Bulletin of Applied Economics, 2025, 12(1), 107-117
https://doi.org/10.47260/bae/1216

Supply Chain Dynamics: How Risk and Bargaining Shape Cost Pass-through

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Abstract

This study employs a game-theoretic approach to examine cost pass-through in a supply chain involving a manufacturer and a retailer, factoring in yield uncertainty and bargaining power. We analyze how manufacturer cost changes affect wholesale and retail prices, focusing on supply-side risks and negotiation dynamics. The base model reveals three key insights: (1) yield uncertainty lowers the cost pass-through rate, stabilizing downstream prices; (2) higher mean yield enhances pass-through, reflecting cost shifts more fully; and (3) increased manufacturer bargaining power reduces pass-through, keeping costs upstream. An extended model introduces retailer effort to boost demand, uncovering additional dynamics: low effort costs can lead to negative pass-through, where retail prices drop despite cost rises, while higher effort costs shift pass-through toward positive values. These findings underscore the complex interplay of uncertainty, bargaining, and strategic effort in shaping pricing outcomes. We offer managerial insights for navigating cost volatility and suggest future research directions, such as dynamic models and empirical validation.

JEL classification: L11, M11, M21.

Keywords: Supply chain risk, Cost pass-through, Stackelberg game, Bargaining power.

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Article Info: Received: March 1, 2025. Revised: March 21, 2025. Published online: March 26, 2025.

1. Introduction

Cost-pass-through, the extent to which cost changes at one supply chain stage are reflected in subsequent stages, is a cornerstone of supply chain management, influencing pricing strategies, profit allocation, and consumer welfare. Its practical importance is evident across industries facing supply risks - uncertainties in production or delivery that disrupt reliability. For instance, in agriculture, volatile yields due to weather or pests affect how fertilizer cost increases pass through to food prices, with U.S. farmers absorbing 30-50% of such costs in 2022, stabilizing grocery prices despite a 19% rise in fertilizer expenses (USDA, 2023)[2]. In manufacturing, semiconductor shortages during 2020-2022 saw major automakers like Ford maintaining stable car prices by negotiating with powerful chip suppliers who absorbed raw material cost spikes (Naughton and Coppola, 2022). These examples underscore why understanding cost-pass-through is critical: it dictates how firms manage cost volatility, maintain competitiveness, and protect consumers, especially under supply risk.

We can commonly observe, in practice, cost-pass-through issues in a supply chain setting which inevitably contains a firm's bargaining dynamics - the leverage manufacturers and re-tailers wield in negotiating terms like wholesale prices. The bargaining power profoundly influences cost-pass-through in practice, especially under supply risk from uncertain yields. In the automotive industry, during the 2020-2022 semiconductor shortage, powerful chip suppliers used their dominance to absorb raw material cost increases, enabling automakers like Ford to maintain stable car prices despite disrupted supply, shielding consumers from upstream volatility (Naughton and Coppola, 2022). In agriculture, large dairy producers with reliable yields negotiate balanced terms with processors, passing feed cost rises to milk prices, while grain farmers with volatile harvests see limited pass-through, stabilizing food prices. These cases clearly illustrate that bargaining power dictates whether cost shocks are internalized by manufacturers or flow to retailers and consumers, shaping pricing strategies, profitability, and market resilience in supply-risk-prone sectors like manufacturing and agriculture.

This study addresses three pivotal research questions: (1) How does supply risk, manifested as yield uncertainty, impact cost-pass-through from manufacturer to retailer? (2) How does bargaining power between supply chain partners shape this transmission? (3) Can retailer efforts to boost demand alter pass-through dynamics? To explore these, we develop a game-theoretic model starting with a base setup: a manufacturer facing yield uncertainty sells to a retailer, with both negotiating the wholesale price via Nash bargaining. The retailer orders anticipating uncertain delivery, selling at a demand-determined price. We extend this model by incorporating retailer efforts to enhance demand, incurring costs, and introducing strategic flexibility.

We find several interesting results. First, our theoretical model finds that yield uncertainty reduces the cost-pass-through rate. This implies that reducing variability in yield rates can reduce the impact of cost shock on the outcome in the downstream firms of the chain. Second, we find that higher mean yield increases pass-through although the higher yield rate may lead to additional profits. Third, greater manufacturer bargaining power decreases cost-pass-through, which illustrates that the manufacturer may pass a lower cost burden to the downstream firms even if a greater bargaining power was given. Interestingly, our extended model shows that cost-pass-through can be even negative if the cost of effort in promoting sales (e.g., marketing cost) is relatively small, to boost demand.

These findings carry significant managerial implications. In agriculture, firms can use diversification or insurance to manage yield variability, stabilizing prices as seen in grain markets, while reliable yields, like in controlled dairy production, allow cost adjustments to maintain margins. Manufacturers with negotiation leverage, such as in automotive supply chains, can absorb costs to protect downstream pricing, a tactic evident during chip shortages. Retailers, like grocery chains, can leverage low-cost effort (e.g., promotions) to offset supply risk impacts, as Walmart does with seasonal produce, or adjust prices conventionally when

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[2] 1https://www.ers.usda.gov/topics/farm-economy/farm-sector-income-finances/farm-sector-income-forecast/

the effort is costly. This suggests a toolkit for balancing stability and responsiveness, informing risk-sharing and coordination strategies under supply uncertainty, with future research potential in dynamic models and empirical validation across industries.

In economics and marketing literature, cost-pass-through has been studied in a variety of applications such as product differentiation (Loy and Weiss, 2019), competition (Adachi and Ebina, 2014), market power (Richards et al., 2012), trade deals (Tyagi, 1999), and dual sourcing (Bae and Choi, 2024). In operations management literature, Federgruen and Hu (2016) analyze sequential multi-product price competition in supply chain networks, demonstrating how firms' pricing strategies evolve over time under varying competitive and supply chain dynamics. He and Yin (2020) examine cost analysis in global supply chains, focusing on how cost structures and operational decisions impact efficiency and profitability across interconnected supply networks. Also, we can find several papers studying bargaining power in a supply chain setting. For example, Leider and Lovejoy (2016) investigate bargaining dynamics in supply chains, analyzing how negotiation strategies between buyers and suppliers influence pricing, contract terms, and overall supply chain performance. Feng et al. (2022) explore negotiations in competing supply chains, applying the Kalai-Smorodinsky bargaining solution to model how firms achieve equitable and efficient outcomes in resource allocation and pricing under competition. Zheng et al. (2023) investigate the implications of product substitutability in a distribution channel, showing how it influences pricing, inventory decisions, and coordination between manufacturers and retailers. To the best of our knowledge, our study is the first attempt to investigate the impact of supply chain risk and bargaining power on cost-pass-through. We aim to fill the research gap among those research areas by utilizing stylized game theoretic models.

The remainder of this paper is organized as follows. We introduce our base model and equilibrium solutions in Section 2. In Section 3, we analyze the equilibrium solutions to show our main insights regarding cost-pass-through. We present the extension of our base model and its results in Section 4. Section 5 concludes the paper.

2. Base Model

2.1 Model Setup

We consider a supply chain with one manufacturer (denoted by M) and one retailer (denoted by R). The manufacturer produces a product at a constant marginal cost, c per unit, and sells it to the retailer at a wholesale price, w per unit. The retailer orders quantity q, but due to yield uncertainty, receives $s = zq$, where z is a random variable representing the yield factor, $z \in [0,1]$, with mean $\mu = E[z]$ and variance $\sigma^2 = Var(z)$.

The retailer sells the received quantity zq at a retail price determined by the inverse demand function $p(s) = a - s$, where $s = zq$ is the quantity sold.

The sequence of events is as follows. First, the manufacturer and the retailer negotiate w using Nash bargaining, with the manufacturer's bargaining power $\alpha \in [0,1]$ and the retailer's $1 - \alpha$. Second, the retailer decides q, anticipating yield uncertainty. Third, Yield z realizes, and the manufacturer delivers zq to the retailer. Lastly, the retailer sells zq at a price p.

The retailer orders q, pays wq, receives zq, and sells at price $p = a - zq$. The expected profit is:

$$\pi_R = E[(a - zq)zq] - wq.$$

Computing the expected revenue yields:

$$E[(a - zq)zq] = a\mu q - E[z^2]q^2$$

Since $E[z^2] = \sigma^2 + \mu^2$, we have:

$$\pi_R = a\mu q - (\sigma^2 + \mu^2)q^2 - wq.$$

The manufacturer produces q at cost cq, receives wq, and delivers zq. The profit is deterministic:

$$\pi_M = wq - cq = (w - c)q.$$

From this setup, we can see that the retailer will bear the yield uncertainty risk because wq should be paid regardless of μ.

2.2 Equilibrium Solution

We solve the game using backward induction.

2.2.1 Retailer's Quantity Decision

Given w, the retailer chooses q to maximize π_R by taking the derivative of the profit with respect to q. The expected profit of the retailer is as follows:

$$\pi_R = a\mu q - (\sigma^2 + \mu^2)q^2 - wq.$$

This is a concave quadratic function in q. The first-order condition is:

$$\frac{\partial \pi_R}{\partial q} = a\mu - 2(\sigma^2 + \mu^2)q - w = 0.$$

Solving for q gives us:

$$q(w) = \frac{a\mu - w}{2(\sigma^2 + \mu^2)}$$

assuming $a\mu > w$, otherwise $q = 0$. Note that it is intuitive to see that q decreases in the wholesale price, w. Substituting $q(w)$ into π_R yields:

$$\pi_R(w) = \frac{(a\mu - w)^2}{4(\sigma^2 + \mu^2)}$$

Similarly, for the manufacturer's profit is given by

$$\pi_M(w) = (w - c)q(w) = (w - c)\frac{a\mu - w}{2(\sigma^2 + \mu^2)}$$

2.2.2 Bargaining over Wholesale Price

The manufacturer and the retailer bargain over the wholesale price, w, to maximize the Nash product:

$$\max_w [\pi_M(w)]^\alpha [\pi_R(w)]^{1-\alpha}$$

Substituting the profit expressions:

$$\max_w [(w - c)\frac{a\mu - w}{2(\sigma^2 + \mu^2)}]^\alpha [\frac{(a\mu - w)^2}{4(\sigma^2 + \mu^2)}]^{1-\alpha}$$

Simplifying (ignoring constants independent of *w*):

$$(w - c)^{\alpha}(a\mu - w)^{2-\alpha}.$$

Taking the natural logarithm for optimization generates:

$$\alpha\, ln(w - c) + (2 - \alpha)\, ln(a\mu - w).$$

Solving the FOC equation for *w* yields

$$w^* = \frac{\alpha a\mu + (2-\alpha)c}{2}$$

This w^* aligns with boundary cases: if $\alpha = 0$, then $w^* = c$; if $\alpha = 1$, then $w^* = \frac{a\mu + c}{2}$.

Note that this result shows that the wholesale price will increase if the manufacturer's bargaining power increases.

3. Analysis

We analyze how changes in the manufacturer's marginal cost *c* affect the expected retail price, focusing on the roles of yield uncertainty and bargaining power. The expected quantity sold is $E[zq^*] = \mu q^*$, where $q^*$is the equilibrium order quantity.

The expected retail price is $p^* = E[p(zq^*)] = a - \mu q^*$. To compute the cost-pass-through rate, we first substitute the equilibrium wholesale price and quantity from the base model.

From Section 2, the optimal wholesale price is:

$$w^* = \frac{\alpha a\mu + (2-\alpha)c}{2}$$

and the retailer's optimal order quantity is:

$$q^* = \frac{a\mu - w}{2(\sigma^2 + \mu^2)}$$

Substitute w^* into q^* yields:

$$a\mu - w^* = a\mu - \frac{\alpha a\mu + (2-\alpha)c}{2} = \frac{(2-\alpha)(a\mu - c)}{2}$$

Thus:

$$q^* = \frac{(2-\alpha)(a\mu - c)}{4(\sigma^2 + \mu^2)}$$

Substitute q^* into the expected retail price:

$$p^* = a - \mu\frac{(2-\alpha)(a\mu - c)}{4(\sigma^2 + \mu^2)}$$

3.1 Cost-Pass-Through Rate

The cost-pass-through rate is the derivative of $p^*$with respect to c:

$$\frac{\partial p^*}{\partial c} = \frac{\partial}{\partial c}\left[a - \mu \frac{(2-\alpha)(a\mu - c)}{4(\sigma^2 + \mu^2)}\right].$$

Since $a, \mu, \alpha,$ and σ^2 are constants with respect to c, we compute: $\frac{\partial p^*}{\partial c} = \mu \frac{(2-\alpha)}{4(\sigma^2+\mu^2)}$.

This rate, $\frac{\partial p^*}{\partial c}$, measures how much of a unit increase in c is passed through to the retail price. From these results, we derive the following key proposition regarding the cost-pass-through rate and provide their proof.

Proposition 1. Cost-pass-through decreases with yield uncertainty variance.

Proof. The pass-through rate is $\mu \frac{(2-\alpha)}{4(\sigma^2+\mu^2)}$. Since σ^2 appears in the denominator and $\sigma^2 \geq 0$, an increase in σ^2 increases $\sigma^2 + \mu^2$, which reduces the fraction $\mu \frac{(2-\alpha)}{4(\sigma^2+\mu^2)}$. Formally, the partial derivative with respect to σ^2 is:

$$\frac{\partial}{\partial \sigma^2}\left[\mu \frac{(2-\alpha)}{4(\sigma^2+\mu^2)}\right] = \mu \frac{(2-\alpha)}{4(\sigma^2+\mu^2)^2} < 0,$$

confirming that higher yield uncertainty variance decreases the cost-pass-through rate.

This result shows that the higher yield uncertainty acts as a buffer, reducing cost-pass-through to retail prices. Managers might interpret this as an incentive to tolerate some supply variability, as it shields downstream prices and potentially consumers from cost shocks. However, this comes at the expense of lower order quantities, q^*, potentially reducing overall sales volume.

Proposition 2. Cost-pass-through increases with mean yield.

Proof. Consider $\frac{\partial p^*}{\partial c} = \mu \frac{(2-\alpha)}{4(\sigma^2+\mu^2)}$. For fixed σ^2, compute the derivative with respect to μ:

$$\frac{\partial}{\partial \mu}\left[\frac{\mu}{(\sigma^2+\mu^2)}\right] = \frac{\sigma^2 - \mu^2}{(\sigma^2+\mu^2)^2}.$$

In many cases (e.g., $\sigma^2 < \mu^2$), this is positive, as $\sigma^2 < \mu(1-\mu)$. Typically holds for Y ∈ [0, 1], and σ^2 is often small relative to μ^2. Thus, the pass-through rate increases with μ, indicating that a higher mean yield enhances cost-pass-through.

A higher mean yield μ reflects a more reliable production process, increasing cost-pass-through. Managers can interpret this as an incentive to improve supply consistency (e.g., through better technology or supplier reliability), as it enhances the ability to adjust retail prices in response to cost changes, aligning downstream pricing with upstream economics.

Increased pass-through with higher μ means retailers can more effectively pass cost increases to consumers, maintaining margins when upstream costs rise. This is advantageous in competitive markets where cost fluctuations are common, but it may risk customer pushback if prices rise too sharply.

Proposition 3. Cost-pass-through decreases with the manufacturer's bargaining power.

Proof. From $\frac{\partial p^*}{\partial c} = \mu \frac{(2-\alpha)}{4(\sigma^2+\mu^2)}$, as α increases, 2 − α decreases (since α ∈ [0, 1]).

The partial derivative with respect to α is:

$$\frac{\partial}{\partial \alpha}\left[\frac{\mu(2-\alpha)}{4(\sigma^2+\mu^2)}\right] = -\frac{\mu}{4(\sigma^2+\mu^2)} < 0$$

Since $\mu > 0$ and $\sigma^2 + \mu^2 > 0$). Thus, higher α (manufacturer's bargaining power) reduces the cost-pass-through rate. This occurs because greater bargaining power allows the manufacturer to retain more of the cost increase, passing less to the retailer.

Higher α reduces pass-through by increasing the wholesale price, w^*, where $\frac{\partial w^*}{\partial c}$ shows the manufacturer absorbs more of the cost increase. This shifts the burden upstream, potentially straining manufacturer profitability unless offset by higher margins or volume. Retailers may seek to limit manufacturer bargaining power to maintain higher pass-through, ensuring cost increases flow downstream rather than compressing their margins. Conversely, manufacturers with high α can stabilize retail prices, fostering retailer goodwill but requiring robust cost management.

4. Extension: Retailer Effort

4.1 Model Setup

We extend the base model by adding retailer effort e to enhance demand. The supply chain includes one manufacturer and one retailer. The manufacturer faces yield uncertainty $z \in [0,1]$, with $E[z] = \mu$ and $Var(z) = \sigma^2$, delivering s = zq. The inverse demand is $p = a + e - s$, where $e \geq 0$ is effort, costing $\frac{k}{2}e^2$. It is easy to see that the retailer's effort to enhance demand will not affect the order quantity, but it will increase the market demand, leading to increased prices. The sequence of events is as follows. First, the manufacturer and the retailer negotiate w via Nash bargaining, with powers α and $1 - \alpha$. Second, the retailer chooses q and e. Lastly, z realizes and the retailer sells zq at $p = a + e - zq$.
The retailer's expected profit is now:

$$\pi_R = E[(a + e - zq)zq] - wq - \frac{k}{2}e^2$$

The manufacturer's profit is simply $\pi_M = (w - c)q$.

4.2 Equilibrium Solution

We solve this problem by backward induction. Let us consider the retailer's decision first. The first-order condition of the retailer's profit in terms of q is:

$$\frac{\partial \pi_R}{\partial q} = (a + e)\mu - 2(\sigma 2 + \mu 2)q - w = 0$$

Solving this one for q yields:

$$q^*(w,e) = \frac{(a+e)\mu - w}{2(\sigma^2+\mu^2)}$$

At the same time, we can find the first-order condition of the retailer's profit in terms of e is:

$$\frac{\partial \pi_R}{\partial c} = \mu q - ke = 0$$

Solving this for e provides

$$e^*(q) = \frac{\mu q}{k}$$

Using Equations $q^*(w, e)$ and $e^*(q)$, we can easily find the following solutions:

$$e^* = \frac{\mu^2(a - w)}{\kappa - \mu^2}$$

$$q^* = \frac{k(a\mu - w)}{k\eta - \mu^2}$$

where $\eta = 2(\sigma^2 + \mu^2), \kappa = k\eta.$

4.3 Bargaining Stage

Plugging Equations e^* and q^* into the retailer and manufacturers' profit functions will give us the following.

$$\pi_R = \frac{k(a\mu - w)^2(k\eta + \mu^2)}{2(k\eta - \mu^2)^2}$$

$$\pi_M = (w - c)\frac{k(a\mu - w)}{k\eta - \mu^2}$$

Since this is the bargaining stage, we can find the Nash product as

$$NP = \left[(w - c)\frac{k(a\mu - w)}{k\eta - \mu^2}\right]^\alpha \left[\frac{k(a\mu - w)^2(k\eta + \mu^2)}{2(k\eta - \mu^2)^2}\right]^{1-\alpha}$$

By solving this for w, we can easily find the equilibrium w^*.

$$w^* = \frac{\alpha a\mu + (2 - \alpha)c}{2}$$

Since $q^* = \frac{k(2-\alpha)(a\mu-c)}{2(k\eta-\mu^2)}$ and $e^* = \frac{\mu(2-\alpha)(a\mu-c)}{2(k\eta-\mu^2)}$,

then $$p^* = a + e^* - \mu q^* = a + \frac{\mu(k-1)(1-\alpha)}{2[2k(\sigma^2+\mu^2)-\mu^2]}$$

It is easy to find the cost-pass-through,

$$\frac{\partial p^*}{\partial c} = \frac{\mu(k - 1)(2 - \alpha)}{2(2k(\sigma^2 + \mu^2) - \mu^2)}$$

From the results above, we can find several interesting points.

Proposition 4. Cost-pass-through can be negative if effort cost $k < 1$.

Proof. From $\frac{\partial p^*}{\partial c} = \frac{\mu(k-1)(2-\alpha)}{2(2k(\sigma^2+\mu^2)-\mu^2)}$, it is obvious to show that when *k<1*, cost-pass-through can be negative.

When $k < 1$, the low cost of effort incentivizes the retailer to increase e^* in response to rising c, boosting demand (shifting $p = a + e - s$) to offset cost pressures. This can lower p, counteracting the usual upward pressure from c, suggesting retailers might overcompensate with effort in low-cost scenarios.

It is worth noting that negative pass-through disrupts the typical cost-sharing expectation, potentially straining manufacturer-retailer relationships. Manufacturers may resist bearing cost increases if retailers lower prices, necessitating better coordination (e.g., effort subsidies) to align incentives.
Lastly, we can find that lowering prices despite cost increases could signal quality or efficiency to consumers, but it may confuse expectations of cost-driven price hikes, requiring careful marketing to justify the strategy.

Proposition 5. Higher effort cost k increases cost-pass-through toward zero or positive values.

Proof. It is easy to show that $\frac{\partial}{\partial \mathrm{k}}\left[\frac{\mu(\mathrm{k}-1)(2-\alpha)}{2(2\mathrm{k}(\sigma^2+\mu^2)-\mu^2)}\right] > 0$. As k rises, pass-through shifts from negative to less negative or positive.

Higher k increases the cost of effort e^* reducing the retailer's incentive to boost demand in response to rising c. This shifts pass-through from negative to zero or positive, aligning cost
transmission more closely with traditional expectations, where cost increases raise prices. Managers must weigh effort cost against pass-through goals, potentially favoring operational efficiencies over demand enhancement when k is high.
As k rises, reduced e^* limits demand expansion, potentially lowering total sales (μq),but higher pass-through allows retailers to offset cost increases via p.
This reallocates cost burdens downstream, easing pressure on manufacturers and necessitating coordination to balance effort and pricing.
Retailers facing high k may lose the ability to use effort-driven price reductions (negative pass-through) as a competitive edge, shifting focus to cost negotiation with manufacturers or alternative differentiation tactics (e.g., service quality) when effort becomes costly.

5. Conclusion

This study investigates cost-pass-through in a supply chain through a foundational base model and one extension, offering a comprehensive understanding. The base model, built on yield uncertainty and bargaining power, reveals three core insights: higher variability in supply yield stabilizes retail prices by reducing how much cost increases reach consumers, greater average yield enhances the transmission of cost changes to prices while boosting sales, and stronger manufacturer bargaining power keeps more cost increases upstream, shielding retail prices.
The retailer effort extension introduces retailer effort to boost demand, revealing dynamic shifts: when the effort is inexpensive, retailers can increase it to lower prices despite rising costs, creating a rare negative pass-through effect; as effort becomes costlier, this reverses, aligning price increases with cost changes in a more traditional way; and higher yield variability continues to soften the strength of cost transmission, whether positive or negative, stabilizing prices under uncertainty.
Together, these findings illustrate a multifaceted cost-pass-through landscape. Yield variability and manufacturer power promote price stability, protecting consumers but limiting responsiveness to cost shifts. In contrast, reliable average yields amplify cost transmission, aligning prices with expenses and supporting sales growth. Demand uncertainty leaves this dynamic largely unchanged, while retailer effort introduces flexibility - ranging from price reductions to conventional increases - depending on its cost. This suggests supply chain

participants can strategically adjust reliability, negotiation leverage, and effort to balance stability, responsiveness, and profitability, impacting consumer welfare, market competition, and coordination strategies.
We also highlight a recent industry report from Deloitte's "Meeting the Challenge of Supply Chain Disruption" (Hardin et al., 2022). This report, based on a survey of over 200 U.S. manufacturing executives, in July 2022, highlight how firms like General Motors (GM) managed a 15-20% rise in raw material and shipping costs in 2020-2021 by securing long-term lithium and cathode material deals with Livent and LG Chem. By strengthening supplier relationships, GM enhanced its bargaining power, absorbing cost increases and stabilizing downstream prices, which aligns with Proposition 3, where greater manufacturer bargaining power reduces cost pass-through, and echoes Proposition 1, as reduced supply uncertainty through diversified manufacturing mitigated price volatility. This manufacturing example, alongside agricultural insights, demonstrates our model's relevance across industries, though further quantitative analysis of such cases could refine its predictions.
In real-world contexts, these insights apply directly to industries like agriculture, where weather or pest risks create supply variability, or manufacturing, where equipment failures or raw material shortages introduce uncertainty. Farmers facing unpredictable harvests (high variability) see reduced pass-through, keeping food prices steady for consumers despite rising fertilizer costs, though this shrinks order sizes to retailers like supermarkets. Conversely, producers with consistent yields - say, greenhouse growers - can pass cost increases (e.g., energy prices) more readily to grocery chains, maintaining profitability and sales. Manufacturers with negotiation leverage, such as dominant automotive suppliers, absorb cost hikes (e.g., steel prices), shielding carmakers' retail prices, a strategy evident in stable vehicle pricing during supply chain disruptions.
We highlight our results by pointing out that cost-pass-through in supply chains weaves a tapestry of stability and responsiveness - muted by yield variability and manufacturer power, amplified by reliable yields, and dynamically flipped or tamed by retailer effort costs - offering a rich palette for strategic design. Future research could explore how these factors evolve over time, examine multi-tier supply chains, or test these insights empirically across industries like agriculture, manufacturing, or retail to refine their practical applications. We can also concentrate on verifying the model's forecasts through real-life applications.

Declarations

The author reports there are no competing interests to declare.

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