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The Impact of a Unified Green Badge Policy on the Ecommerce Platform

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Abstract. This study examines the impact of a unified green badge policy on sales and seller competition in e-commerce platforms. The Climate Pledge Friendly badge on Amazon exemplifies the benefits of such a badge, including increased sales to eco-conscious consumers, improved product visibility, and enhanced brand trust and loyalty. Despite these advantages, there is limited research on how green badges affect seller competition. We address this gap using a three-stage game model. First, two sellers set their prices and product sustainability levels, considering the marketplace's commission rate and badge threshold. Second, the marketplace sets the badge threshold and recommends products based on inferred consumer preferences. Third, consumers determine their purchases, and firms realize profits. The equilibrium is characterized by a symmetric pure-strategy perfect Bayesian equilibrium (PBE) under imperfect information. Our findings show that at equilibrium, product prices and demand increase with the probability of adopting the unified green badge, provided certain conditions are met. Market competition also intensifies with the proportion of badged products, especially when these products hold a market share greater than 50%. This research provides strategic insights for sellers on green certification, pricing, and product features, and offers guidance for e-commerce platforms on the benefits of unified eco-labeling practices, aiding in sustainable marketing strategies.

Keywords: Game Theory, Sustainability, Green Label, Ecommerce, Bayesian Inference

1. Introduction

Advocates of a unified green badge on a marketplace for sellers highlight four main benefits. First, more consumers are becoming eco-conscious, potentially increasing sales for products with the badge [1]. The certification badge enables consumers to identify and purchase sustainable products more responsibly by showcasing endorsements from government agencies, non-profit organizations, and independent laboratories on eligible product listings [2]. A 2018 survey revealed that 48% of U.S. consumers expressed willingness to modify their consumption behaviors to mitigate environmental impacts. Concurrently, the market for sustainable products has expanded steadily, demonstrating a compound annual growth rate (CAGR) of 3.5% since 2014 [3]. In September 2019, Amazon became a co-founder of The Climate Pledge, a commitment to achieve the objectives of the Paris Climate Agreement a decade ahead of schedule. Then, in 2020, Amazon revealed its Climate Pledge Friendly program, which gives products that are deemed sustainable by Amazon a Climate Pledge Friendly badge. Additionally, products are not charged a fee to participate in this program. Qualifying products are highlighted in shopping results and product pages and featured in a dedicated Amazon section, increasing exposure and potential sales. Products labeled as Climate Pledge Friendly receive prioritized placement in Amazon's search rankings, conferring a distinct market

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advantage [4]. The certification badge serves as a visible marker of a brand's dedication to sustainable practices, thereby enhancing consumer confidence and fostering long-term brand allegiance [1].

Given the varying potential impacts of a unified green label policy on product sales and seller competition, and the lack of studies on how green badges affect seller competition on E-commerce platforms, it aims to fill that gap. We examine the causal impact of eco-label unification on sales and seller competition through a three-stage game. First Stage: both sellers concurrently determine their pricing strategies and select the sustainability levels for their respective products, considering the marketplace's commission rate and the inferred badge threshold. Second Stage: The marketplace observes prices and infers sustainability levels, sets the badge threshold, and recommends products to consumers based on their inferred preferences. Third Stage: Consumers determine their purchasing choices, leading to the realization of profits. The model derives a symmetric pure-strategy perfect Bayesian equilibrium (PBE), characterized by identical equilibrium prices and product sustainability levels for both sellers. This game involves imperfect information, where neither the marketplace nor sellers know consumers' exact preferences or product sustainability levels. The PBE ensures that all parties maximize their expected profits based on anticipated consumer behavior.

Upon deriving the equilibrium solution, the analysis reveals that in equilibrium, the price and demand of each product increase with the probability of adopting the unified green badge, provided certain conditions are met. Market competition also intensifies with the probability, as the proportion of products with the badge in the same category increases, assuming these products collectively hold a market share greater than 50%.

We are among the first to explore the impact of a unified green badge policy on sales and seller competition. Our game structure incorporates three key characteristics of green consumption: 1. This functionality enables the e-commerce platform to generate personalized recommendations and endogenously set the threshold for a unified green badge. 2. It enables sellers' prices and product sustainability to influence the marketplace's decisions endogenously. 3. The model explicitly accounts for sellers' competitive pricing strategies within its analytical framework.

Our findings are significant for sellers, helping them make informed decisions regarding green certification. We provide strategic recommendations for adjusting pricing and product features to optimize demand post-badge adoption. Additionally, our results offer Amazon valuable insights into the CPF badge's impact, particularly its positive effect on expanding the customer base, especially among older individuals and males, for green products. Our research serves as a benchmark for other e-commerce and online third-party platforms considering the implementation of a unified eco-labeling practice, providing a comprehensive guide for sustainable marketing strategies.

2. Literature review

2.1. Impact of green label on product demand

For sellers, three main issues stand out: higher prices, lower quality, and poor aesthetics in product design. First, consumer willingness to pay for sustainable products exhibits significant heterogeneity. While a substantial segment of the market remains price-sensitive and reluctant to pay sustainability premiums, a distinct eco-conscious consumer segment demonstrates positive willingness-to-pay for environmentally preferable alternatives. This divergence in consumer preferences creates important implications for sustainable product pricing strategies and market segmentation [5,6]. Thus, a higher price only seems to harm products sales to the segment of eco-unconscious or price-sensitive consumers [7]. Second, alternative materials or energy sources that reduce a product's environmental impact can limit or even diminish its functionality. Prior research has shown that sustainability is often perceived as a liability in terms of product functions, leading consumers to view sustainable products as having inferior performance [8-11]. Third, sometimes the product design might be less emphasized when mainly focusing on the sustainability of the product, potentially harming product attractiveness. Product design is of great importance in promoting

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product sales [12-14]. However, when mainly focusing on the environmental impact of the products, sometime the product may be less attractiveness visually [15].

2.2. Impact of a unified green badge policy on marketplace

From the marketplace's perspective, critics of a unified green badge policy primarily highlight three limitations. First, merely labeling products with the Climate Pledge Friendly badge does not directly reduce Amazon's carbon emissions. Unlike its e-commerce competitors, such as Target and Walmart, Amazon does not account for the emissions associated with manufacturing products by other companies—such as Levi's, Nintendo, and Frigidaire—when reporting its total emissions each year. These products, even when labeled with Climate Pledge Friendly badges on Amazon, are only "shipped from" and "sold by" Amazon. Consequently, some people are skeptical, viewing Amazon's addition of these badges as an attempt to distance itself from the broader climate impact [16].

Second, the badge isn't as obvious as other product categories, greatly reducing its impact. Amazon has established a dedicated "Climate Pledge Friendly" product portal featuring multiple categories, including Apparel, Beauty, Computers & Office, Electronics, Grocery, and Health & Household. When users select a category such as Apparel, they are directed to a standard product listing page. While the left sidebar displays departmental navigation filters, the Climate Pledge Friendly certification badge only becomes visible upon accessing individual product detail pages [17].

Third, the trustworthiness of certifications might be questionable, and the number of available certifications is limited. Although Amazon endeavors to routinely evaluate and reassess the certification landscape to incorporate more third-party certifications, some critics argue that the current number of external certifications remains insufficient. Some certifications like B Corporation [18] might potentially be added. But more importantly, the certifications themselves aren't completely trustworthy and accurate in representing the climate impact of the products [19].

3. Model structure

In this section, we try to establish a game theory model where we explore the impact of a unified green badge policy of the marketplace. This section outlines the foundational assumptions governing our model of the tripartite online marketplace ecosystem, comprising platform, sellers, and consumers. We begin by formalizing the seller-side assumptions that underpin our analytical framework. There are some works using analytical models for the transactions on online marketplaces where recommendation system is a dominant feature and that sellers can strategically adjust price to affect recommendation outcomes [20-23]. However, none of them study green product regularization with a unified badge policy in such an online marketplace. Our model extends prior online marketplace frameworks with recommendation algorithms and consumer profiling [24], but also incorporate the unified green badge policy.

3.1. Sellers

We consider a duopoly market where two competing sellers (A and B) offer differentiated but substitutable sustainable products through an online platform. The sellers simultaneously make two strategic decisions: (1) setting their respective product prices (denoted as p_A and p_B), and (2) agreeing to pay a fixed percentage commission rate r (where $0 < r < 1$) to the marketplace platform as part of the revenue-sharing agreement. Second, specific to our context of green consumption, the two sellers also decide the level of sustainability of their product which can either be very sustainable or be harmful to the environment, denoted as f_A and f_B, respectively. For convenience sand without lack of generalizability, we assume that $f_A, f_B \in [-1, 1]$. When $f_j > 0$, this means that the product is a green product; when $f_j < 0$, this means that the product harms the environment; when $f_j = 0$, this means that the product has no impact on the environment. Their marginal production costs excluding the green features are assumed to be zero, while the marginal cost associated

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with green features (e.g., sustainable ingredients or materials, etc.) is assumed be a linear function of the level of sustainability of product j, green feature cost = $c_0 + c_g \cdot f_j$.

The marketplace generates revenue through a commission-based model, collecting a fixed percentage r of each transaction value between sellers and consumers. Consequently, its total profit is proportional to the aggregate revenue generated by sellers A and B. Formally, for each unit sold of product j ∈ {A, B}, the marketplace earns $r \times p_j$ while the seller retains $(1 - r) \times p_j$.

In our baseline model, we treat the commission rate r as an exogenous parameter, reflecting prevailing industry practices where platform commission rates typically remain stable despite market fluctuations. This assumption aligns with empirical observations that major online marketplaces rarely adjust their commission structures even in response to significant market changes.

3.2. Marketplace

The marketplace also makes two decisions. First, a dominant feature of online ecommerce platforms is the wide application of recommendation system. Thus, we model the marketplace's recommendation system as selecting a single product j ∈ {A, B} to present to each consumer, consistent with the operational reality that recommendation algorithms typically curate a limited subset of items from the full product catalog. This framework captures two key features: (1) exclusivity in recommendations (only one product is suggested per consumer), and (2) selectivity, mirroring how real-world systems filter products from a much larger inventory. Since the unified green badge policy is a new practice, we initially assume that the feature of whether being badged is not incorporated into the recommendation system of the marketplace.

Second, the unique decision in our context is that based on its own standard of sustainable products and the level of sustainability of products in the same category as product A and B, the marketplace decides whether to add its own unified green badge to the green products. The decision is made with a green threshold, $I_0 \in [0, 1]$, defined as the level of sustainability above which the product is qualified to be badged by the marketplace. To be more specific, if and only if $\hat{f}_j \geq I_0$, will product j be qualified to have the unified green badge developed by the marketplace, where we have $\hat{f}_j$ being the inferred level of sustainability of product j by the marketplace which we'll introduce in detail on its distribution later.

3.3. Consumers

Conditional on awareness of both products, consumers exhibit heterogeneous horizontal preferences between options A and B. We model this preference structure through individual-specific utility functions, where consumer i's valuation can be expressed as [25]:

$$u_i = \left(\alpha + o_i\right)q_{iA} + \left(\alpha - o_i\right)q_{iB} - \frac{\beta}{2}\left(q_{iA}^2 + q_{iB}^2 + 2zq_{iA}q_{iB}\right) - p_A q_{iA} - p_B q_{iB} \quad (1)$$

In Equation (1), the utility parameters are defined as follows:

1) q_{ij} represents consumer i's consumption quantity of product j ∈ {A,B}

2) α denotes the baseline marginal utility common to all consumers

3) o_i captures private preference heterogeneity, where:

$o_i \sim U[-\theta, \theta]$ reflects uniformly distributed relative preferences.

$\theta > 0$ quantifies the population's preference diversity.

Higher o_i values indicate stronger intrinsic preference for product A.

4) $\beta > 0$ governs diminishing marginal utility effects.

5) $z > 0$ measures cross-product substitutability, indicating how price changes in one product affect demand for the other.

Leveraging the virtual nature of online marketplaces that eliminates physical shelf-space constraints, and considering the extensive product assortment typically offered by such platforms, we assume that it is essential to model heterogeneity in consumer knowledge about each product as well as their preference for

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sustainable products. Thus, we divide consumers into four segments based on their consumer knowledge in general and preference for sustainability. Suppose that uninformed consumer segment is with size $k \in (0, 1)$, among which $m_1 \in (0, 1)$ are green consumers; informed consumer segment is with size $1 - k \in (0, 1)$, among which $m_2 \in (0, 1)$ are green consumers.

Segment 1: uninformed, non-green consumers. This segment is with size $k(1 - m_1) \in (0, 1)$. We model consumers as having recommendation-dependent awareness, meaning they only consider products presented by the platform's recommendation system. When consumer i receives a recommendation for product $j \in \{A,B\}$, their consumption choice reduces to a single-product optimization problem where the quantity of the non-recommended product $q_{-j} = 0$, and they determine the optimal quantity q_j by maximizing the utility function in Equation (1). Notably, this segment of consumers does not incorporate sustainability attributes into their purchase decisions—the recommendation itself solely determines their consideration set, regardless of whether the product carries the eco-certification badge. This framework captures two essential features of platform-mediated consumer behavior: the recommendation system's gatekeeping role in shaping product awareness, and the consequent simplification of the utility maximization problem to only recommended products. To be more specific, if product A is recommended, a consumer i's optimal purchase quantity is given by $q_{iA,UN} = (\alpha + o_i - p_A) / \beta$, $q_{iB,UN} = 0$, where the subscript UN denotes for uninformed, non-green consumers, and her surplus is $CS_{iA,UN} = (\alpha + o_i - p_A)^2 / (2\beta)$. Alternatively, if product B is recommended, the purchase quantity will be $q_{iA,UN} = 0$, $q_{iB,UN} = (\alpha - o_i - p_B) / \beta$, and her surplus is $CS_{iB,UN} = (\alpha - o_i - p_B)^2 / (2\beta)$.

Segment 2: uninformed, green consumers. This segment is with size $k\, m_1 \in (0, 1)$. Consumer purchase behavior in this model is driven entirely by platform recommendations. Consumers only consider and purchase products that appear in their personalized recommendation feed, disregarding all non-recommended alternatives regardless of product attributes or availability. Moreover, these consumers will only buy products that are badged, as they know little about the products per se and only the unified green badge issued by the third-party marketplace is convincing for them. To be more specific, if product A is recommended, a consumer i's The sub-optimal purchase quantities with the restriction that the product needs to be badged is $q_{iA,UG} = \mathbb{1}(f_A \geq I_0) \cdot (\alpha + o_i - p_A) / \beta$, $q_{iB,UG} = 0$, where $\mathbb{1}$ is the indicator function and the subscript UG denotes for uninformed, green consumers, and her surplus is $CS_{iA,UG} = \mathbb{1}(f_A \geq I_0) \cdot (\alpha + o_i - p_A)^2 / (2\beta)$. In other words, if and only if $f_A \geq I_0$ and product A is recommended, will she buy the product. Alternatively, if product B is recommended, the purchase quantity will be $q_{iA,UG} = 0$, $q_{iB,UG} = \mathbb{1}(f_B \geq I_0) \cdot (\alpha - o_i - p_B) / \beta$, and her surplus is $CS_{iB,UG} = \mathbb{1}(f_B \geq I_0) \cdot (\alpha - o_i - p_B)^2 / (2\beta)$.

Segment 3: informed, non-green consumers. This segment is with size $(1 - k) \cdot (1 - m_2) \in (0, 1)$. This consumer segment maintains full awareness of both products independent of platform recommendations. Their purchase decisions remain unaffected by the marketplace's suggestion algorithms, as they systematically evaluate all available options in the product category. Also, the level of sustainability of a product j will not influence the purchase decision of this segment. A consumer i belonging to the non-green segment will buy both products to maximize her utility. The optimal purchase quantities are $q_{iA,IN} = [\alpha \cdot (1 - z) + o_i \cdot (1 + z) - p_A + zp_B] / [\beta \cdot (1 - z^2)]$ and $q_{iB,IN} = [\alpha \cdot (1 - z) - o_i \cdot (1 + z) - p_B + zp_A] / [\beta \cdot (1 - z^2)]$, where the subscript IN identifies informed, non-environmentally conscious consumers. Ceteris paribus, increased competition intensity (captured through higher values of parameter z) reduces equilibrium purchase quantities for both products. For this consumer segment, the resulting surplus is given by:

$$CS_{i,IN} = \frac{2\left[p_A^2 + p_B^2 + (2+z)o_i^2 + (2-z)\alpha^2 - p_B\left((2-z)\alpha - o_i(2+z)\right) - p_A\left((2-z)\alpha + o_i(2+z)\right)\right] - zp_Ap_B}{(4-z^2)\beta} \quad (2)$$

Segment 4: informed, green consumers. This segment is with size $(1 - k) \cdot m_2 \in (0, 1)$. This consumer segment demonstrates full product awareness independent of platform recommendations, with purchase decisions remaining unaffected by the marketplace's suggestion algorithms. These consumers systematically evaluate all available options within the product category when making purchasing choices. Also, since this segment already knows about the product well, they are fully aware of the green features of the two products and do not need to rely on the unified green badge issued by the third-party marketplace to buy

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green products. A consumer i belonging to the green segment will also buy both products to maximize her utility. However, only green products are purchased. The sub-optimal purchase quantities with the restriction that the product needs to be sustainable are $q_{iA,IG} = \mathbb{1}(f_A > 0) \cdot [\alpha \cdot (1 - z) + o_i \cdot (1 + z) - p_A + zp_B] / [\beta \cdot (1 - z^2)]$ and $q_{iB,IG} = \mathbb{1}(f_B > 0) \cdot [\alpha \cdot (1 - z) - o_i \cdot (1 + z) - p_B + zp_A] / [\beta \cdot (1 - z^2)]$, where the subscript IG denotes for informed, green consumers.. Ceteris paribus, an increase in competition intensity (captured by parameter z) reduces equilibrium purchase quantities for both products in the market.

3.4. Marketplace's consumer profiling and product inference

Consumer profiling. A distinctive capability of digital marketplaces is their capacity to collect behavioral data and construct individualized consumer preference profiles. Our model formalizes how the marketplace infers consumers' relative preferences between products A and B. For each consumer, the marketplace receives a noisy signal ôi based on the consumer's actual relative preference oi. To parsimoniously model the marketplace's inference precision, we assume the signal follows: $\hat{o}_i = o_i$ with probability σ, and $\hat{o}_i$ follows the uniform distribution on $[-\theta, \theta] \setminus \{o_i\}$ with probability $1 - \sigma$. The probability of the generated signal $\hat{o}_i$ conditional on the actual o_i is

$$\Pr\left(\hat{o}_i \leq x \,\middle|\, o_i\right) = \begin{cases} \frac{(x+\theta)(1-\sigma)}{2\theta}, \text{ if } x<o_i, \\ \sigma+\frac{(x+\theta)(1-\sigma)}{2\theta}, \text{ if } x\geq o_i. \end{cases} \tag{3}$$

It can be mathematically demonstrated that $\hat{o}_i$ follows a uniform distribution over $[-\theta, \theta]$ unconditionally. Using Bayesian updating, the marketplace's posterior belief about a consumer's true preference oi given the observed signal $\hat{o}_i$ can be expressed as:

$$\Pr\left(o_i \leq x \,\middle|\, \hat{o}_i\right) = \begin{cases} \frac{(x+t)(1-\sigma)}{2\theta}, \text{ if } x<\hat{o}_i, \\ \sigma+\frac{(x+t)(1-\sigma)}{2\theta}, \text{ if } x\geq \hat{o}_i. \end{cases} \tag{4}$$

The marketplace's conditional expectation of consumer preference is given by $E[o_i \mid \hat{o}_i] = \sigma \cdot o_i$., derived from its posterior belief. Here, $\sigma \in (0, 1]$ quantifies the inference precision, with three characteristic cases:

1) Uninformative Limit ($\sigma \to 0$): The signal becomes asymptotically uninformative, leaving the posterior identical to the uniform prior $U[-\theta, \theta]$.

2) Perfect Precision ($\sigma = 1$): The signal perfectly reveals true preferences ($\hat{o}_i = o_i$ with probability 1).

3) Imperfect Inference ($\sigma \in (0,1)$): The signal provides partial but incomplete information about o_i.

We interpret σ as the profiling accuracy parameter, representing the platform's technological capability to discern exact consumer preferences through data analytics.

Product inference. Similarly, we assume that the marketplace also infers the level of sustainability based on seller's disclosed information on the products. For each product j, the marketplace receives a noisy signal, $\hat{f}_j$, based on the seller's disclosed information and historical transaction data. We model the marketplace's inference of product sustainability levels through the following signal structure: for a product j with sustainability level $f_j \in [-1,1]$, the marketplace observes a signal $\hat{f}_j$ that equals fj with probability h, and follows a uniform distribution on $[-1,1] \setminus \{ f_j \}$ with probability $1-h$. Here, the parameter $h \in [0,1]$ captures the platform's accuracy in inferring true sustainability levels, where $h = 1$ represents perfect inference and $h = 0$ corresponds to completely random signals. This formulation allows the model to capture varying degrees of inference precision in sustainability assessment. However, since we are interested in the badge threshold $I_0 > 0$, we only look at the truncated probability on [0, 1], which becomes that $\hat{f}_j = f_j$ with probability $\gamma = 2h / (h + 1)$, and $\hat{f}_j$ follows the uniform distribution on $(0, 1] \setminus \{f_j\}$ with probability $1 - \gamma$. The probability of the generated signal f_j conditional on the actual f_j is

$$\Pr\left(\hat{f}_j \geq x \,\middle|\, f_j,\ x > 0\right) = \begin{cases} (1-\gamma)(1-x), & \text{if } x\leq f_j, \\ 1-(1-\gamma)x, & \text{if } x>f_j. \end{cases} \tag{5}$$

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The unconditional distribution for $\hat{f}_j$ is also a uniform distribution on [0, 1]. By Bayes rule, the marketplace's posterior belief for product j's level of sustainability f_j conditional on the signal $\hat{f}_j$ is

$$\Pr\left(f_j \geq x \,\middle|\, \hat{f}_j,\ x > 0\right) = \begin{cases} (1-\gamma)(1-x), & \text{if } x \leq \hat{f}_j, \\ 1-(1-\gamma)x, & \text{if } x > \hat{f}_j. \end{cases} \tag{6}$$

Based on the marketplace's posterior belief, the expectation of fj conditional on $\hat{f}_j$ is $E[f_j \mid \hat{f}_j] = \gamma \cdot f_j$. The probability $\gamma \in (0, 1]$ captures the precision and expertise of the marketplace's inference about products' level of sustainability when products are green.

3.5. Seller's inference on badge threshold

In addition, we assume that the sellers also infer the badge threshold decided by the marketplace based on the proportion of products badged within the same category and receives a noisy signal $\hat{I}$.

We model the seller's badge threshold inference process through a probabilistic signal structure. The seller receives a signal $\hat{I}$ that either: (1) perfectly matches the true threshold I_0 with probability ε, or (2) is randomly drawn from a uniform distribution over [0,1] excluding I_0 with probability 1-ε. This formulation, where $\Pr(\hat{I}|I_0) = \varepsilon$ when $\hat{I} = I_0$ and (1-ε) otherwise, captures varying degrees of inference precision through parameter $\varepsilon \in [0,1]$. The model encompasses three distinct cases: perfect information (ε=1), complete uncertainty (ε=0), and partial information (0<ε<1), providing a flexible framework to analyze certification threshold perceptions.

$$\Pr\left(\hat{I} \leq x \,\middle|\, I_0\right) = \begin{cases} (1-\varepsilon)x, & \text{if } x < I_0, \\ \varepsilon+(1-\varepsilon)x, & \text{if } x \geq I_0. \end{cases} \tag{7}$$

The unconditional distribution of the signal $\hat{I}$ follows a uniform distribution over the interval [0, 1]. Applying Bayesian updating, sellers derive their posterior belief about the true certification threshold I_0 conditional on observing $\hat{I}$ as follows:

$$\Pr\left(I_0 \leq x \,\middle|\, \hat{I}\right) = \begin{cases} (1-\varepsilon)x, & \text{if } x < \hat{I}, \\ \varepsilon+(1-\varepsilon)x, & \text{if } x \geq \hat{I}. \end{cases} \tag{8}$$

Based on the sellers' posterior belief, the expectation of I_0 conditional on $\hat{I}$ is $E[I_0 \mid \hat{I}] = \varepsilon \cdot I_0$. The probability $\varepsilon \in (0, 1]$ captures the precision of seller's inference about the badge threshold for the focal category.

4. Game structure and equilibrium outcome

We now describe the game structure and derive the equilibrium using backward induction.

4.1. Game structure

The game unfolds in three sequential stages. Initially, sellers A and B simultaneously determine their respective prices (p_A and p_B), incorporating the platform's commission rate r into their pricing strategies; they also design the level of sustainability of their own products, f_A and f_B, based on the marginal cost of incorporating and maintaining those sustainable features, and also based on their inferred badge threshold for products set by the marketplace within the same category. The game's second stage involves the marketplace: (1) observing sellers' prices, (2) assessing product sustainability levels, and (3) establishing the certification threshold while making personalized recommendations based on inferred consumer preferences ($\hat{o}_i$). The final stage features consumer purchases and profit realization. This structure captures three crucial green market dynamics: (i) the platform's endogenous threshold-setting and recommendation

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personalization, (ii) the influence of sellers' pricing and sustainability choices on platform decisions, and (iii) strategic price competition between sellers. The relationship between actual consumer preferences (o_i) and inferred signals ($\hat{o}_i$) will be detailed subsequently.

We characterize the symmetric pure-strategy perfect Bayesian equilibrium (PBE) where both sellers adopt identical pricing and sustainability levels in equilibrium. This imperfect information game reflects two key informational constraints: (1) neither the platform nor sellers observe consumers' true preference types o_i when making decisions, and (2) the platform cannot directly verify products' sustainability attributes. The equilibrium analysis accounts for these information asymmetries while maintaining the PBE requirement that all players' beliefs remain consistent with optimal strategies; and the seller does not know the badge threshold set by the marketplace. In our Perfect Bayesian Equilibrium framework, all players act sequentially rational - sellers and the marketplace optimize expected profits while accounting for consumers' utility maximization based on their private types o_i. Consumer payoffs are completely determined by: (1) product prices p_A and p_B, (2) individual preference parameter o_i, and (3) the recommended product. Crucially, consumers face no inference problem in equilibrium since they make purchase decisions with full information about all relevant variables.

4.2. Equilibrium outcome

The marketplace's recommendation system accounts for both sellers' pricing strategies, incentivizing them to compete for recommendations through price adjustments. The marketplace aims to maximize the total profit of green products, while the sellers aim to maximize their total net profit.

We model sellers' pricing decisions as endogenous choices and employ backward induction to solve the game, beginning our analysis from the platform's recommendation stage.

Consider an uninformed, non-green consumer i with the signal oi who will not be influenced by whether the product is badged or not. If the marketplace recommends product A to this consumer, its expected profit (denoted by $\Pi_{i,UN}$) from her conditional on her signal $\hat{o}_i$ is $E[\Pi_{iA,UN} \mid \hat{o}_i] = E[q_{iA,UN} \mid \hat{o}_i] \cdot rp_A = rp_A \cdot (\alpha + \sigma\hat{o}_i - p_A) / \beta$; alternatively, if the marketplace recommends product B to consumer i, its expected profit from her is $E[\Pi_{iB,UN} \mid \hat{o}_i] = rp_B \cdot (\alpha - \sigma\hat{o}_i - p_B) / \beta$. Since the goal of the marketplace is to maximize profit and we have already make the assumption that whether being badged is not a feature incorporated in the recommendation system, it will recommend product A to consumer i if and only if $E[\Pi_{iA,UN} \mid \hat{o}_i] \geq E[\Pi_{iB,UN} \mid \hat{o}_i]$, which gives the threshold as $\hat{o}_i \geq (p_A - p_B) \cdot (p_A + p_B - \alpha) / \sigma \cdot (p_A + p_B)$, which we denote as $\hat{o}_0(p_A, p_B) := (p_A - p_B) \cdot (p_A + p_B - \alpha) / \sigma \cdot (p_A + p_B)$.

Next, consider an uninformed, green consumer i with the signal oi who only purchase badged products. If the marketplace recommends product A to this consumer, its expected profit (denoted by $\Pi_{i,UG}$) from her conditional on her signal ôi and inferred product A's level of sustainability $\hat{f}_A$ is $E[\Pi_{iA,UG} \mid \hat{o}_i, \hat{f}_A] = E[q_{iA,UG} \mid \hat{o}_i, \hat{f}_A] \cdot rp_A = Pr(\hat{f}_A \geq I_0) \cdot rp_A \cdot (\alpha + \sigma\hat{o}_i - p_A) / \beta = (1 - 1/2\gamma I_0^2) \cdot rp_A \cdot (\alpha + \sigma\hat{o}_i - p_A) / \beta$; alternatively, if the marketplace recommends product B to consumer i, its expected profit from her is $E[\Pi_{iB,UG} \mid \hat{o}_i] = (1 - 1/2\gamma I_0^2) \cdot rp_B \cdot (\alpha - \sigma\hat{o}_i - p_B) / \beta$. Since the goal of the marketplace is to maximize profit and we have already make the assumption that whether being badged is not a feature incorporated in the recommendation system, it will recommend product A to consumer i if and only if $E[\Pi_{iA,UG} \mid \hat{o}_i] \geq E[\Pi_{iB,UG} \mid \hat{o}_i]$, which gives the threshold as $\hat{o}_i \geq (p_A - p_B) \cdot (p_A + p_B - \alpha) / \sigma \cdot (p_A + p_B)$, which we is the same as $\hat{o}_0(p_A, p_B) = (p_A - p_B) \cdot (p_A + p_B - \alpha) / \sigma \cdot (p_A + p_B)$ and obviously, in a symmetric equilibrium, $\hat{o}_0 = 0$.

Moreover, if sellers want to maximize total profit, we assume that the green segment of consumers are large enough and remove the situation where $f_j \leq 0$ as this will lead to zero demand from the green segment of consumers. Thus, from now on the optimal solutions are derived conditional on the fact that $f_j > 0$.

For the platform, the inferred demand of product A is based on f_j

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$$
\begin{aligned}
D_A^{(M)} &= k\left(1-m_1\right) \bullet \int_{\hat{o}_0}^{\theta} E\left[q_{iA,UN}\hat{o}_i\right] dF_{\hat{o}_i}\left(\hat{o}_i\right) + k m_1 \bullet \int_{\hat{o}_0}^{\theta} E\left[q_{iA,UG}\hat{o}_i,\ \hat{f}_A\right] dF_{\hat{o}_i}\left(\hat{o}_i\right) \\
&\quad + (1-k)\left(1-m_2\right) \int_{-\theta}^{\theta} E\left[q_{iA,IN}\hat{o}_i\right] dF_{o_i}\left(o_i\right) + (1-k) m_2 \int_{-\theta}^{\theta} E\left[q_{iA,IG}\hat{o}_i\right] dF_{o_i}\left(o_i\right) \\
&= \frac{k(1-m_1)}{2\beta}\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] + \frac{k m_1}{2\beta}\left(1-\gamma\right)\left(I_0+1\right)\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] \\
&\quad + \frac{(1-k)(1-m_2)}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right] + \frac{(1-k)m_2}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right] \\
&= \frac{k}{2\beta}\left[1-m_1+(1-\gamma)(1-I_0)m_1\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] + \frac{1-k}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right].
\end{aligned}
$$

where the first term is the expected purchase quantity from segment 1, the second term is the expected purchase quantity from segment 2, the third term is the expected purchase quantity from segment 3, and the fourth term is the expected purchase quantity from segment 4.

Similarly, the demand of product B is based on $\hat{f}_j$

$$
\begin{aligned}
D_B^{(M)} &= k \bullet \left(1-m_1\right) \bullet \int_{-\theta}^{\hat{o}_0} E\left[q_{iB,UN}\hat{o}_i\right] dF_{\hat{o}_i}\left(\hat{o}_i\right) + k \bullet m_1 \bullet \int_{-\theta}^{\hat{o}_0} E\left[q_{iB,UG}\hat{o}_i,\ \hat{f}_B\right] dF_{\hat{o}_i}\left(\hat{o}_i\right) + \\
&\quad \left(1-k\right) \bullet \left(1-m_2\right) \int_{-\theta}^{\theta} E\left[q_{iB,IN}\middle|\hat{o}_i\right] dF_{o_i} o_i) + \left(1-k\right) \bullet m_2 \int_{-\theta}^{\theta} E\left[q_{iB,IG}\middle|\hat{o}_i\right] dF_{o_i} o_i) \\
&= \frac{k}{2\beta}\left[1-m_1+(1-\gamma)(1-I_0)m_1\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_B-\frac{\sigma\hat{o}_0}{2}\right] + \frac{1-k}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_B+\frac{z}{1-z^2}p_A\right].
\end{aligned}
$$

where the first term is the expected purchase quantity from segment 1, the second term is the expected purchase quantity from segment 2, the third term is the expected purchase quantity from segment 3, and the fourth term is the expected purchase quantity from segment 4.

Now, we have the profit of marketplace as

$$
\begin{aligned}
\Pi_M = r p_A \bullet \frac{k}{2\beta}\left[1-m_1+(1-\gamma)\left(1-I_0\right)m_1\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] \\
+ r p_A \bullet \frac{1-k}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right] \\
+ r p_B \bullet \frac{k}{2\beta}\left[1-m_1+(1-\gamma)\left(1-I_0\right)m_1\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_B-\frac{\sigma\hat{o}_0}{2}\right] \\
+ r p_B \bullet \frac{1-k}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_B+\frac{z}{1-z^2}p_A\right],
\end{aligned}
\tag{11}
$$

based on which we can derive the first order derivative of I_0 as

$$
\frac{\partial \Pi_M}{\partial I_0} = -\frac{rk(1-\gamma)m_1}{2\beta}\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha p_A+\frac{\theta\sigma}{2}p_A-p_A^2-\frac{\sigma\hat{o}_0}{2}p_A+\alpha p_B+\frac{\theta\sigma}{2}p_B-p_B^2-\frac{\sigma\hat{o}_0}{2}p_B\right] \tag{12}
$$

In the symmetric equilibrium, we have $p^*_A = p^*_B = p$ and $\hat{o}_0 = 0$, thus

$$
\frac{\partial \Pi_M^*}{\partial I_0} = -\frac{rk(1-\gamma)m_1}{2\beta} p\left[\alpha+\frac{\theta\sigma}{2}-p\right] \tag{13}
$$

where the optimal I_0 depends on the equilibrium price.

To obtain the equilibrium price, we look at the demand and profit of each seller. For seller A, the inferred demand is based on $\hat{I}$

$$\begin{aligned}
D_A^{(S)} &= k(1-m_1) \bullet \int_{\hat{o}_0}^{\theta} E\left[q_{iA,UN}\hat{o}_i\right] dF_{\hat{o}_i}(\hat{o}_i) + km_1 \bullet \int_{\hat{o}_0}^{\theta} E\left[q_{iA,UG}\hat{o}_i,\ \hat{I}\right] dF_{\hat{o}_i}(\hat{o}_i) \\
&+ (1-k)(1-m_2)\int_{-\theta}^{\theta} E\left[q_{iA,IN}\hat{o}_i\right] dF_{o_i}(o_i) + (1-k)m_2 \int_{-\theta}^{\theta} E\left[q_{iA,IG}\hat{o}_i\right] dF_{o_i}(o_i) \\
&= \frac{k(1-m_1)}{2\beta}\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] + \frac{km_1}{2\beta}\left[\varepsilon+(1-\varepsilon)f_A\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] \\
&+ \frac{(1-k)(1-m_2)}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right] + \frac{(1-k)m_2}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right] \\
&= \frac{k}{2\beta}\left[1-m_1+\varepsilon m_1+(1-\varepsilon)m_1 f_A\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] + \frac{1-k}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right]..
\end{aligned}$$

where the first term is the expected purchase quantity from segment 1, the second term is the expected purchase quantity from segment 2, the third term is the expected purchase quantity from segment 3, and the fourth term is the expected purchase quantity from segment 4.

Now, we can derive the net profit of product A as

$$\begin{aligned}
\Pi_A &= rp_A \bullet \frac{k}{2\beta}\left[1-m_1+\varepsilon m_1+(1-\varepsilon)m_1 f_A\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p_A-\frac{\sigma\hat{o}_0}{2}\right] \\
&+ rp_A \bullet \frac{1-k}{\beta}\left[\frac{\alpha}{1+z}-\frac{\alpha}{1-z^2}p_A+\frac{z}{1-z^2}p_B\right] - c_g f_A - c_0,
\end{aligned} \tag{15}$$

Given symmetry, we have that $p^*_A = p^*_B = p$, $f^*_A = f^*_B = f$, and $\hat{o}_0 = 0$, which gives

$$\begin{aligned}
\Pi_A^* &= \frac{rk}{2\beta}\left[1-m_1+\varepsilon m_1+(1-\varepsilon)m_1 f\right]\left[\left(\alpha+\frac{\theta\sigma}{2}\right)p-p^2\right] \\
&+ \frac{r(1-k)}{\beta}\left[\frac{\alpha}{1+z}p+\frac{z-\alpha}{1-z^2}p^2\right] - c_g f - c_0,
\end{aligned} \tag{16}$$

based on which we can derive the FOC as

$$\frac{\partial \Pi_A^*}{\partial p} = \frac{rk}{2\beta}\left[1-m_1+\varepsilon m_1+(1-\varepsilon)m_1 f\right]\left[\alpha+\frac{\theta\sigma}{2}-2p\right] + \frac{r(1-k)}{\beta}\left[\frac{\alpha}{1+z}+\frac{z-\alpha}{1-z^2}p\right] = 0 \tag{17}$$

$$\frac{\partial \Pi_A^*}{\partial f} = \frac{rk(1-\varepsilon)m_1}{2\beta}p\left[\left(\alpha+\frac{\theta\sigma}{2}\right)-p\right] - c_g = 0 \tag{18}$$

To ensure maximization, we also need to add some limitations based on SOC

$$\frac{\partial^2 \Pi_A^*}{\partial p^2} = -\frac{rk}{\beta}\left[1-m_1+\varepsilon m_1+(1-\varepsilon)m_1 f\right] + \frac{r(1-k)}{\beta}\frac{z-\alpha}{1-z^2} \le 0 \tag{19}$$

$$\frac{\partial^2 \Pi_A^*}{\partial f^2} = 0 \le 0 \tag{20}$$

Thus, if $\partial\Pi_A^* / \partial p = 0$, we can derive the relationship between equilibrium price and product sustainability level as

$$p = \alpha + \frac{\theta\sigma}{2} - \frac{(k-1)[(2\alpha+\theta\sigma)(z-\alpha)+2(1-z)\alpha]}{2[k(1-z^2)[1-m_1+\varepsilon m_1+(1-\varepsilon)m_1 f]+(k-1)(z-\alpha)]} \tag{21}$$

where if we replace the probability of having a badge as Pbadge = $\Pr(f \ge I_0 \mid \hat{I}) = \varepsilon + (1-\varepsilon)f$, we have the following relationship

$$p = \alpha + \frac{\theta\sigma}{2} - \frac{(k-1)[(2\alpha+\theta\sigma)(z-\alpha)+2(1-z)\alpha]}{2[k(1-z^2)[1-m_1+m_1 P_{badge}]+(k-1)(z-\alpha)]} \tag{22}$$

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We can obviously see that price p increases with the probability of having a badge if

$$\frac{(k-1)[(2\alpha+\theta\sigma)(z-\alpha)+2(1-z)\alpha]}{k(1-z^2)m_1} > 0 \tag{23}$$

And the relationship between demand and the probability of having a badge becomes

$$D_A^{(S)} = \frac{k}{2\beta}\left[1-m_1+m_1 P_{badge}\right]\left[1+\frac{\hat{o}_0}{\theta}\right]\left[\alpha+\frac{\theta\sigma}{2}-p\right]+\frac{1-k}{\beta}\left[\frac{\alpha}{1+z}+\frac{z-\alpha}{1-z^2}p\right] \tag{24}$$

where we can see that seller's demand $D_A^{(S)}$ increases with the probability of having a badge if $p < \alpha + \theta\sigma / 2$, which is already satisfied in Equation (23). By symmetry, the same applies to the expected demand of product B, denoted as $D_B^{(S)}$. This is easy to understand, as increased probability of being badged for a product also means increased expected demand from uninformed, green consumers who rely on and only trust a unified green badge authorized by the marketplace when purchasing green products.

Also, if we look back at the profit maximization of the marketplace, we can find that if $p < \alpha + \theta\sigma / 2$ which is satisfied in Equation (23), we have that the FOC in Equation (13)

$$\frac{\partial \Pi_M^*}{\partial I_0} = -\frac{rk(1-\gamma)m_1}{2\beta}p\left[\alpha+\frac{\theta\sigma}{2}-p\right] < 0$$

which means that the smaller the threshold (i.e., the larger the proportion of products adopting the green badge), the larger the profit, and the optimal threshold is simply 0 in equilibrium.

To capture market competition, we also calculate the Herfindahl-Hirschman Index (HHI) as an indicator for market concentration, calculated by summing the squares of the market shares of all firms operating in a particular market; the indicator has been widely adopted in past research [26-27]. The HHI gives higher weights to larger firms with higher values indicate greater market concentration. The formula for calculating the Herfindahl–Hirschman Index is

$$HHI = \sum_{i=1}^{n} s_i^2 \tag{25}$$

where n is the number of firms in the market, and s_i is the market share of the i-th firm. In our model, we suppose that the rest of products in the same category having the demand of D_0. Thus, we have the HHI calculated as

$$HHI^{(S)} = \frac{(D_0)^2+\left(D_{A\ 0}^{(S)}\right)^2+\left(D_B^{(S)}\right)^2}{\left(D_0+D_A^{(S)}+D_B^{(S)}\right)^2} = \frac{(D_0)^2+2(D_E)^2}{(D_0+2D_E)^2} \tag{26}$$

which is based on the fact that in equilibrium $D_A^{(S)} = D_B^{(S)} = D_E$. If we look at the first order derivative based on the chain rule

$$\frac{\partial HHI^{(S)}}{\partial P_{badge}} = \frac{\partial HHI^{(S)}}{\partial D_E}\frac{\partial D_E}{\partial P_{badge}} = -\frac{4D_0(2D_E-D_0)(D_E+D_0)}{(D_0+2D_E)^4}\frac{\partial D_E}{\partial P_{badge}} \tag{27}$$

which we can see that this derivative is smaller than 0 if and only if $2D_E > D_0$, as we already prove that the larger the $D_A^{(S)}$ and $D_B^{(S)}$ in the equilibrium. Thus, if $2D_E > D_0$ and with the condition in Equation (23) is satisfied, HHI (market concentration level) decreases if the probability of having a badge increases, which alternatively means that market competition level increases with the proportion of the products having the badge (the probability of having a badge at the individual product level can be understood as the proportion of the products having the badge at the market level).

To summarize we have the following conclusion derived at the equilibrium: At the equilibrium, the price and demand of each product increases with the probability of adopting the unified green badge if condition

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in Equation (23) is satisfied; the level of market competition also increases with the probability with the proportion of the products having the badge in the same category if condition in Equation (23) is satisfied and the two products have total market share larger than 50% in the same category.

5. Conclusion and future work

In conclusion, the adoption of a unified green badge on a marketplace offers significant benefits, including increased sales to eco-conscious consumers, enhanced product visibility, improved brand trust, and opportunities for small brands to demonstrate sustainability. Our study addresses the gap in understanding the impact of green badges on seller competition in e-commerce platforms through a comprehensive three-stage game model.

Our findings indicate that at equilibrium, the adoption of the unified green badge can lead to higher product prices and demand, as well as intensified market competition, especially when the badge is prevalent within a product category. This game structure allows for personalized marketplace recommendations and considers the strategic pricing decisions of sellers, emphasizing the importance of sustainability.

For sellers, our research provides strategic insights into green certification and recommendations for optimizing pricing and product features post-badge adoption. For platforms like Amazon, the results highlight the CPF badge's potential to attract a broader customer base, particularly among older individuals and males.

Future research directions could include exploring the long-term effects of green badges on market dynamics, the impact of different types of eco-labels, and consumer behavior in response to multiple badges. Additionally, examining the role of technology in enhancing the accuracy and efficiency of badge implementation could further refine sustainable marketing strategies.

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