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ISSN 2959-6130

# Navigating Geopolitical Risk: A Multi-Objective Optimization Framework for Dual-Source Procurement of Advanced Lithography Equipment at SMIC

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**Abstract:**

Because the U.S. and its allies are tightening export controls on semiconductor equipment, Chinese chip foundries now face huge challenges in getting lithography tools. This study uses SMIC as a case example to analyze the situation. This paper aims to question a common purchasing strategy used by many foundries, which focuses too much on short-term cost savings but ignores the importance of having a backup plan to protect against supply shocks. In 2024, SMIC's net profit dropped by half, mostly because the costs of equipment depreciation went up sharply. This financial drop clearly shows the high risk of depending on just one supply channel. To solve this problem, a multi-objective stochastic programming model is built in this study. This model can help SMIC find a better balance between older, imported equipment and new domestic alternatives. Hopefully, this balance can help the company push its monthly output past one million 8-inch equivalent wafers in 2025. The model tries to reach four goals at the same time: making more profit, protecting supply chain security, ensuring new machines work well with current production lines, and helping domestic equipment improve. By finding the Pareto-optimal frontier, the study calculates the best ratio between the two types of equipment. Through this method, a new purchasing system is created to balance financial profits with supply safety, while still keeping costs low and production smooth.

**Keywords:** Lithography Equipment; SMIC; Dual-Sourcing Strategy; Supply chain security; Domestic alternatives

ISSN 2959-6130

# 1. Introduction

## 1.1 Research Context and Problem Statement

The strategic denial of advanced semiconductor manufacturing equipment has emerged as a central instrument in the technological rivalry between major economies. Under this backdrop, advanced lithography systems are no longer just commercial equipment. They have become something closer to geopolitical leverage points. Foreign multinational companies have long dominated the lithography market, and developed countries are now tightening export controls together. Because of this, cross-border supply of high-end equipment is facing disruptions that are becoming more and more normal, not just occasional. In response, SMIC has started using a dual-sourcing strategy. Under this approach, the company continues to run its older, imported systems while slowly bringing in new domestic equipment. Most of these local tools are supplied by Shanghai Micro Electronics Equipment (SMEE). To put it simply, SMIC's new purchasing model focuses on two main tasks: maintaining their current foreign machinery and gradually introducing domestic options, relying heavily on SMEE for local support. However, this dual-track system faces major challenges on both a small and large scale. On a micro level, companies still prefer to make purchasing choices based on lowering costs, just as they always have. Lithography machines involve very high sunk costs. Because of this, if a company is forced to change its equipment too quickly, it often deals with lower yields and financial losses while trying to fix the new process. As a result, managers frequently overlook the long-term value of having a backup plan, which is actually a great way to protect against supply chain disruptions. On a macro level, things are also difficult because most current research on dual-sourcing supply chains looks at industries with much lower technical barriers. For example, a lot of studies focus on the automotive industry instead of advanced technology sectors. But semiconductor lithography is quite different from those industries. It involves extremely specialized assets, very long qualification cycles, and high sensitivity to yield. Because of these differences, the usual dual-sourcing approaches used in other industries don't really work here. Traditional models cannot be applied directly to core semiconductor equipment, which is highly exclusive in terms of technology. Given all this, there is a clear need to build a more complete decision-making framework, one that takes into account both policy shocks and multiple layers of uncertainty, in order to make semiconductor equipment procurement more resilient.

## 1.2 Theoretical Foundations and Literature Review

Earlier research on supply chain resilience has paid more and more attention to how geopolitical risks are changing the way companies choose their suppliers. Singh and Misra point out that if a company relies too much on a single equipment supplier, like ASML, it becomes very vulnerable when export bans or service restrictions happen. Standard force majeure clauses often can't fully cover these kinds of risks [1]. Because of this, this study proposes a dual-source procurement model, one that combines "keeping existing foreign equipment running" with "gradually bringing in domestic equipment," in order to make the supply chain more resilient. That said, pushing for localization without careful planning is not easy, and it doesn't come without cost. Araz et al. point out that in high-risk situations, if a company tries too aggressively to replace foreign equipment with local alternatives, without a proper system in place, it can easily throw off the original balance between supply and demand. This, in turn, tends to raise the overall cost of operations [2]. These extra costs often come from unexpected drops in yield, along with the extra work needed to requalify equipment when immature domestic tools are brought into high-precision production lines. As for what happens during this transition period, Zheng et al. add that while local equipment makers are still catching up technologically, they often lower their prices first to compete for market share. This actually gives companies a chance to build a more layered dual-source structure, one that combines "imported equipment as a backup" with "gradual domestic substitution" [3].

## 1.3 Research Gaps in High-Tech Dual-Sourcing Studies

Current research still tends to split into two separate directions. One line of work focuses on modeling how firms interact strategically with each other when facing technological constraints. The other line looks at dual-sourcing mainly in industries that are already mature and don't involve highly specialized assets, such as automotive manufacturing. Berger et al. proposed the basic research framework of dual-source supply chain optimization in low-barrier industries [4]. The dual-supplier strategies in the automotive industry and other traditional manufacturing industries were analyzed in the traditional manufacturing environment and decision analysis. Azinhais studied how the automotive industry managed supply chain disruptions caused by semiconductor shortages [5]. However, the work was limited to the low-complexity operational logic of the automotive manufacturing industry, excluding situations involving high-tech semiconductor equipment. Cao empirically examined the risk management strategies of semiconductor equipment suppliers in the context of a technical embargo and an unpredictable international environment [6]. The author considered that previous relevant studies have only offered fragmented analyses of corporate strategic interactions and have lacked comprehensive, unified strategic research frameworks. Xiong et al. summarized the literature on the resilience of the semiconductor supply chain and found that existing research mainly examines resilience in low-end industrial supply chains, overlooking the purchasing and operational characteristics of high-exclusivity core semiconductor equipment [7]. Thus, few academics have examined the procurement of highly specialized, technologically important semiconductor equipment. Existing models that focus on standard cost-minimization strategies would underestimate the strategic redundancy advantage of safety stock. Anupindi and Akella emphasized that traditional supply chain decision models focus on cost management rather than supply instability, but disregard the strategic risk-reduction and redundancy benefits of safety stock for disruptions in the supply of high-tech equipment [8]. It provides a simple theoretical framework for analyzing supply diversification under uncertainty. Moreover, existing quantitative models do not consider delivery risks, micro-production-line yield variations, capacity constraints, and macro-geopolitical policy effects within a common quantitative decision-making framework. Ye et al. developed an evolutionary game model to enhance the security of the semiconductor supply chain from a macro-policy perspective and found that supply chain decision systems rarely incorporate multi-stakeholder policy simulation and macro-geopolitical policy dynamics [9]. Wang et al. noted that there is limited research to distinguish micro-level production-line yield volatility and capacity-constraint risks from macro-supply risk assessments, and proposed a supply chain risk evaluation methodology for the chip industry from a micro-operational viewpoint using LDA and multi-layer Bayesian networks [10]. Semiconductor manufacturing in modern wafer fabs has distinct aims regarding cost, risk, and operational efficiency. But no advanced dynamic multi-objective optimization models are available for the precise allocation of two types of equipment due to the dispersion of research techniques and simplistic modeling logic.

### 1.4 Conceptual Framework and Analytical Approach

In an effort to overcome these gaps, this research creates a novel paradigm that relates purchase choices to distinct risk levels. Traditional buying models generally do not include macro-level policy changes and micro-level manufacturing difficulties. To do this, this paper first analyzes the evolution of connections in the worldwide trade network for lithography equipment. This article investigates the impact of external political restrictions on SMIC's supply chain by quantifying shipping uncertainty and the risks of supply interruptions due to export limits. Then these large risk variables are considered as boundary conditions. At the same time, minor limitations from real industrial output are included in the model. For instance, the report points to SMIC's actual goal to increase its monthly capacity to nearly one million 8-inch wafers by 2025. In this case, the research evaluates the impact of several uncertainties on buying decisions, such as changes in the production yield, mismatch of the factory capacity, and whether the backup equipment can fulfill the criteria. Then, a dynamic multi-objective model is developed to include regulatory restrictions, supply concerns, and capacity constraints. This strategy is a step beyond the previous notion of attempting to save money. Instead, it balances four frequently conflicting goals: to make more profit, keep the supply chain secure, match production capacity, and use more local equipment. All of these aims are brought together in one decision-making framework. Finally, the research calculates the Pareto front for this model and finds the precise ratio on how to split the ratio for the two supply sources. It illustrates just how much a country ought to depend on keeping present foreign machinery operating versus gradually bringing in home technology. This technique provides a pragmatic solution for wafer companies that are facing these competing goals by finding the optimal balance between cost, risk, and capacity.

## 2. Industry Context and Structural Tensions in Equipment Procurement

### 2.1 Market Structure and Geopolitical Constraints

The global lithography equipment industry is highly concentrated, with just a few companies controlling most of the market. ASML alone holds most of the advanced DUV and EUV technologies. Because of this kind of monopoly, export controls have become easier to use as a political tool. As a result, China's access to cutting-edge equipment has been limited for a long time, and this has made cross-border supply uncertainty even worse.

### 2.2 Capacity Expansion versus Supply Fragility

In this context, SMIC, one of the leading domestic wafer fabrication companies, has kept expanding its production capacity. By 2025, its monthly capacity is expected to go beyond 1 million 8-inch-equivalent wafers, which has created huge demand for equipment procurement [11,12]. However, decisions around dual-sourcing procurement are still mostly based on experience and cost, and there isn't yet a systematic way to weigh the risks involved. At the moment, the main domestic supplier of lithography equipment is Shanghai Micro Electronics. But its products are still limited to mature process nodes, and there's still a noticeable gap in resolution and stability compared to international leading equipment [13]. On top of that, demand from downstream sectors like AI and automotive chips

ISSN 2959-6130

keeps fluctuating a lot, which adds even more pressure on the supply side. Fabs are being squeezed from several directions at once, including delivery delays, mismatches in capacity, and difficulties in getting substitute equipment qualified.

### 2.3 Limitations of Incumbent Procurement Practices

These pressures, taken together, show that a sourcing strategy focused only on cost isn't enough anymore. This is why there's a real need to build an integrated decision-making framework, one that takes policy frictions, supply uncertainties, and fab-level capacity constraints all into account at the same time. In the end, this creates a real tension: fabs need to scale up output, but relying on just one sourcing approach is becoming less and less realistic.

## 3. Structural Vulnerabilities in SMIC's Dual-Source Procurement Architecture

### 3.1 Geopolitical Triggers and Supply Chain Fragility

The intersection of extraterritorial export controls and concentrated equipment supply creates a condition of structural fragility; wherein geopolitical risk propagates directly into operational discontinuity. For a long time, the company relied heavily on a single supplier, ASML, based in the Netherlands, and mainly bought high-end DUV and EUV lithography systems from it. However, this very concentrated single channel has made the supply chain extremely vulnerable with the increasing intensity of geopolitical export controls [1]. Under this kind of pressure, resilience-focused sourcing logic suggests that companies should bring in a secondary domestic source, so risk can be spread out and strategic hedging becomes possible. Based on theories around supply chain resilience and dual-sourcing procurement, adding a domestic secondary source really is necessary, both to share risk and to hedge strategically. There is also real-world evidence that backs this up. Even though SMIC reached record revenue of $8.03 billion in 2024, its gross margin actually dropped from 19.3% to 18.0%, and net profit fell by half, from $900 million to $490 million (Figure 1). This was mainly due to faster equipment depreciation and one-time costs from reconfiguring the supply chain [14]. The fact that revenue went up while profit didn't clearly show how much damage geopolitical conflict can do to a company's overall performance. Domestic manufacturers may lower their prices on purpose to compete for market share while they're still catching up technologically. But given how uncertain new equipment can be when it comes to production yield, companies still need to move away from relying on a single source. Instead, they should gradually shift toward a layered dual-sourcing structure, one that combines "imported equipment as a backup" with "domestic substitution" [3].

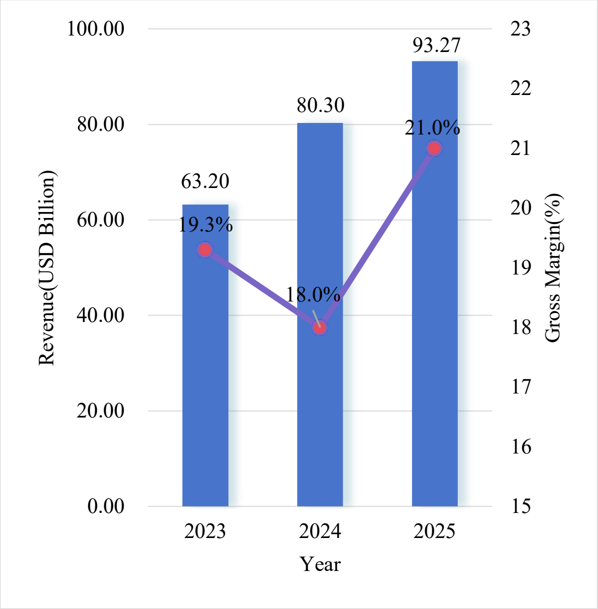


Fig. 1(a) SMIC Revenue and Gross Margin Trends

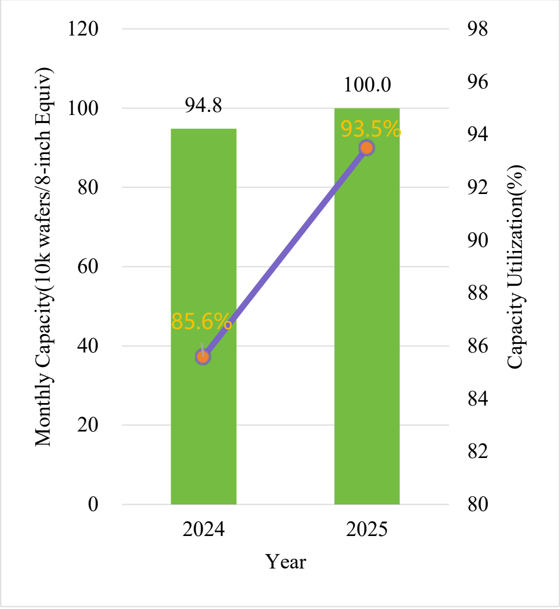


Fig. 1(b) SMIC Monthly Capacity & Utilization Change

**Fig. 1 SMIC's Core Operational and Financial Indicators Comparison Trend Chart (Photo credit: Origin)**

### 3.2 Multi-Objective Trade-offs and Procurement Imbalances

Sourcing equipment under this kind of geopolitical pressure means firms need to balance four goals at the same time: keeping profits stable, keeping the supply chain secure, making sure equipment matches production line needs, and pushing forward domestic equipment localization. In such a volatile environment, firms can't focus on cost alone when making procurement decisions. The SMIC case shows that current procurement needs to coordinate all four of these goals together: improving profitability, keeping the supply chain secure, matching production capacity, and localizing equipment. The problem is, these four goals often conflict with each other, which puts firms in a difficult position. For example, buying cheaper domestic equipment from startups can help save money. But under heavy pressure from supply disruptions, if a company increases the share of domestic equipment too aggressively, without careful planning, chip yields can actually drop. Araz et al. make a similar point, noting that pursuing localized substitution too aggressively under high-risk conditions can throw off the balance between supply and demand, and end up raising total costs instead of lowering them [2]. On the other hand, stockpiling too many imported DUV systems, to prepare in advance, isn't a good solution either. This kind of hoarding adds to fixed-asset depreciation costs, without really improving effective capacity utilization. In fact, this dynamic was a major reason behind the 150-basis-point drop in gross margin seen in 2024 [14]. Figure 2 shows the Pareto-optimal frontier generated from a two-stage stochastic programming model. It illustrates the trade-offs among the four sourcing objectives, and points out which procurement configurations are non-dominated, meaning no other option performs better on every dimension at once.

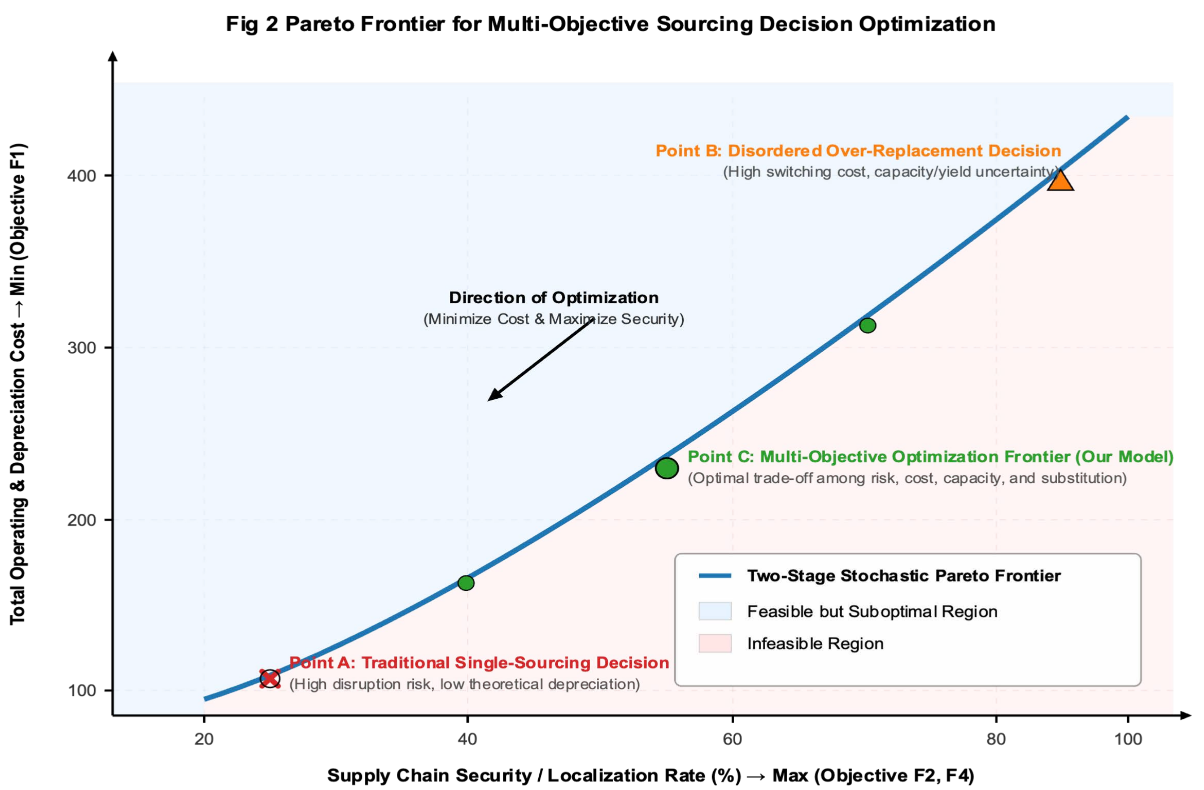


**Fig. 2 Pareto Frontier for Multi-Objective Sourcing Decision Optimization (Photo credit: Origin)**

In 2025, SMIC showed that it could flexibly mix imported and domestic equipment. That year, monthly capacity went beyond 1 million wafers, revenue grew by 16.2% to reach $9.327 billion, and capacity utilization actually went against the overall trend, hitting 93.5% [12]. This suggests that firms need to keep adjusting the procurement ratio between the two types of equipment dynamically, rather than fixing it once and leaving it unchanged. That said, a real challenge still remains. There isn't yet a mature model to guide firms on how to precisely and quantitatively allocate the two types of equipment and inventory, especially in an environment shaped by dual uncertainties, external macro-geopolitical risks on one side, and delivery lead times on the other.

ISSN 2959-6130

## 4. Strategic Pathways for Resilient Dual-Source Procurement

The two key problems facing SMIC in its bid to ramp up to one million wafers are interruptions in its external supply chain and imbalanced internal decision-making. This research tackles these issues with some strategic suggestions. The purpose is to allow the business to set up a stronger buying system, which can effectively balance financial profitability and supply chain security.

### 4.1 Institutionalizing Strategic Redundancy through Tiered Dual-Sourcing

At the moment, it is extremely difficult to alter the fact that high-end lithography equipment still depends primarily on foreign providers. That's why corporations shouldn't rush to a "one-size-fits-all" strategy to replace everything with domestic equipment. Rather, a gradual step-by-step approach makes a lot more sense. For older, established technologies, organizations may gradually test and employ more domestic equipment, such as that from Shanghai Microelectronics. Applying these local techniques at a broader scale, they can assist in driving technological improvements earlier in the supply chain. However, for high-end technology, it is still vital to continue to use imported equipment and maintain enough spare parts. At the moment, it is the foreign equipment that keeps manufacturing going. Also a system of 'strategic safety stock' should be put in place. Therefore, organizations need to segregate the safety supply of the crucial parts from their regular inventory. If they do, supply chain security may be a long-term gain rather than just a short-term expense. This method will help firms get out of the rut of concentrating primarily on saving money, which typically restricts their long-term planning.

### 4.2 Operationalizing Multi-Objective Stochastic Optimization for Procurement Decisions

To address the conflicts between the four major aims (profit, supply chain safety, capacity matching, and domestic equipment), this paper should no longer use personal experience or simple estimates. Instead, this paper may get considerably better assistance in decision-making by employing mathematical models like two-stage stochastic programming. In this paper, a novel decision-making paradigm is proposed. It takes into account a number of important variables, such as the likelihood of political risks, delays in equipment delivery, and the amount of output a manufacturing line may lose. This model can get the Pareto frontier. This allows the paper to dynamically compute the optimal buying ratio between imported and indigenous equipment. The model has the ability to self-adjust when there are changes in the external environment, for example, when export limits tighten or loosen. This allows enterprises to strike a more precise balance between saving money and maintaining stability and security in the supply chain.

### 4.3 Collaborative Ecosystems for Equipment Qualification and Process Integration

Acquiring equipment isn't only a financial transaction. Throughout reality, it demands intense integration throughout the complete industrial manufacturing process. Now, the resolution and stability of domestic tools are still far from modern international machines. To fill this gap, corporations could cooperate with manufacturers to establish initiatives such as "Joint R&D Center" or "Process Verification Platform". At the same time, it is a good idea to include performance terms in purchase agreements. These clauses should be focused exclusively on machine yield and stability. This will motivate local suppliers to improve to meet SMIC's precise manufacturing requirements. Such coordination may shorten testing cycles and make the equipment more dependable, which reduces the operational risks of having to switch vendors. This will eventually contribute to building a really robust and reliable household equipment system.

## 5. Conclusion

### 5.1 Core Findings

This research investigates the effects of political regulations on the dual-source supply chain of SMIC. It states that the organization lacks balance in making purchase decisions when many aims conflict. This is supported by real-world data. SMIC's net profit fell 45% in 2024 due to higher equipment depreciation and high costs for switching the supply chain. This reduction plainly indicates that the company's financial basis is not robust enough to endure shocks simply due to the growth of sales. High-tech firms need to cease looking at expenses from one point of view. Instead, companies should undertake multi-objective planning, with long-term survival as the primary goal. In 2025, SMIC managed to boost its monthly manufacturing capacity to more than one million wafers. This they did by combining foreign and domestic equipment in a flexible way. Such achievement shows the need to keep a dynamic change in the ratio between the two kinds of machines, which is a fantastic approach to reducing political risks.

### 5.2 Contributions & Implications

This paper makes fresh theoretical contributions to the literature of dual-sourcing supply chains. It accomplishes this by including the political risk elements and the losses of the production yield in one model. This technique contributes to bridging a large gap in the existing research, particularly for buying circumstances with high risks and sole suppliers. At the practical level, the Pareto-optimal borders of this research might be a beneficial tool for plant managers in support of their judgments. This instrument helps businesses to spread their purchase expenditures among diverse suppliers of equipment even under large uncertainty. These results are also generally relevant for industrial policymakers. This gives them a proper feel for the scale of backup planning that is required, without at the same time having to squander funds.

### 5.3 Limitations & Future Research

However, there are significant limitations to this research since the present quantitative analysis is mostly based on secondary data. This paper mostly utilized public materials such as SMIC's financial reports and research studies. So, the model may miss highly particular factors like rapid changes in production output, differing material quality, or unpredictable supply delays. Nor do public data often reveal the actual operational constraints that occur on the manufacturing floor amid a crisis. Future studies might address this difficulty by focusing on gathering primary data. For instance, researchers may perform on-site surveys of semiconductor manufacturing or undertake in-depth interviews with industry professionals. Having these direct insights would assist in enhancing the parameter tuning of the multi-objective model. This would result in strategic counsel more appropriate to a company's actual manufacturing environment, perhaps offering more realistic and beneficial solutions for the semiconductor sector.

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