generic active ingredients and formulations. The continuing dominance of R&D-based multinationals with headquarters in the United States and Germany, in particular, complicates one-sided diagnoses of a shift towards the global South, however. At the extreme end, the largest capital consolidated via the generics revolution, the Syngenta Group, pushes the envelope on the overlap between generic and R&D firms beyond market participation and production to direct ownership through strategic acquisitions.

The generics revolution is offering lower cost products and driving rising pesticide use especially in low-income countries (Shattuck et al. 2023). It is also making older compounds, the environmental and health harms of which are largely well known, increasingly accessible. Efforts to shift the needle on conventional agriculture away from intensive pesticide use will have to contend with the industry's new structure and changing landscape of corporate actors and interests. The new production geographies that we outline for the first time here suggest a more complex terrain for both regulation and governance. Increasing weed resistance to glyphosate in particular is spurring a return to older generation herbicides, deepening dependence on cheap generics more likely to be manufactured in China and India, no matter the label under which they are sold. The relative decline in the cost for pesticides facilitated by the growth of generic production capacity over the last two decades, materialized in the new production geography we have outlined here, raises serious questions for environment and health regulation. Efforts to shift towards less intensive pesticide use, to regulate acutely toxic or residual active ingredients, to respond to new paradigms of toxicity presented by 'newer' generation chemicals from the 1970s and to transform pesticide dependence in general will have to contend with the industry's new structure and changing landscape of corporate actors and interests.

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Data Availability Statement

The data that support the findings of this study are available from S&P Global. Restrictions apply to the availability of these data, which were used under licence for this study. Data are available from the authors with the permission of S&P Global.

Endnotes

[1] The term agrochemical (or agrichemical) is not clearly defined. It usually refers to pesticides but may also include synthetic fertilizers. In this paper, we use the terms agrochemical and pesticide interchangeably. In either case, we refer exclusively to substances for agricultural use.

[2] The industry for agricultural and agrochemical market data has also been subject to a wave of acquisitions. Since the beginning of our project in 2020, Phillips McDougall was acquired by IHS Markit, which was then purchased by S&P Global.

[3] We use the corrected COMTRADE database available in the Global Pesticide Use and Trade Database available on the Open Science Framework: https://osf.io/dyu38/?view_only=7e39ab440f104ed2b61591a086f89a0b. See Shattuck et al. (2023) for methods on gap-filling COMTRADE data and its limitations.

[4] Authors' calculations, based on GloPUT trade data showing which countries are net exporters of pesticide or report consuming more pesticide than their trade balance in formulated product, and S&P Global Directory of Chemical Producers.

[5] ChemChina's acquisition of Syngenta and the subsequent formation of Syngenta Group means that all factories producing for the firm are headquartered in China.

[6] The numbers reported in Wang (2024) refer to approved and planned investments exceeding 10,000 MT compiled from publicly available government and company information in 2023. They thus provide estimates and do not reflect actual production capacities.

[7] These data were collected from companies at the ex-factory level and concern sales of formulated product. For values in money terms, the value of formulated products (product value) is regarded as being equal to the value of the active ingredient formulated (active value). The assumption is that other coformulant substances are negligible in money terms. Product value can therefore be treated as a proxy for active value. However, this is not possible when looking at volume data. Only major product and country market segments are included.

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