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Research on the Identification, Assessment, and Prevention of Four-Dimensional Supply Chain Risks in E-Bike Cross-Border E-Commerce

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Abstract. Against the backdrop of continued cross-border e-commerce expansion and growth in overseas cycling markets, electric bicycles (E-bikes) are defined by their bulky form factors, integrated electromechanical systems, and lithium battery components. Their cross-border supply chains are constrained by logistics and warehousing limitations, and further exposed to technical regulations, environmental compliance requirements, and shifting geopolitical policies. Existing studies have identified cross-border e-commerce supply chain risks from the perspectives of logistics, information flow, and capital flow, yet have paid insufficient attention to the interconnections between the physical attributes of bulky electromechanical products, overseas after-sales services, and full life-cycle product traceability. Building on a review of relevant literature, this study adopts the SCOR process framework for risk identification and develops four risk dimensions: bulky-goods logistics fulfillment, overseas warehousing and reverse logistics services, technical regulations and environmental compliance, and geopolitical policies and financial transmission. It further proposes two categories of risk prevention and control approaches: collaborative governance between enterprises and industry associations, and market operation and brand building. This study provides a reference for Chinese E-bike enterprises engaged in cross-border business to improve their risk identification and prevention mechanisms, and offers a research basis for industry associations to deliver overseas warehousing services, compliance support, and risk early warnings.

Keywords: E-bike, cross-border e-commerce, supply chain risk, overseas warehouse, risk prevention and control

1. Introduction

Cross-border e-commerce has become an integral component of foreign trade development. Industry reports and customs export statistics indicate that bicycle products and their cross-border sales form an important part of China's manufacturing sector's participation in global markets. Meanwhile, logistics, customs clearance, payment, and platform governance in cross-border transactions have grown increasingly complex [1, 2]. When entering overseas markets via cross-border e-commerce, E-bikes face not only the supply-demand fluctuations and fulfillment risks common to general

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merchandise, but also distinctive challenges related to bulky-goods transportation, component coordination, overseas after-sales service, and product traceability.

Existing studies have established a general analytical framework for supply chain risks in cross-border e-commerce, in which logistics, information flow, and capital flow interact with one another. Factors such as policy changes, customs clearance efficiency, system stability, information distortion, and transaction credit can all affect supply chain performance [3]. Recent empirical research shows that cross-border e-commerce policies can reduce firms' supply chain risks by alleviating information asymmetry, optimizing supply chain allocation, and improving supply-demand matching. Nevertheless, these findings are largely derived from general firm samples and do not fully explain how the physical characteristics of specific product categories and their after-sales service chains shape the formation of supply chain risks [4].

Focusing on E-bikes as bulky electromechanical products, this study follows the logical thread of "industry background, research gap, research approach". It first explains the role of the SCOR model in risk identification, then identifies risks across four interrelated dimensions: logistics, warehousing, compliance, and geopolitical policies. Finally, it puts forward risk prevention and control recommendations for enterprises, industry associations, and market operations. Compared with general studies on cross-border e-commerce risks, this study emphasizes the impacts of product size, assembly requirements, and after-sales service demands on overseas warehousing and reverse logistics, and examines technical regulations, environmental rules, and geopolitical policies within a unified risk chain.

2. Theoretical basis and industry characteristics

2.1. SCOR model and risk assessment logic

The SCOR model summarizes supply chain activities into the Plan, Source, Make, Deliver, and Return processes. It can be used to identify the process stages where risks may occur. It does not directly provide the probability of risk occurrence in a specific industry [5]. In existing studies, indicator weights reflect the relative importance of different risk factors within the same evaluation system. Composite coefficients depend on the study sample, indicator selection, and calculation method. Values reported in different studies cannot be directly compared. They should not be regarded as the actual probabilities of risk occurrence in the E-bike industry. Based on this principle, this study uses the SCOR model to identify risk sources. The assessment focuses on risk triggers, transmission paths, and responsibilities for risk prevention and control.

2.2. E-bike cross-border supply chain processes and risk nodes

The E-bike cross-border supply chain starts with the procurement of upstream components. It then includes product assembly, domestic consolidation, cross-border first-leg transport, overseas warehousing, last-mile delivery, payment collection, and after-sales service. Compared with small and lightweight goods, E-bikes have larger dimensions and greater weight. They also have specific assembly requirements and battery components. These characteristics create closer links among logistics, warehousing, service, and compliance activities. Table 1 summarizes the main supply chain nodes and their risk-specific characteristics.

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Table 1. Main nodes and risk-specific characteristics of the E-bike cross-border supply chain

Process node	General cross-border risks	E-bike-specific characteristics	Corresponding dimension
Upstream procurement and production	Supplier stability, quality, and demand forecasting	Frames, motors, batteries, and after-sales spare parts require coordinated supply. Assembly quality can affect subsequent returns, replacements, and repairs.	Compliance and geopolitical risks
Domestic consolidation and cross-border first-leg transport	Freight rate fluctuations, cargo damage, delivery time, and information gaps	Packaging for bulky goods, volumetric weight, and battery components increase the requirements for transport planning and document management.	Logistics fulfillment
Overseas warehousing and last-mile delivery	Inventory deviations, warehousing costs, delivery, and returns	Overseas warehouses need to support assembly and adjustment, spare-parts management, repair response, and battery safety management.	Warehousing and reverse logistics
Sales, payment collection, and after-sales service	Demand fluctuations, exchange rates, payments, and customer complaints	E-bikes have a relatively high average order value and a long after-sales service process. Demand deviations can increase inventory and tied-up capital.	Geopolitical and financial risks

As shown in Table 1, E-bike risks are not limited to a single supply chain node. Logistics delays can increase warehousing pressure and tied-up capital. Inventory deviations can cause imbalances in the allocation of after-sales spare parts and repair resources. Incomplete compliance documentation may also affect customs clearance, platform sales, and product recalls at the same time. Existing platform cases show that limited transport information transparency, high reverse logistics costs, and insufficient overseas warehouse coverage can reduce cross-border supply chain fulfillment stability [6].

3. Identification of four-dimensional supply chain risks in E-bike cross-border e-commerce

3.1. Bulky-goods logistics fulfillment risk

The bulky nature of E-bikes makes the costs and delivery times of first-leg transport, transshipment, and last-mile delivery more sensitive to billing rules and changes in transport capacity. Platform logistics does not apply exactly the same cost structure to small and lightweight goods and bulky goods. Amazon's U.S. marketplace provides an example. In 2022, fulfillment fees increased by 5.2%, together with fuel and inflation surcharges. In 2023, charges were based on the greater of actual weight or volumetric weight, and a storage utilization surcharge was also introduced [7]. For E-bikes with high volumetric weight, there is less room to balance freight costs, inventory utilization, and selling prices.

Logistics risks can also increase because of information gaps and after-sales service needs. Cross-border transport routes are long and involve many participants. Enterprises may not be able to adjust

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replenishment and customer communication plans in time if shipment status, customs clearance progress, or exception information is not shared promptly. General studies on cross-border e-commerce identify demand fluctuations, supply disruptions, and logistics transport as important sources of internal risk. E-bike enterprises should also include packaging suitability, stocks of damage-prone parts, and the availability of repair spare parts in their fulfillment plans [8].

3.2. Overseas warehousing and reverse logistics service risks

Overseas warehouses can shorten delivery distances. They also concentrate inventory, facilities, personnel, customs clearance, and service capacity at overseas nodes. Existing studies classify overseas warehouse risks into operational risks, policy and regulatory risks, slow-moving inventory risks, and customs clearance risks. These studies also show that warehousing systems, cargo tracking, and the selection of third-party service providers can affect inventory accuracy and fulfillment quality [9]. For E-bikes, overseas warehouses are responsible not only for storage and sorting. They also need to coordinate assembly and adjustment, spare-parts shipment, return inspection, repair referral, and battery disposal.

Reverse logistics services are a key link through which warehousing risks are transmitted to brand risks. The AliExpress case shows that cross-border returns and exchanges are constrained by high freight costs, long processing times, and complex customs clearance. Reverse logistics costs may sometimes exceed the value of the goods [6]. E-bike enterprises may face a dual mismatch between inventory and service capacity during peak seasons if they allocate overseas warehouse capacity only according to sales volume. They may also face this mismatch if they do not establish repair processes, spare-parts storage locations, and graded rules for handling returned products at the same time.

3.3. Technical regulations and environmental compliance risks

Cross-border sales of E-bikes require enterprises to address product quality, intellectual property rights, platform rules, transport-related documentation, and technical requirements in destination countries. Legal and regulatory risks faced by cross-border e-commerce exporters include intellectual property risks, new tax policies, and tighter platform rules. Platform reviews, store management rules, and product delisting mechanisms can quickly turn compliance problems into operating losses [7]. For E-bikes, product design, component sourcing, product instructions, repair records, and battery information should be included in traceable compliance records. These records can prevent information gaps during sales, customs clearance, and after-sales service.

Environmental rules further extend compliance responsibilities to upstream supply chain activities. The EU Batteries and Waste Batteries Regulation extends compliance requirements for power batteries from individual product performance to broader life-cycle management. Enterprises need to retain traceable records for product information, waste battery management, and related compliance requirements [10]. Information distortion, information security problems, and delays in information sharing can affect the stability of logistics systems. These problems may also affect supply chain performance [3]. E-bike enterprises need to manage regulatory tracking, product data, and after-sales records within the same closed-loop management system.

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3.4. Risks from geopolitical policies and financial transmission

Geopolitical conflicts, trade policies, exchange rate changes, and cross-border payments are not independent risks. The EU anti-dumping investigation into E-bikes from China shows that trade remedy measures can directly affect market access and pricing strategies for specific product categories [11]. Changes in destination-country rules may extend customs clearance and delivery times. These changes may increase in-transit inventory and tied-up capital. Changes in market demand can also be transmitted through transaction relationships among suppliers, brand owners, and service providers. Empirical studies show that supply chain risks can be transmitted in both upstream and downstream directions. Information sharing, optimization of supply chain configuration, and the ability to match supply and demand are important mechanisms for reducing these risks [4].

For small and medium-sized E-bike exporters, changes in trade policies involve more than individual taxes and fees. Platform fees, foreign exchange gains and losses, warehousing costs, and after-sales expenses can also reduce gross margins. Cross-border settlement fees, delayed payments by buyers, and account freezes may increase financial pressure. Related studies recommend multi-currency settlement, exchange rate hedging, market diversification, and contingency plans to reduce exposure to risks from a single market or a single settlement arrangement [6, 12].

4. Risk prevention and control recommendations for the E-bike cross-border supply chain

4.1. Collaborative governance between enterprises and industry associations

Enterprises should establish a risk register covering logistics, warehousing, compliance, and geopolitical policies. In logistics, enterprises should select transport solutions based on product structure and set alerts for abnormal events at key nodes. In overseas warehousing, enterprises should determine inventory levels and service capacity based on demand forecasts, spare-parts turnover, and graded return handling. In compliance management, enterprises should centrally archive product documents, supplier certificates, customs clearance documents, and after-sales records. For geopolitical policy risks, enterprises should regularly update target-market rules, foreign exchange exposure, and alternative supply plans.Industry associations can develop industry guidelines for overseas warehousing service quality, repair personnel competence, dangerous-goods management, product documentation management, and return and exchange processing times. They can also provide small and medium-sized enterprises with information on destination-country regulations, evaluations of third-party service providers, and compliance training. These measures can connect the identification, response, and review of the four types of risks [5].

4.2. Market operations and brand building

Market operations should support risk prevention and control rather than operate separately from the supply chain. Enterprises can clearly explain delivery times, installation requirements, repair channels, spare-parts supply, and return and exchange rules on product pages, in after-sales communication, and in customer reviews. This can reduce complaints and returns caused by information asymmetry. Enterprises should also conduct searches and reviews of product designs, trademarks, and product descriptions before entering target markets. They should avoid using unclear promotional claims or unauthorized materials to gain short-term traffic [7].

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Brand building should be based on stable fulfillment and verifiable services. Enterprises can improve customer trust through cooperation with local repair providers, standardized spare-parts services, and searchable after-sales records. They can also adjust product portfolios and market presence according to changes in market demand and policies. Studies on cross-border e-commerce supply chains generally emphasize the importance of demand forecasting, safety stock, logistics quality, and market diversification. These measures can support long-term competitiveness only when they are aligned with the product structure, warehousing services, and compliance capabilities of E-bike enterprises [8, 12].

5. Conclusions and research outlook

This study draws three main conclusions. First, the bulky size, electromechanical systems, and lithium battery components of E-bikes give rise to a four-dimensional risk structure encompassing logistics fulfillment, overseas warehousing, technical compliance, and geopolitical policies, with the four dimensions interacting closely with one another. Second, alongside traditional tariffs, compliance rules, environmental requirements, and geopolitical conflicts are reshaping enterprises' risk priorities; firms can no longer confine risk management to transportation or tariff-related costs alone. Third, while existing studies have provided general tools for identifying and assessing cross-border e-commerce supply chain risks, dynamic risk indicators, overseas after-sales data, and full life-cycle traceability mechanisms remain insufficient for specific product categories such as E-bikes.

This study has several limitations. First, it is based primarily on existing literature and does not incorporate first-hand operational data from E-bike enterprises. Second, it does not quantitatively compare regulatory frameworks, logistics costs, and after-sales costs across different destination countries. Third, the weights of the four risk dimensions and the strength of risk transmission have not been validated using industry-wide samples. Future research can combine enterprise interviews, platform transaction data, and overseas warehouse operational data to develop dynamic early-warning indicators for the E-bike industry, and test the effectiveness of risk prevention and control measures across different markets, firm sizes, and supply chain configurations.

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