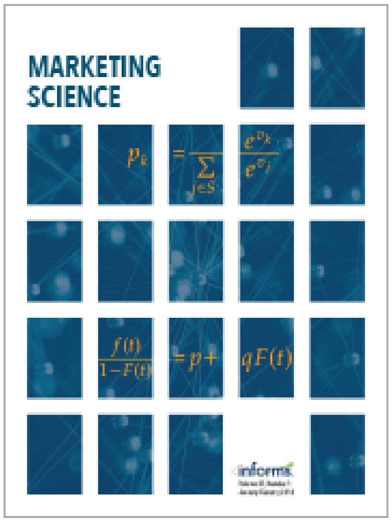

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Explaining Bundle-Framing Effects with Signaling Theory

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Abstract. Many sellers bundle add-ons (e.g., in-flight entertainment, hotel amenities) with core services (e.g., transportation, lodging). One surprising empirical finding is that consumers often believe bundle frames provide greater value than equivalent unbundle frames ($10 > $9 + $1) despite equal all-inclusive prices. Although these context or framing effects appear irrational in isolation, the bundle-framing effect might reflect market relationships caused by underlying seller motives. We show that bundling can signal information about product appeal, that is, popularity. Specifically, only sellers of wide-appeal (popular) add-ons (e.g., well-liked entertainment, sought-after hotel amenities, standard side salads, popular excursions) have an incentive to bundle their add-ons with their core products (e.g., flights, hotel rooms, restaurant entrées, cruise trips). By contrast, sellers of narrow-appeal (niche) add-ons (e.g., unorthodox entertainment, unpopular amenities, exotic side salads, unusual excursions) find that bundling is undesirable because they lose core revenue. Consequently, bundling can convey information about horizontally differentiated markets even when the total all-inclusive price equals that of unbundling. Perhaps some presumed consumer biases can reveal market relationships. Frames provide information about the framer.

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1. Introduction: Logical Equivalence ≠ Informational Equivalence

This paper investigates seemingly irrational consumer decisions involving bundle-framing or bundle-context effects. Substantial empirical evidence suggests the existence of framing effects (Kahneman and Tversky 2000), where logically equivalent presentations of an offer in a decision problem systematically cause people to make different responses or choices. We study framing effects in a bundling context, that is, "bundle-framing effects." Our research objective is to propose a rational reconstruction of the bundle-framing effect by showing that frames convey information.

We study bundle frames involving add-ons (e.g., free breakfast at hotels, free garage parking at restaurants) because of their special properties. First, consumers are usually less familiar with the value of add-ons than core products because add-ons are more numerous and often changing. Thus, product uncertainty is more prevalent for add-ons. Second, there are fewer reasons to bundle add-ons. For add-ons, unbundling is equivalent to partial mixed bundling because, by definition, the add-on is available only with the core. Hence, bundling seldom increases profits under certainty (see Appendix A). Third, rational consumers may realize that bundled add-ons disclose some unknown market information. Finally, Fruchter et al. (2011, p. 72) suggest "additional benefits" might be required for bundled add-ons (which they call "free") to be uniquely optimal. We suggest bundling can provide the benefit of signaling. That benefit may explain why some consumers prefer bundled add-ons even when they pay higher all-inclusive prices for bundles.

Given the same all-inclusive prices, unbundled add-ons seem logically superior to bundled add-ons. Bundling requires an add-on purchase, while unbundling gives consumers the option of either buying the core with the add-on (a bundle) or buying the core alone (not buying the add-on). Given the same total all-inclusive prices, consumers should prefer unbundle frames. For example, given an $1,100 cruise and an optional $50 city tour at a port of call, consumers should prefer separate prices to an all-inclusive price of $1,150, because having two prices gives them the option of not buying the excursion. In general, unbundled prices provide consumers greater flexibility.

However, the psychology literature reveals that consumers often more highly value products in a bundle frame (i.e., sold at a single price) than products sold separately (Gaeth et al. 1991, Johnson et al. 1999, Heeler et al. 2007, Palmeira and Srivastava 2013, McQuilken et al. 2015). More interestingly, considerable empirical evidence shows that some consumers prefer bundle frames to separate products systematically even when the bundle price is higher than the sum of the separate component prices (Naylor and Frank 2001, Repetti et al. 2015). These preferences for bundles are more prevalent for consumers unfamiliar with add-ons and for less frequently purchased product categories (Naylor and Frank 2001, Hamilton and Koukova 2008, Reinders et al. 2010, Arora 2011). We replicate the bundle-framing effects with an experiment showing that only the uninformed consumer group prefers a bundled option given the same monetary outlay (see the online appendix).

These empirical observations imply that the bundle frame provides some information about bundled products to consumers less familiar with the add-on. Although rationality supposedly implies equivalence of different frames, logical equivalence does not always mean informational equivalence. Presentation formats themselves can convey information. Remember, framing is a linguistics concept that involves the communication of subtle information (Lakoff and Johnson 1999). For example, sentences with the same exact words but slightly different inflections or cadence can convey dramatically different meanings. In real markets, consumers may use market relationships created by seller incentives when comparing otherwise equivalent frames. For example, when consumers believe a pricing format attempts to manipulate their decisions, they will prefer alternative formats (Kachersky and Kim 2010). Even frames that change consumer affect (e.g., lighting, music, other atmospherics) can indirectly influence consumer inferences (Iyer and Kuksov 2010). Therefore, framing can provide information about the framer, and that information can be subtle. In our case, consumers make inferences about seller incentives for bundling, which can influence their decisions. In real markets, the existence of one frame rather than another provides information.

We argue that the bundle-framing effect, which seems irrational in isolation, reflects learned market relationships regarding seller incentives. In the spirit of Wernerfelt (1995), consumers infer information from contexts based on experiences with similar contexts largely created by seller incentives. Consumers' ability to infer information may depend on experiences rather than fully understanding the market mechanism. Sellers may also learn the profitability of actions in a context by experimentation rather than understanding the theoretical mechanism creating that relationship. However, at equilibrium, it appears sellers and consumers act as if both understand the underlying market mechanism. Hence, we use standard signaling theory (e.g., Spence 1973, Bagwell and Riordan 1991) with full rationality to explain the bundle-framing effect.

The general argument that framing can convey information is not entirely new. One seminal study adopting a similar argument is that by Wernerfelt (1995). This study explains compromise effects (Simonson 1989), where many consumers prefer a middle option in choice sets. Using a fully rational model, Wernerfelt (1995) shows that seemingly irrational compromise effects can reflect learned relationships in real markets. For example, consumers of average size (the most popular size) in the population can rationally prefer the average size in an assortment of sizes without knowing actual physical sizes. In a follow-up study, Prelec et al. (1997) measure the importance of information in context effects. They find the inference effect accounts for two-thirds of the context effect and for one-half of the cross-category context-effect variance. Similarly, Kamenica (2008) considers endogenous compromise context effects as sellers attempt to manipulate consumers' beliefs. Kamenica (2008) finds that the compromise context effect and choice overload might arise as market equilibria when sellers respond to consumers' contextual inference in their product design. We study still another context effect where bundle frames can signal product popularity or appeal.

One potentially interesting implication of this research strand is that, rather than assuming consumer irrationality, consistent with evolutionary game theory, we can learn about real-world market relationships from so-called consumer biases. Like biological environments, markets can reflect complex interactions of players that result in learnable generalizations. When equivalent frames for consumers are not equivalent for the framer, like linguist frames, seller frames can convey information, and consumers can infer seller information from different frames.

Like this research strand, we use rational learning to explain when and why consumers may prefer a bundle frame to an equivalent unbundle frame. In theory, rational learning requires the equivalence between what consumers infer and what occurs in real markets. We show that the seemingly irrational bundle-framing effects can reflect market information: bundling can signal information about product popularity or appeal. For example, a bundled city tour at a particular port of call may be attractive to most cruise ship passengers (Seidl et al. 2007). By contrast, an unbundled scuba diving tour can be very attractive to one passenger type, while another type may find scuba terrifying and stressful (Merchant 2011).

Specifically, only sellers of popular or wide-appeal add-ons (e.g., well-liked entertainment, sought-after hotel amenities, standard side salads, popular excursion tours) have an incentive to bundle add-ons with their core (e.g., flights, hotel rooms, restaurant entrées, cruise trips). However, sellers of niche or narrow-appeal add-ons (e.g., unorthodox entertainment, unpopular amenities, exotic side salads, unusual excursion tours) find bundling undesirable, because bundling decreases core revenue from informed consumers. Thus, bundle frames reflect seller incentives to include popular products that appeal to most consumers, while unbundle frames reflect seller incentives to target niche markets. Different seller incentives to bundle allow uninformed consumers to use bundle frames to infer add-on popularity and expect bundled add-ons to match their tastes as well. For example, restaurants include the most popular sides and sauces with meals, airlines include the most popular amenities at their airport lounges, document/graphics software packages include the most popular fonts, etc. However, these sellers unbundle sides with narrow appeal, less popular amenities, niche fonts, respectively. Rational consumers can infer this market information and prefer bundle frames to unbundle frames even though the bundle frames provide no obvious logical benefit and are often logically (not informationally) inferior.

In real markets, interestingly, sellers seem to know that bundling can signal information about product appeal (popularity). Many hotels (e.g., Wynn Resorts, Westin Hotels and Resorts, and Fairmont Hotels and Resorts) announce that they bundle the most sought-after amenities in required resort fees. Holdnak and Jewett (1994) study the effect of bundling popular recreational services into the basic room rate at a large upscale resort and find bundling wide-appeal services increases user participation and resort revenue from these services. This finding suggests that resorts can use bundle frames to expand their add-on markets to include uninformed consumers who are uncertain about which amenities will be useful to them.

Moreover, David Martin Tait (2016), a commercial airline executive, observes that although ultra-low-cost airlines offered "à la cart options" (i.e., completely unbundled add-ons), some airlines have now moved to bundling the most popular add-ons, and passengers have reacted positively. All three current U.S. transcontinental legacy carriers (i.e., Delta, American, and United Airlines) claim to bundle the most popular add-ons (e.g., popular onboard wines, full episodes of hit shows, and box sets of the most popular TV shows). BMW, like other automakers, bundles wide-appeal add-ons (e.g., Bluetooth, cruise control, and power sources), while it unbundles niche add-ons like matching BMW Louis Vuitton custom-designed luggage that includes a BMW business case, garment bag, and two travel bags. Table 1 shows 20 products in 11 major categories from Amazon.com where the sellers claim to bundle their most popular add-ons.

We also contribute to the signaling literature. We find that prices do not reveal the product appeal (popularity) because, whether bundled or unbundled, all-inclusive prices can be the same in horizontally differentiated markets. Moreover, bundle signals can be costless to sellers, unlike other signaling mechanisms (e.g., advertising). Last, in our signaling framework, bundling can increase seller profits with popular add-ons and still improve consumer surplus, while traditional explanations for bundling (e.g., negatively correlated consumer valuations and entry barriers) often imply that sellers use bundling to extract consumer surplus.

This paper proceeds as follows. Section 2 provides a review of related research: bundling and signaling. Section 3 shows that bundling signals popular add-ons, while unbundling signals niche add-ons; that is, we explain both seller incentives for bundling and consumer preferences for bundles (bundle-framing effects). Section 4 provides conclusions and suggests implications.

2. Literature Review

2.1. Bundling Add-Ons

We show rational consumers can infer information about add-ons from whether they are bundled with the core. We contribute to the growing literature that examines add-ons. For example, Fruchter et al. (2011) explore a popular trade press view; bundled add-ons are free, while unbundled add-ons require fees. Their full-information model shows free add-ons can occur when consumers have similar valuations for add-ons. However, even then, bundling is no more profitable than unbundling with small fees. Thus, they conclude free add-ons may require bounded rationality such as zero price effects (Shampanier et al. 2007, Anderson 2009).

Given bounded rationality (hidden add-on prices), Ellison (2005) finds sellers can use add-on pricing to soften competition. When add-on prices are naturally unobservable, and sellers compete only on core price (see Ellison and Ellison 2009, Ellison and Wolitzky 2012), sellers can suffer from adverse selection—lower core prices can attract more price-sensitive consumers who will pay less for add-ons. Adverse selection lessens the incentive to compete on core prices. Surprisingly, unlike Ellison (2005), Lin (2017) finds that bundling can intensify competition in rational markets (with no hidden add-on fees). Lin (2017) suggests that low-quality hotels can bundle add-ons to compete with high-quality hotels. When the marginal costs of add-ons are small, low-quality hotels can bundle add-ons to increase total demand. However, screening is still more profitable for high-quality hotels, so they unbundle add-ons such as Wi-Fi.

Table 1. Bundling Popular Add-Ons (Amazon.com)

Core	Bundled wide-appeal add-ons
Arts, crafts, and sewing	
Tattoo airbrushing system (ASIN: B00HFELV5M)	Four face paints with different colors: "4 most popular custom body art water-based airbrush face paint colors"
Beauty	
Tanning machine	Four tan solutions: "four of Norvell's most popular solutions"
Diffuser	Three essential oils—peppermint, sweet orange, and lavender: "top 3 customer favorites"
Mach 3 razor	A chrome stand: "fits neatly on all vanities"
Electronics	
USB cable (ASIN: B006MWXZM0)	Four connector tips: "4 extra popular connector tips"
Photo inkjet printer	A 4×6 (inch) glossy print pack: "print popular photo sizes"
Health and personal care	
Antibacterial microfiber face cloths	A castor oil: "today's most popular cosmetic and beauty formulas"
Vibratory oral motor tool (ASIN: B001BC2C9S)	Oral motor tips: "most popular sensory oral motor tips"
Home and kitchen	
Mist air purifier (ASIN: B01IPKT95I)	Natural scented oils—eucalyptus, green tea, lavender, and juniper: "our best selling and most popular oils"
Cocktail shaker (ASIN: B0178M8DNS)	A recipe e-book: "lets you re-create popular cocktail beverages from the past and present"
Industrial and scientific	
Pet vacuum	A mini head: "and the popular mini head"
Iron holder (ASIN: B000TGNWCS)	A tip cleaner: "popular 599B tip cleaner"
Musical instruments	
49-key keyboard (ASIN: B003V4BFXI)	An educational software: "with popular songs"
Acoustic guitar	A song book: "songbook includes many hit songs from the past and present including hits from country, bluegrass . . . "
Patio, lawn, and garden	
Bird basket feeder	Bird suet cake: "popular suet blend attracts these [14] colorful songbirds: cardinals, chickadees, goldfinches . . . "
Sports and outdoors	
Swimming goggles (ASIN: B01LEQZPU8)	Nose bridges: "perfect comfortable fit for adults and kids"
Inflatable sports kayak (ASIN: B01N8VWB5T)	A movable kayak seat, a carry bag, a foot pump, and a repair kit: "everything you need to get started!"
Tools and home improvement	
Vacuum (ASIN: B00GTJO65G)	A crevice tool and a (wet or dry) floor tool: "most popular vacuum attachments"
Brewer (ASIN: B01LZZM4GL)	Coffee pods and a storage drawer: "packed with Keurig's most popular beverages and accessories"
Toys and games	
Quadcopter (drone)	A transmitter: "contains the popular TGY-i6 2.4 Ghz transmitter"

Note. ASIN, Amazon Standard Identification Numbers (accessed November 20, 2016).

While Ellison (2005) and Lin (2017) focus on boundedly rational and rational consumers, respectively, Shulman and Geng (2013) consider both consumer types. They find that in rational markets, high-quality sellers unbundle and gain from add-on fees, while low-quality sellers suffer. However, add-on fees can enhance low-quality sellers' profits, as boundedly rational consumers are unaware of add-on fees when purchasing the core.

Another research stream studies add-on bundling within product lines in rational markets. For example, Anderson and Dana (2009) derive conditions on quality provisions when a single quality (bundling) is optimal (see also Johnson and Myatt 2003). Shugan et al. (2017) find that a product line can increase profits with optimal bundling strategies. Their analytical and empirical findings suggest that lines with low core differentiation (e.g., airlines) bundle at the high-end of their line, while lines with high core differentiation (e.g., hotels) bundle at the low-end of their line. They suggest that sellers should strategically choose the quality of bundled add-ons to minimize line cannibalization.

Unlike these research streams that assume either rationality or lack thereof, we show rational markets with transparent prices can appear irrational until we recognize that consumers can use market relationships to infer seller types. Our signaling model for this inference provides a rational explanation for seemingly irrational consumer behavior involving bundle frames.

2.2. Signaling Product Information

The signaling literature considers how consumers can infer information from the nature of seller offers. For example, when sellers strengthen their marketing mix, consumers receive a signal of product information such as quality and low price (Milgrom and

Roberts 1986, Wernerfelt 1988, Bagwell and Riordan 1991, Moorthy and Srinivasan 1995, Milewicz and Herbig 1996, Anderson and Simester 1998, Jiang et al. 2014). Weakening the marketing mix can also serve as a signaling mechanism, for example, refraining from advertising (Kuksov et al. 2013), restricting production (Stock and Balachander 2005), demarketing (Miklós-Thal and Zhang 2013), etc. Franchising can also be a signal (Dant et al. 2007). These signals are often costly, unlike our bundle signaling.

We find that bundling can signal that add-ons have wide appeal. Appeal signaling differs from quality signaling in Choi (2003) and Sarin et al. (2003), who suggest bundling can signal quality. For example, a specific hunting excursion on African tours may be of higher quality than alternative hunting excursions (i.e., more games, greater variety of wildlife, better trophy potential). However, photographic safaris may be more popular than hunting excursions. Similarly, fast food restaurants bundle their most popular add-ons (e.g., fries, soft drinks) rather than their arguably highest-quality add-ons (e.g., garden salads, fresh juices).

Both Choi (2003) and Sarin et al. (2003) argue that bundling leverages information to aid new product introductions for firms with existing products. In a two-period model, Choi (2003) finds only high-quality sellers can irrevocably bundle high-quality new products with established products. A low first-period bundle price eliminates first-period profits for all sellers. However, after a first-period trial reveals quality, high-quality sellers obtain positive profits, but low-quality sellers obtain negative profits. Thus, bundling eliminates low-quality sellers.

We build on Choi's (2003) idea that bundling can signal, but our findings, private information, and signaling mechanism are very different. Unlike Choi's (2003), our add-on products differ in appeal (popular or niche) but not cost, which produces different equilibrium outcomes. (1) Add-ons with different appeal can coexist. (2) Either add-on type can be more profitable. (3) Whether the add-on is bundled signals appeal type. (4) Prices do not necessarily reveal the appeal type. In Choi (2003), low introductory bundle prices eliminate low-quality products; however, consumers still make inferences based on bundle and unbundle frames rather than prices. Our signaling allows market expansion in existing markets, not necessarily at high (or low) prices.

Next, our private information differs from past research (Choi 2003). We model horizontally differentiated markets where types reflect popularity rather than quality (i.e., seller costs). Niche products can have higher prices and costs than popular add-ons. Consider cruise lines' high-cost add-on scuba tours appealing to a niche market and more popular low-cost city tours that appeal to more passengers (e.g., the elderly, families with children, the less physically fit, and risk-averse passengers). The narrow-appeal scuba tours usually have much higher prices than the wide-appeal city tours. Hence, there is no obvious relationship between appeal and quality with respect to both costs and valuations. Our add-ons have the same quality and, perhaps, the same all-inclusive price.

Last, our signaling mechanism differs from that of Choi (2003) in many respects. First, we do not require Choi's (2003) key cost conditions for a separating equilibrium because our signaling mechanism is not cost driven. Second, Choi (2003) considers irrevocable bundling (common for software products), while we consider costless bundling (common for add-on products). Third, given a focus on new product introduction, Choi (2003) employs a repeat purchase mechanism (Kihlstrom and Riordan 1984) to enforce credibility. The repeat purchase is unnecessary in our single-period model.

3. Bundling Add-Ons Under Consumer Uncertainty

We consider bundle-framing effects for add-ons. Shugan el al. (2017) define an add-on as having three characteristics: (1) most consumers value the add-on less than the core; (2) sellers suffer greater losses from losing core sales than losing add-on sales; (3) add-ons can be free (some sellers) or require a fee (other sellers); and (4) add-ons are available only when consumers purchase the core. For example, inflight entertainment is available only with a flight ticket.

For add-ons, we find that unbundling is equivalent to partial mixed bundling, so unbundling weakly dominates bundling for all sellers but strictly dominates for some sellers (see Appendix A). That difference between sellers under certainty allows consumers to identify the add-on types under uncertainty. Therefore, favorable consumer responses to bundling over unbundling can be rational despite the same all-inclusive price (i.e., logical equivalence). This section derives conditions when bundling provides valuable information (beyond prices) about the add-on so that choosing the bundled add-on over the equivalent unbundled add-on is rational. Specifically, we show that there exists an equilibrium where bundling provides a separating signal of product popularity or appeal. Table 2 summarizes our notation.

Consider a monopolist who sells the core and add-on. The seller can bundle (B) the core and add-on or unbundle (U) the core and add-on. There exist two types of add-ons: wide appeal (w-type) and narrow appeal (n-type) add-ons. For example, intercontinental flights offer both popular add-ons (e.g., light snacks, preassigned seats) and services with more limited appeal (e.g., blankets, noise-canceling headphones).

Table 2. Notations

Variables	Description
Subscripts	
W, N	For the w-type and n-type, respectively
B, U	For bundling and unbundling strategies, respectively
e, h	For easy-to-please and hard-to-please consumer segments, respectively
C, a, A	For the core, add-on, and "all-inclusive" (i.e., core plus add-on), respectively
Exogenous parameters	
θ	The fraction of h-consumers
γ	The fraction of consumers who are unaware of the add-on type
q_w	Uninformed h's prior beliefs of the w-type add-on
$\tilde{v}$	The valuation for the core
α	The valuation for the add-on
F	The cumulative distribution function of $\tilde{v}$
f	The probability density function of $\tilde{v}$
Endogenous variables	
$q_w(\cdot)$	Uninformed h's posterior beliefs of the w-type add-on
p_{WB}, p_{NB}	Bundle price of w-types and n-types, respectively
p_{WC}, p_{NC}	Core price of w-types and n-types, respectively
p_{Wa}, p_{Na}	Add-on price of w-types and n-types, respectively
p_{WA}, p_{NA}	All-inclusive price for unbundled core and add-on of w-types and n-types, respectively
π_{WB}, π_{NB}	Bundling profits of w-types and n-types, respectively
π_{WU}, π_{NU}	Unbundling profits of w-types and n-types, respectively

Most passengers will pay for popular (w-type) add-ons, while only some will pay more for niche (n-type) add-ons. Of course, airlines that target different market segments might find different add-ons have wide appeal. In many other industries (e.g., hotels, restaurants), sellers provide both the w-type add-on (e.g., hotel bath care products, restaurant breadbaskets) and the n-type add-on (e.g., hotel golf courses, restaurant durian desserts).

For the w-type add-on, all consumers will pay $\alpha > 0$. For the n-type add-on, consider two consumer segments: easy-to-please (e) and hard-to-please (h). Segment e will pay α for the n-type add-on (add-on seeking). Segment h will pay zero. Let θ denote the fraction of segment h. The marginal costs for the core and both types of add-ons are normalized to zero (i.e., symmetric costs). As is apparent in Section 3.2, we show how bundling can signal w-types even when prices provide no information about add-on types, that is, different types have the same price. Note, we can find cases where sellers offer bundles at the same all-inclusive price; for examples, see Table 3. This appears to be a questionable strategy (without signaling) because consumers, who observe only the bundle offer, might not value the add-on and not purchase at the bundle price.

Given the two types of add-ons with different appeal, informed consumers know the appeal of add-ons, while uninformed consumers are uncertain. Informed or not, segment e values all add-ons. Thus, the uncertainty exists only for h. Let γ denote the fraction of h-consumers who are unaware of the add-on type. Let q_w and $q_w(\cdot)$ denote uninformed h's prior and posterior beliefs of the w-type add-on. Each fraction of consumer segment has unobserved heterogeneous valuations for the core, denoted $\tilde{v} > 0$. Let $F(\cdot)$ denote the cumulative distribution function of $\tilde{v}$. We normalize the market size to one.

Our signaling game begins with nature determining the add-on type. Observing the add-on type, the seller bundles or unbundles the add-on. Given the seller's offer, uninformed consumers update their posterior beliefs about the add-on type. Then, consumers decide whether to accept the seller's offer. To solve this signaling game, we adopt a perfect Bayesian equilibrium concept. Figure 1 shows the time line of the game.

3.1. Symmetric Information

As a benchmark, we consider $\gamma = 0$ (symmetric information). For B and U, w-types' profits are $\pi_{WB}(p_{WB}) = p_{WB}[1 - F(p_{WB} - \alpha)]$ and $\pi_{WU}(p_{WC}, p_{Wa}) = (p_{WC} + p_{Wa}) \cdot [1 - F(p_{WC} + p_{Wa} - \alpha)]$ for $p_{Wa} \le \alpha$, respectively, where p_{WB}, p_{WC}, and p_{Wa} denote the w-types' bundle, core, and add-on prices, respectively. Given homogeneous add-on valuations, w-types are indifferent between B and U; $\pi_{WU}(p_{WC}, p_{Wa} = p_{WA} - p_{WC}) = \pi_{WB}(p_{WB} = p_{WA})$, where $p_{WA} > p_{WC}$ denotes the w-types' unbundled all-inclusive price. The w-types' optimal prices, p^*_{WB} and (p^*_{WC}, p^*_{Wa}), should satisfy the following first-order conditions:

$$p^*_{WB} = \frac{1 - F(p^*_{WB} - \alpha)}{f(p^*_{WB} - \alpha)}, \quad p^*_{WA} = \frac{1 - F(p^*_{WA} - \alpha)}{f(p^*_{WA} - \alpha)}, \tag{1}$$

where $p^*_{WA} = p^*_{WC} + p^*_{Wa}$, $f = \partial F / \partial v$, and the hazard function of $\tilde{v}$, $f(v)/[1 - F(v)]$, is strictly increasing, making the optimal bundle price p^*_{WB} unique.

Similarly, n-types' profits are given by $\pi_{NB}(p_{NB}) = p_{NB} \cdot [\{1 - F(p_{NB})\}\theta + \{1 - F(p_{NB} - \alpha)\}(1 - \theta)]$ for B; for U, $\pi_{NU}(p_{NC}, p_{Na}) = p_{NC}[1 - F(p_{NC})]\theta + p_{NA}[1 - F(p_{NA} - \alpha)] \cdot (1 - \theta)$, where p_{NB}, p_{NC}, p_{Na}, and $p_{NA} = p_{NC} + p_{Na}$ denote the n-types' bundle, core, add-on, and unbundled all-inclusive prices, respectively. Then, there exist unique optimal prices, p^*_{NB} and (p^*_{NC}, p^*_{Na}), such that they satisfy the following first-order conditions:

$$p^*_{NB} = \frac{[1 - F(p^*_{NB})]\theta + [1 - F(p^*_{NB} - \alpha)](1 - \theta)}{f(p^*_{NB})\theta + f(p^*_{NB} - \alpha)(1 - \theta)}, \tag{2}$$

$$p^*_{NC} = \frac{1 - F(p^*_{NC})}{f(p^*_{NC})} \quad \text{and} \quad p^*_{NA} = \frac{1 - F(p^*_{NA} - \alpha)}{f(p^*_{NA} - \alpha)}, \tag{3}$$

where $p^*_{NA} = p^*_{NC} + p^*_{Na}$. Note,

$$0 < p^*_{NA} - p^*_{NC} = \frac{1 - F(p^*_{NA} - \alpha)}{f(p^*_{NA} - \alpha)} - \frac{1 - F(p^*_{NC} + \alpha - \alpha)}{f(p^*_{NC} + \alpha - \alpha)}, \quad p^*_{NA} < p^*_{NC} + \alpha;$$

that is, $v + \alpha - p^*_{NA} > v - p^*_{NC}$ for any core valuation $v > 0$ (i.e., incentive compatibility holds). Equations (1) and (2) lead to Lemma 1. All proofs are in Appendix B.

Table 3. Bundle Price = Core Price + Add-On Price (Amazon.com)

Core and list price when sold alone	Add-on and list price when sold alone	Total price when sold as bundle
Sea Eagle: Inflatable Explorer Kayak Price: \$999.00	Sea Eagle: QuikRow Kit Price: \$399.00	Price: \$1,399.00
Canon: ImageCLASS Laser Printer Price: \$77.54	Canon: 125 Toner Cartridge—Black Price: \$58.99	Price: \$136.53
DEWALT: Circular Saw Price: \$99.00	DEWALT: Lithium Ion Battery 2-Pack Price: \$149.00	Price: \$248.00
Epiphone: Les Paul Tribute Plus Electric Guitar Price: \$749.00	Marshall: Amp/Hosa: Guitar Cable Price: \$79.99 + \$7.95 = \$87.94	Price: \$836.94
DJI: Mavic Pro (Drone) Price: \$999.00	DJI: Mavic Battery Price: \$85.02	Price: \$1,084.02
Garmin: Vívoactive (Smartwatch) Price: \$134.00	Garmin: Heart Rate Monitor/Strap Price: \$24.78	Price: \$159.99
PowerBridge: Single Outlet (In-wall) Price: \$59.95	PowerBridge: HDMI Cables Price: \$9.00	Price: \$68.95
AmazonBasics: Paper and Credit Card Shredder Price: \$29.99	AmazonBasics: Lubricant Sheets Price: \$7.49	Price: \$37.48

Note. This table reports Amazon's prices on July 21, 2017.

Lemma 1. *If both sellers bundle, the w-type charges a higher bundle price than the n-type. Precisely,* $p^*_{WB} > p^*_{NB}$.

Lemma 1 considers the case when both sellers bundle, which is not an equilibrium. In this case, the w-type will charge a higher bundle price because bundling forces all consumers to consider buying both the core and add-on. Hence, w-types, with a higher fraction of consumers who value the add-on (achieve a better fit), have higher optimal bundle prices. When both seller types bundle, bundle prices might reveal the types. However, n-types strictly prefer unbundling that offers a product menu (core and bundle) for consumers with different tastes. From Equations (1) and (3), Lemma 2 follows.

Lemma 2. *The n-type strictly prefers unbundling, while the w-type is indifferent, where they charge the same all-inclusive prices. Precisely,* $\pi_{NU}(p^*_{NC}, p^*_{Na}) > \pi_{NB}(p^*_{NB})$ *and* $\pi_{WU}(p^*_{WC}, p^*_{Wa}) = \pi_{WB}(p^*_{WB})$; $p^*_{WB} = p^*_{NC} + p^*_{Na}$.

For the n-type add-on, unbundling divides consumers into two homogeneous groups based on their valuations: one that does not value the add-on and the other that values the add-on. Thus, n-types find it more profitable to unbundle the core and add-on to induce consumers to self-select. By contrast, w-types will obtain the same profits regardless of whether they bundle or unbundle because all consumers will pay for the popular add-ons. Given that w-type and n-type add-ons have the same quality, sellers charge the same all-inclusive prices. Hence, prices do not reveal the add-on type. However, given that n-types strictly prefer unbundling under certainty (Lemma 2), we can construct a perfect Bayesian equilibrium where bundling signals w-types.

3.2. Asymmetric Information

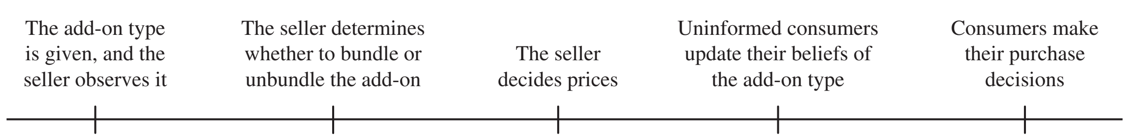
In a separating equilibrium, from Lemma 2, n-types unbundle. Then, w-types can signal their type by bundling; uninformed consumers infer that the bundled add-on is of the w-type. For Bayesian consistent posterior beliefs, n-types should have no incentive to mimic w-types. Precisely, $\pi_{NU}(p^*_{NC}, p^*_{Na}; q_w(U) = 0) \geq \pi_{NB}(p^*_{WB}; q_w(p^*_{WB}) = 1) = p^*_{WB}[\{1 - F(p^*_{WB})\}(1-\gamma)\theta + \{1 - F(p^*_{WB} - \alpha)\}\{1 - (1-\gamma)\theta\}]$, which implies a sufficient number of informed consumers; that is,

$$\gamma \leq \frac{p^*_{NC}[1 - F(p^*_{NC})] - p^*_{WB}[1 - F(p^*_{WB})]}{p^*_{WB}[F(p^*_{WB}) - F(p^*_{WB} - \alpha)]}. \qquad \text{(R1)}$$

The right-hand side of R1 is between 0 and 1 because p^*_{NC} is a unique maximizer of $p[1 - F(p)]$ and $p^*_{NC}[1 - F(p^*_{NC})] < p^*_{WB}[1 - F(p^*_{WB} - \alpha)]$; $p^*_{WB} - \alpha < p^*_{NC} < p^*_{WB}$. Proposition 1 follows.

Proposition 1. *Given* R1, *there exists a perfect Bayesian separating equilibrium, where the w-type bundles the core and add-on at* p^*_{WB}, *and the n-type unbundles at* (p^*_{NC}, p^*_{Na}). *Although consumers face the same all-inclusive price* $p^*_{WB} = p^*_{NC} + p^*_{Na}$, *consumers can still identify the n-type because only the n-type sells add-ons at a strictly positive price,* p^*_{Na}.

Figure 1. Time Line of the Signaling Game



Proposition 1 proves bundling can be a costless signal of wide appeal, unlike, for example, advertising. With a sufficiently large number of informed consumers, n-types will not forsake core profits from them to increase add-on profits from uninformed consumers by mimicking w-types' bundling. Thus, the core is a hostage that makes bundling a credible but costless signal. Given different seller incentives to bundle, uninformed h rationally infer that bundled add-ons have wide appeal (will match their tastes) and unbundled add-ons have narrow appeal (will not match their tastes). These rational inferences about matching information cause only uninformed consumers to perceive an incremental value from bundles. Hence, given the same all-inclusive price ($p^*_{WB} = p^*_{NC} + p^*_{Na}$), uninformed consumers buy add-ons only when bundled with the core.

In Proposition 1, the signaling message consists of the bundling strategy and price. To isolate the signal of bundling, let only the bundling strategy serve as a signaling message. Then, at a separating equilibrium, n-types never consider a bundling strategy at any price; $\pi_{NU}(p^*_{NC}, p^*_{Na}; q_w(U) = 0) \geq \pi_{NB}(\tilde{p}_{NB}; q_w(B) = 1)$, which requires a much larger fraction of informed consumers, that is,

$$\gamma \leq \frac{[g_0(p^*_{NC}) - g_0(\tilde{p}_{NB})] + [g_\alpha(p^*_{NA}) - g_\alpha(\tilde{p}_{NB})]odds(1-\theta)}{\tilde{p}_{NB}[F(\tilde{p}_{NB}) - F(\tilde{p}_{NB} - \alpha)]}, \tag{R2}$$

where $\tilde{p}_{NB}$ is the n-type's optimal bundle price given $q_w(B) = 1$, $g_\alpha(x) = x[1 - F(x - \alpha)]$, and $odds(\theta) = \theta/(1-\theta)$. Proposition 2 follows.

Proposition 2. *Given R2, there exists a perfect Bayesian separating equilibrium where bundling alone is a signal of the w-type add-on.*

Proposition 2 shows a restricted condition when consumers can infer the add-on type by observing only whether add-ons are bundled or unbundled; that is, bundling alone can signal appeal even when consumers do not observe the prices. From Propositions 1 and 2, three claims follow. First, given sufficiently small (large) valuations for add-ons, the profitability of unbundling increases as the line differentiation, α, increases (decreases; see Shugan et al. 2017). Then, n-types have less incentive to mimic bundling, and w-types require less informed h to signal (Claim 1). Next, given that only the bundle frame is the w-type's signaling message (regardless of price), for mimicking, n-types can charge their optimal bundle prices rather than w-types' optimal bundle price. Then, n-types have more incentive to mimic bundling because mimicking price is unnecessary. Hence, a separating equilibrium requires more informed h (Claim 2). Last, as θ decreases to 0 (i.e., the fraction of segment e increases to 1), the n-type's optimal bundle price ($\tilde{p}_{NB}$) approaches the w-type's optimal bundle price (p^*_{WB}); R2 converges to R1 (Claim 3). See Appendix B for formal statements and formal proofs of these claims.

We show that bundling can reveal appeal but not necessarily quality. When consumers have homogeneous preferences for add-ons, sellers can signal wide appeal by bundling. The bundling-signal credibly separates add-on markets, because with narrow-appeal add-ons (i.e., consumers having heterogeneous preferences), sellers unbundle add-ons to target their niche. Interestingly, bundling can signal wide appeal even when e consumers are willing to pay more for n-type add-ons than w-type add-ons (i.e., consumers who value all add-ons obtain greater utility from niche add-ons). Similarly, when segments e and h differ sufficiently in their valuations for n-type add-ons, n-types unbundle their add-ons to target e consumers and, by bundling add-ons, w-types can signal wide appeal (see the online appendix for a formal analysis).

We can also find a pooling equilibrium, where both types unbundle the add-on. However, in a pooling equilibrium, w-types earn strictly less profits ($q_w < 1$) compared to their bundle profits in a separating equilibrium ($q_w = 1$) because w-types lose the add-on sales from uninformed h. Therefore, the intuitive criterion (Cho and Kreps 1987) eliminates pooling equilibria as well as dominated separating equilibria (that can occur because we allow all possible out-of-equilibrium beliefs in the previous analysis). Proposition 3 follows.

Proposition 3. *Given R1, only the equilibrium in Proposition 1 survives the intuitive criterion.*

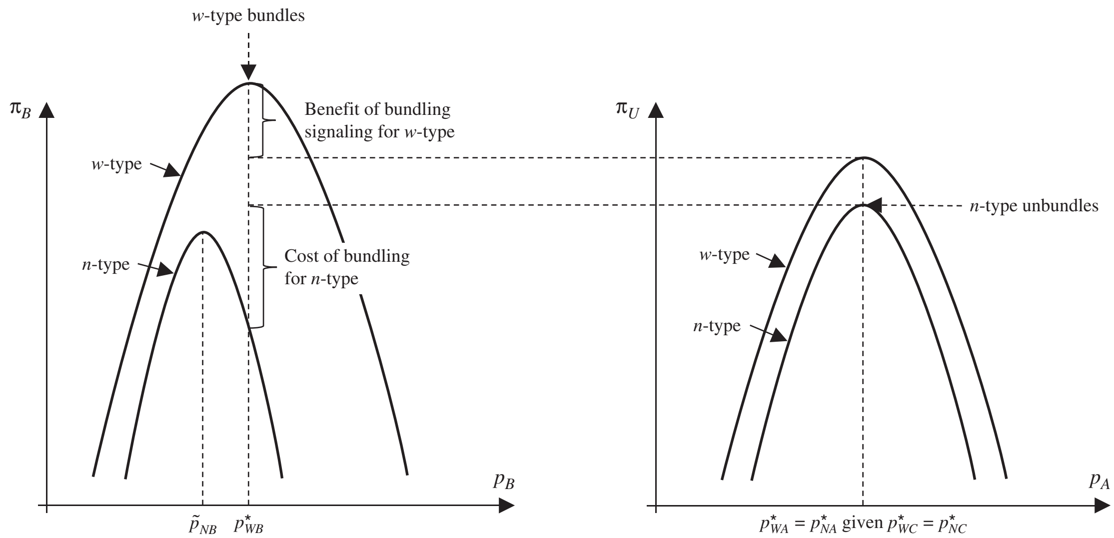
Figure 2 illustrates the profit advantage and disadvantage of bundling for each seller type necessary to maintain a unique bundle-as-a-signal equilibrium. In Appendix C, we develop an illustrative model to show equilibria in other parameter spaces, comparative statics, and social welfare analysis.

We established that it is rational for consumers to infer that bundled add-ons have wide appeal, while unbundled add-ons have narrow appeal, despite the same all-inclusive price. These rational inferences cause uninformed consumers to perceive an incremental benefit from bundle frames. We suggest managers can use bundling to signal their add-on appeal without incurring signaling costs. Other signaling strategies, such as advertising, can be more costly to implement.

4. Conclusions

We provide a rational explanation for the seemingly irrational bundle-framing effect; namely, given the same all-inclusive price for a core and add-on, uninformed consumers prefer a bundle frame to an unbundle frame, while informed consumers do not. Previous empirical studies replicate the bundle-framing effect in different settings and contexts. It seems irrational that

Figure 2. Bundling Signaling



some consumers prefer bundled add-ons to unbundled add-ons given the same all-inclusive price, because only unbundle frames provide an alternative of not buying the add-on. We develop a signaling model to show that these seemingly irrational preferences could be a rational response to inferred seller incentives to employ different frames; that is, the frame provides information about the framer. The existence of one frame rather than another in a real market can convey information.

Although two frames (bundle and unbundle) seem logically equivalent to rational consumers who want bundled components, these frames are not equivalent for sellers of different types of add-ons. We show that consumers unaware of the add-on types can infer those types from the incentives of sellers to use different frames. Specifically, consumers can infer the appeal of add-ons from sellers' incentive to bundle or unbundle the add-ons. For example, hotels include well-liked amenities, restaurants include their most favored side dishes, auto manufacturers include their most sought-after accessories, software makers include their most popular fonts, etc. Sellers unbundle unusual amenities, exotic sides, auto accessories with narrow appeal, niche fonts, etc.

Remember that with unbundling, consumers who buy the core can either buy the add-on or not. With bundling, consumers who buy the core must buy the add-on. Hence, sellers can bundle popular add-ons that appeal to the entire market because the wide-appeal add-ons match most consumers' tastes. However, the opportunity costs of bundling are high for add-ons that appeal to niche markets or fewer consumers, even though some consumers will pay high prices. Bundling the niche add-ons reduces core revenues from informed consumers who do not value those add-ons. Therefore, sellers have little incentive to bundle the narrow-appeal add-ons. Understanding different seller incentives to bundle, uninformed consumers can rationally infer that bundled add-ons have a wide appeal and would likely match their tastes, that is, provide a greater value than unbundled ones. However, informed consumers do not find this signaling information valuable. Thus, only uninformed consumers prefer bundles. Our findings complement those of Wernerfelt (1995), in which signaling the average (most popular) products explains, in part, the compromise effect, where we may interpret providing the product size as "cheap talk."

The signaling effects of bundling can also explain why sellers provide free add-ons. Fruchter et al. (2011) find free add-ons are equivalent to small fees that target all consumers. They suggest that we might require psychological benefits from zero prices or something "free" to obtain a unique "free" add-on equilibrium. However, preserving rationality in consumer choice, we provide a rational reason for bundling (offering free add-ons): sellers can expand add-on markets to include uninformed consumers by signaling add-on popularity.

Moreover, we show that, given the same quality (i.e., horizontal differentiation), prices do not necessarily reveal seller types because sellers of all types adopt the same prices. However, bundling, even alone, can signal wide appeal and is costless to sellers, unlike other signaling devices (e.g., advertising). Because our signal is appeal or popularity rather than quality, our signaling mechanism is not driven by cost differences associated with differences in quality. Last, traditional explanations suggest that sellers extract consumer surplus by bundling. However, we find that bundling helps consumers make better choices by revealing the add-on popularity. Thus, bundling can increase the profits of sellers with popular add-ons and still improve consumer surplus (see Appendix C).

In sum, we show that framing reveals information about the framer. Uninformed consumers may prefer bundle frames because bundling signals the incentives of sellers with popular add-ons. Thus, signaling can help these sellers improve their profits, providing another profitable benefit from bundling. Our findings are particularly important in product categories where, in each period, new uninformed consumers enter the market and sellers offer many different add-ons.

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Appendix A. Without Uncertainty: Bundling, Unbundling, and Mixed Bundling

We show that unbundling add-ons is equivalent to the partial mixed bundling of add-ons. It might appear that sellers have three pricing strategies in a one-period game: bundling (selling the core and add-on at one price), unbundling (selling the core and add-on at separate prices), and mixed bundling (selling the core at one price and the bundle at another price). However, unbundling and partial mixed bundling provide consumers with the same options: buying only the core and buying the add-on with the core (the bundle). Thus, unbundling creates a product line, which weakly dominates having a single bundle product, or bundling at best provides infinitesimally greater profits under very specific conditions. Unless we introduce other factors (e.g., signaling), having multiple products seems best.

Consider a monopolist selling a core and an add-on in one period. A unit mass of consumers each buy at most one unit. Consumers have unobserved heterogeneous valuations for the core and add-on, denoted by $\tilde{\nu}$ and $\tilde{\alpha}$, respectively. Let $f(\nu,\alpha)$ denote the joint density for $(\tilde{\nu},\tilde{\alpha})$. We assume $(\tilde{\nu},\tilde{\alpha})$ is a continuous random vector on a compact set, K, where given any $(\nu,\alpha)\in K$, $\nu\geq\underline{\nu}$ and $\alpha\geq\underline{\alpha}$ for some constants $\underline{\nu}$, $\underline{\alpha}>0$. Without loss of generality, consumers' reservation utility and marginal costs are zero.

For bundling (B), let p_B denote the bundle price. Equation (A.1) shows the bundling profits

$$\pi_B(p_B)=p_B\int_{K_B(p_B)} f\,d\nu\,d\alpha, \tag{A.1}$$

where $K_B(p_B)=\{(\nu,\alpha)\in K\mid p_B\leq\nu+\alpha\}$. For unbundling ($U$), let p_C and p_a denote the core and add-on prices, respectively. Consumers buy the core if and only if $p_C+p_a\leq\nu+\alpha$ or $p_C\leq\nu$. Given a core purchase, consumers buy the add-on if and only if $p_a\leq\alpha$. Thus, the unbundling profits are

$$\pi_U(p_C,p_a)=p_C\int_{K_B(p_C+p_a)\cup K_C(p_C)} f\,d\nu\,d\alpha + p_a\int_{K_B(p_C+p_a)\cap K_a(p_a)} f\,d\nu\,d\alpha, \tag{A.2}$$

where $K_C(p_C)=\{(\nu,\alpha)\in K\mid p_C\leq\nu\}$ and $K_a(p_a)=\{(\nu,\alpha)\in K\mid p_a\leq\alpha\}$. For mixed bundling ($M$), given the core and bundle prices (p_C and p_B), consumers buy the core if and only if $p_C\leq\nu$ and $\nu-p_C>(\nu+\alpha)-p_B$. Consumers buy the bundle if and only if $p_B\leq\nu+\alpha$ and $(\nu+\alpha)-p_B\geq\nu-p_C$. Thus, the mixed bundling profits are

$$\pi_M(p_C,p_B)=p_C\int_{K_C(p_C)\cap K_M^c(p_C,p_B)} f\,d\nu\,d\alpha + p_B\int_{K_B(p_B)\cap K_M(p_C,p_B)} f\,d\nu\,d\alpha, \tag{A.3}$$

where $K_M(p_C,p_B)=\{(\nu,\alpha)\in K\mid(\nu+\alpha)-p_B\geq\nu-p_C\}$. From Equations (A.2) and (A.3), Lemma A.1 follows.

Lemma A.1. *Partial mixed bundling is equivalent to unbundling.*

Proof. Given p_C and p_a for U, we will show $\pi_M(p_C,p_C+p_a)=\pi_U(p_C,p_a)$. By definition, we have $\pi_M(p_C,p_C+p_a)=p_C\cdot\int_{K_C(p_C)\cap K_M^c(p_C,p_C+p_a)} f + (p_C+p_a)\int_{K_B(p_C+p_a)\cap K_M(p_C,p_C+p_a)} f = p_C\int_G f + p_a\int_{K_B(p_C+p_a)\cap K_a(p_a)} f$, where $G=[K_C(p_C)\cap K_a^c(p_a)]\cup[K_B(p_C+p_a)\cap K_a(p_a)]$ because $K_M(p_C,p_C+p_a)=K_a(p_a)$ and $[K_C(p_C)\cap K_a^c(p_a)]\cap[K_B(p_C+p_a)\cap K_a(p_a)]=\phi$. Hence, we only need to show $G=K_B(p_C+p_a)\cup K_C(p_C)$. Clearly, $G\subset K_B(p_C+p_a)\cup K_C(p_C)$. To show $K_B(p_C+p_a)\cup K_C(p_C)\subset G$, choose any $(\nu,\alpha)\in K_B(p_C+p_a)\cup K_C(p_C)$.

Case 1. $(\nu,\alpha)\in K_B(p_C+p_a)$. Suppose $(\nu,\alpha)\in K_a(p_a)$. Clearly, $(\nu,\alpha)\in K_B(p_C+p_a)\cap K_a(p_a)\subset G$. Suppose $(\nu,\alpha)\in K_a^c(p_a)$, that is, $p_a>\alpha$. Then, $(\nu,\alpha)\in K_C(p_C)$; otherwise, $p_C>\nu$ and $p_C+p_a>\nu+\alpha$, which is contradictory to $(\nu,\alpha)\in K_B(p_C+p_a)$. Hence, $(\nu,\alpha)\in K_C(p_C)\cap K_a^C(p_a)\subset G$.

Case 2. $(\nu,\alpha)\in K_C(p_C)$. Suppose $(\nu,\alpha)\in K_a^c(p_a)$. Clearly, $(\nu,\alpha)\in K_C(p_C)\cap K_a^c(p_a)\subset G$. Suppose $(\nu,\alpha)\in K_a(p_a)$, that is, $p_a\leq\alpha$. Then, $p_C+p_a\leq\nu+\alpha$. Hence, $(\nu,\alpha)\in K_B(p_C+p_a)\cap K_a(p_a)\subset G$. Q.E.D.

Lemma A.1 implies that, under certainty, the profits from unbundling are weakly greater than the bundle profits, because, unlike bundling, unbundling facilitates screening (e.g., Soberman 2003, Banciu et al. 2010, Lin 2017). Moreover, unlike independent components, consumers should always buy add-ons with the core regardless of whether they are bundled or not, diminishing the advantage of pure bundling that inhibits consumers from buying individual products separately. Proposition A.1 follows.

Proposition A.1. *Without signaling, when consumers have positive valuations for both the core and add-on, bundling produces no greater profits than unbundling; precisely, there are p_C and p_a such that $\pi_U(p_C,p_a)\geq\pi_B(p_B^*)$, where p_B^* denotes an optimal bundle price.*

Proof. Let $p_a^o=\underline{\alpha}>0$ and $p_C^o=p_B^*-p_a^o$. Note that p_B^* exists because π_B is continuous on a compact set. Given p_B^*, there exists $(\nu_1,\alpha_1)\in K$ such that $p_B^*=\nu_1+\alpha_1$; $p_C^o=\nu_1+\alpha_1-p_a^o\geq\underline{\nu}+\underline{\alpha}-p_a^o=\underline{\nu}>0$. Then, we consider unbundling the core and add-on at $(p_C^o>0,p_a^o>0)$; $\pi_U(p_C^o,p_a^o)\geq p_C^o\int_{K_B(p_C^o+p_a^o)} f + p_a^o\int_{K_B(p_C^o+p_a^o)\cap K_a(\underline{\alpha})} f=(p_C^o+p_a^o)\int_{K_B(p_C^o+p_a^o)} f=\pi_B(p_B^*)$. Q.E.D.

Without the positive-value condition in Proposition A.1, Corollary A.1 proves that the profit improvement of B is arbitrarily small; in theory, the seller is at best indifferent between U and B.

Corollary A.1. *Given $\underline{\alpha} \ge 0$, for any $\varepsilon > 0$, there are p_C and p_a such that $\pi_B(p_B^*) - \pi_U(p_C, p_a) < \varepsilon$.*

Proof. We only need to consider $\underline{\alpha} = 0$. Let $p_C^o = p_B^* - \xi$ and $p_a^o = \xi$ for any $0 < \xi < p_B^*/2$. Then, $\pi_U(p_C^o, p_a^o) \ge p_C^o \int_{K_B(p_C^o + p_a^o)} f + p_a^o[\int_{K_B(p_C^o+p_a^o)} f - \int_{K_a^c(p_a^o)} f] \ge p_B^* \int_{K_B(p_B^*)} f - p_a^o \|f\|_\infty \int_{K_a^c(p_a^o)} 1 \ge \pi_B(p_B^*) - \|f\|_\infty \xi^2 \bar{\nu}$, where $\bar{\nu} = \sup\{\nu: (\nu, \alpha) \in K\}$. Given $\varepsilon > 0$, choose any $\xi < [\varepsilon/(2\bar{\nu}\|f\|_\infty)]^{1/2}$. Then, $\pi_B(p_B^*) - \pi_U(p_C^o, p_a^o) \le \|f\|_\infty \xi^2 \bar{\nu} < \varepsilon/2 < \varepsilon$. Q.E.D.

Our results highlight that the bundling of add-ons differs from the bundling of independent products. This difference can be dramatic. For example, bundling can be strictly more profitable than unbundling given negatively correlated valuations or other distributions of valuations where bundling decreases heterogeneity (e.g., Adams and Yellen 1976). However, the following example shows that a strong negative correlation can lead to the opposite for add-ons.

Example. When consumer valuations for the core and add-on exhibit a strong negative correlation, unbundling can be more profitable than bundling. Consider uniformly distributed add-on valuations, that is, $\tilde{\alpha} \sim U(\underline{\alpha}, \bar{\alpha})$, and core valuations negatively correlated with the add-on valuations, that is, $\tilde{\nu} = V + \beta\tilde{\alpha}$ and $-1 < \beta < 0$, where $\bar{\alpha} > 2\underline{\alpha} > 0$ and $-\beta\bar{\alpha} < V < (1+\beta)(\bar{\alpha} - 2\underline{\alpha})$.

Proof. Given $\tilde{\alpha} \sim U(\underline{\alpha}, \bar{\alpha})$, $\tilde{\nu} = V + \beta\tilde{\alpha} \sim U(\underline{\nu}, \bar{\nu})$, where $\nu = V + \beta\bar{\alpha}$ and $\bar{\nu} = V + \beta\underline{\alpha}$. Let $\tilde{b} = \tilde{\nu} + \tilde{\alpha}$. Then, we have $\tilde{b} = V + (1+\beta)\tilde{\alpha} \sim U(V + (1+\beta)\underline{\alpha}, V + (1+\beta)\bar{\alpha})$. For B, $\pi_B(p_B) = p_B[V + (1+\beta)\bar{\alpha} - p_B]r_B$, where $r_B = [(1+\beta)(\bar{\alpha} - \underline{\alpha})]^{-1}$. Therefore, the optimal bundle price and profits are $p_B^* = [V + (1+\beta)\bar{\alpha}]/2$ and $\pi_B(p_B^*) = (p_B^*)^2 r_B$. Let $p_C^o = [\beta(1+\beta)\bar{\alpha} + (2+\beta)V]/[2(1+\beta)]$ and $p_a^o = [(1+\beta)\bar{\alpha} - V]/[2(1+\beta)]$. Check $\underline{\nu} < p_C^o < \bar{\nu}$, $\underline{\alpha} < p_a^o < \bar{\alpha}$, and $p_C^o + p_a^o = p_B^*$. For $\tilde{\nu} \le p_C^o$, $\tilde{\nu} + \tilde{\alpha} = [(1+\beta)\tilde{\nu} - V]/\beta \ge [(1+\beta) \cdot p_C^o - V]/\beta = p_B^*$ and $\tilde{\alpha} = (\tilde{\nu} - V)/\beta \ge (p_C^o - V)/\beta = p_a^o$. For $\tilde{\nu} > p_C^o$, $\tilde{\alpha} < p_a^o$. Thus, $\pi_U(p_C^o, p_a^o) = p_C^o + p_a^o(p_C^o - V - \beta\bar{\alpha})/[\beta(\underline{\alpha} - \bar{\alpha})] = p_C^o + p_a^o p_B^* r_B = p_C^o(1 - p_B^* r_B) + (p_B^*)^2 r_B > \pi_B(p_B^*)$ because $p_B^* r_B < 1$. Q.E.D.

Appendix B. Proofs

Proof of Lemma 1. Let $H = (1-F)/f$. Suppose $p_{NB}^* \ge p_{WB}^*$. Then, $p_{NB}^* \ge H(p_{WB}^* - \alpha) \ge H(p_{NB}^* - \alpha) > ([1 - F(p_{NB}^*)]\theta + [1 - F(p_{NB}^* - \alpha)](1-\theta))/(f(p_{NB}^*)\theta + f(p_{NB}^* - \alpha)(1-\theta))$ because H is strictly decreasing. From Equation (2), it is a contradiction. Consequently, $p_{WB}^* > p_{NB}^*$. Q.E.D.

Proof of Lemma 2. From Equation (1), $\pi_{WB}(p_{WB}^*) = p_{WB}^*[1 - F(p_{WB}^* - \alpha)] = p_{WA}^*[1 - F(p_{WA}^* - \alpha)] = (p_{WC}^* + p_{Wa}^*)[1 - F(p_{WC}^* + p_{Wa}^* - \alpha)] = \pi_{WU}(p_{WC}^*, p_{Wa}^*)$ for any $p_{WC}^* = p_{WA}^* - p_{Wa}^* > 0$ and $0 < p_{Wa}^* < \alpha$. Next, we will show $\pi_{NU}(p_{NC}^*, p_{Na}^*) > \pi_{NB}(p_{NB}^*)$. Since $(1-F)/f$ is strictly decreasing, p_{WB}^* and (p_{NC}^*, p_{Na}^*) are unique and $p_{Na}^* > 0$. Note $p_{NC}^* + p_{Na}^* = p_{NA}^* = p_{WB}^*$. Then, $\pi_{NU}(p_{NC}^*, p_{Na}^*) = p_{NC}^*[1 - F(p_{NC}^*)]\theta + p_{NA}^*[1 - F(p_{NA}^* - \alpha)](1-\theta) \ge p_{NB}^*[1 - F(p_{NB}^*)]\theta + p_{WB}^*[1 - F(p_{WB}^* - \alpha)](1-\theta) > p_{NB}^*[\{1 - F(p_{NB}^*)\}\theta + \{1 - F(p_{NB}^* - \alpha)\}(1-\theta)] = \pi_{NB}(p_{NB}^*)$ because $p_{WB}^* > p_{NB}^*$ (from Lemma 1), and p_{WB}^* is unique. Q.E.D.

Proof of Propositions 1 and 2. Given R1 and R2, the proofs are straightforward from Lemma 2. Q.E.D.

Proof of Proposition 3. Consider separating equilibria for any $p_{WB} \ne p_{WB}^*$. Then, we have $\pi_{WB}(p_{WB}; q_w(p_{WB}) = 1) < \pi_{WB}(p_{WB}^*; q_w(p_{WB}^*) = 1)$ because the optimal bundle price p_{WB}^* is unique. Given R1, consumers know that n-types never bundle at p_{WB}^*. Thus, w-types have an incentive to deviate to charge p_{WB}^*. Next, consider pooling equilibria. No bundling pooling equilibrium exists, because for any $0 < q_w < 1$, w-types have higher bundle prices than n-types, so given any bundle price, either of the sellers will deviate to charge the optimal bundle price. For unbundling pooling equilibria, we have $\pi_{WU}(p_{WC}, p_{Wa}; q_w < 1) = p_{WC}[1 - F(p_{WC})]\gamma\theta + (p_{WC} + p_{Wa}) \cdot [1 - F(p_{WC} + p_{Wa} - \alpha)](1 - \gamma\theta) < p_{WA}[1 - F(p_{WA} - \alpha)] \le p_{WA}^*[1 - F(p_{WA}^* - \alpha)] = \pi_{WB}(p_{WB}^*; q_w(p_{WB}^*) = 1)$. Q.E.D.

Claim 1. *Given sufficiently small α, R1 becomes less restricted as α increases. Similarly, given sufficiently large α, R1 becomes less restricted as α decreases.*

Proof. Let RHS_1 denote the right-hand side of R1. Differentiating RHS_1 with respect to α,

$$\frac{\partial \mathrm{RHS}_1}{\partial \alpha} = \left(f(p_{WB}^*)[p_{WB}^* - H(p_{WB}^*)](1 - \mathrm{RHS}_1)\frac{\partial p_{WB}^*}{\partial \alpha} - \mathrm{RHS}_1 \cdot p_{WB}^* f(p_{WB}^* - \alpha) \right) \cdot (p_{WB}^*[F(p_{WB}^*) - F(p_{WB}^* - \alpha)])^{-1}. \tag{B.1}$$

Differentiating Equation (1) with respect to α, $\partial p_{WB}^*/\partial\alpha = H'(p_{WB}^* - \alpha)(\partial p_{WB}^*/\partial\alpha - 1)$. Thus, $\partial p_{WB}^*/\partial\alpha = -H'(p_{WB}^* - \alpha)/[1 - H'(p_{WB}^* - \alpha)] > 0$ ($\because H' < 0$). Check $\lim_{\alpha\to 0} \mathrm{RHS}_1 = 0$. We need to show only $\lim_{\alpha\to 0} \partial\mathrm{RHS}_1/\partial\alpha > 0$. From (B.1), $\lim_{\alpha\to 0} \partial\mathrm{RHS}_1/\partial\alpha = [H'(p_{NC}^*)]^2/[2p_{NC}^*\{1 - H'(p_{NC}^*)\}] > 0$ because $\lim_{\alpha\to 0} p_{WB}^* = p_{NC}^*$ and $\lim_{\alpha\to 0} \partial p_{WB}^*/\partial\alpha = -H'(p_{NC}^*)/[1 - H'(p_{NC}^*)]$. We can similarly prove for the case of a sufficiently large α. Q.E.D.

Claim 2. *R2 is a more restricted condition than R1.*

Proof. Suppose R2 holds. Then, $\pi_{NU}(p_{NC}^*, p_{Na}^*; q_w(U) = 0) \ge \pi_{NB}(\tilde{p}_{NB}; q_w(B) = 1) \ge \pi_{NB}(p_{WB}^*; q_w(p_{WB}^*) = 1)$. Thus, R1 also holds. Q.E.D.

Claim 3. *R2 converges to R1 as θ goes to 0.*

Proof. Note that the value $\tilde{p}_{NB}$ maximizes $\pi_{NB}(p_{NB}; q_w(B) = 1) = p_{NB}[\{1 - F(p_{NB})\}(1-\gamma)\theta + \{1 - F(p_{NB} - \alpha)\}\{1 - (1-\gamma)\theta\}]$. Thus, $\tilde{p}_{NB}$ satisfies the following first-order condition:

$$\tilde{p}_{NB} = \frac{[1 - F(\tilde{p}_{NB})](1-\gamma)\theta + [1 - F(\tilde{p}_{NB} - \alpha)][1 - (1-\gamma)\theta]}{f(\tilde{p}_{NB})(1-\gamma)\theta + f(\tilde{p}_{NB} - \alpha)[1 - (1-\gamma)\theta]}. \tag{B.2}$$

Let $L = \lim_{\theta\to 0} \tilde{p}_{NB}$. From (B.2), $L = H(L - \alpha)$. Thus, $L = p_{WB}^*$. Then, as $\theta \to 0$, the right-hand side of R2 (RHS_2) converges to RHS_1, that is, $\lim_{\theta\to 0} \mathrm{RHS}_2 = \mathrm{RHS}_1$. Q.E.D.

Appendix C. An Illustrative Model

We develop a simple model with closed-form solutions for other equilibria, comparative statics, and social welfare analysis. We consider a certain fraction of uninformed h who believe that the add-on is of the w-type, denoted by q. More precisely, uninformed consumers' prior beliefs of w-type are either $1 - \varepsilon$ or ε for an arbitrary small $\varepsilon > 0$. Thus, uninformed consumers still update their posterior beliefs, while we can eliminate the complexity of pooling equilibria that depend on consumers' prior beliefs.

We consider a uniform distribution of consumer valuations. For consumers who consider the add-on, let their bundle valuations be uniformly distributed on $[0,1/\beta]$. For consumers who do not consider (or do not value) the add-on, let their core (or bundle) valuations be uniformly distributed on $[0,1/\beta']$, where $\beta'>\beta$. In other words, there is a positive linear correlation between add-on and core valuations for consumers who value the add-on.

Given $0\le q\le 1$, for w-types and n-types, bundle and unbundle profits are

$$\begin{aligned}\pi_{WB}(p_{WB};q)&=p_{WB}(1-\beta' p_{WB})\gamma\theta(1-q)\\&\quad+p_{WB}(1-\beta p_{WB})[1-\gamma\theta(1-q)],\\ \pi_{NB}(p_{NB};q)&=p_{NB}(1-\beta' p_{NB})\theta(1-\gamma q)\\&\quad+p_{NB}(1-\beta p_{NB})[1-\theta(1-\gamma q)],\end{aligned}\tag{C.1}$$

$$\begin{aligned}\pi_{WU}(p_{WC},p_{WA};q)&=p_{WC}(1-\beta' p_{WC})\gamma\theta(1-q)\\&\quad+p_{WA}(1-\beta p_{WA})[1-\gamma\theta(1-q)],\\ \pi_{NU}(p_{NC},p_{NA};q)&=p_{NC}(1-\beta' p_{NC})\theta(1-\gamma q)\\&\quad+p_{NA}(1-\beta p_{NA})[1-\theta(1-\gamma q)],\end{aligned}\tag{C.2}$$

respectively. From Equation (C.1), the optimal bundle prices of w-types and n-types are

$$\begin{aligned}p^*_{WB}&=1/[2\{\gamma\theta(1-q)(\beta'-\beta)+\beta\}],\\ p^*_{NB}&=1/[2\{\theta(1-\gamma q)(\beta'-\beta)+\beta\}].\end{aligned}\tag{C.3}$$

From Equation (C.2), the optimal core and bundle price of w-types and n-types are

$$p^*_{WC}=p^*_{NC}=1/(2\beta'),\quad p^*_{WA}=p^*_{NA}=1/(2\beta).\tag{C.4}$$

From Equation (C.4), we can show that buyers of the bundle get greater utility compared to when they buy the core (i.e., incentive compatibility holds); given a bundle valuation $b\ge 1/(2\beta)$, $[b-1/(2\beta)]-[b\beta/\beta'-1/(2\beta')]=(\beta'-\beta)[b-1/(2\beta)]/\beta'\ge 0$. Substituting the equilibrium prices in Equations (C.3) and (C.4), we can derive the equilibrium profits in Equation (C.5)

$$\begin{aligned}\pi^*_{WB}(q)&=1/[4\{\gamma\theta(1-q)(\beta'-\beta)+\beta\}],\\ \pi^*_{NB}(q)&=1/[4\{\theta(1-\gamma q)(\beta'-\beta)+\beta\}],\\ \pi^*_{WU}(q)&=[\beta'-\gamma\theta(1-q)(\beta'-\beta)]/(4\beta'\beta),\\ \pi^*_{NU}(q)&=[\beta'-\theta(1-\gamma q)(\beta'-\beta)]/(4\beta'\beta).\end{aligned}\tag{C.5}$$

Comparing profits reveals the optimal strategies

$$\begin{aligned}\Delta\pi^*_{WUB}(q)&=\pi^*_{WU}(q)-\pi^*_{WB}(q)\\&=\frac{(\beta'-\beta)^2\gamma\theta(1-q)[1-\gamma\theta(1-q)]}{4\beta'\beta[\gamma\theta(1-q)(\beta'-\beta)+\beta]}\ge 0,\\ \Delta\pi^*_{NUB}(q)&=\pi^*_{NU}(q)-\pi^*_{NB}(q)\\&=\frac{(\beta'-\beta)^2\theta(1-\gamma q)[1-\theta(1-\gamma q)]}{4\beta'\beta[\theta(1-\gamma q)(\beta'-\beta)+\beta]}\ge 0.\end{aligned}\tag{C.6}$$

From Equation (C.6), $\Delta\pi^*_{WUB}(1)=0$ and $\Delta\pi^*_{NUB}(0)>0$; that is, at a separating equilibrium, n-types unbundle the core and add-on, and w-types bundle to differentiate their strategy. Then, w-types will not deviate to unbundle because $\pi^*_{WB}(1)\ge\pi_{WU}(p^*_{NC},p^*_{NA};q=0)$. For a separating equilibrium, n-types should have no incentive to mimic w-types; $\pi^*_{NU}(0)\ge\pi_{NB}(p^*_{WB};q=1)$, that is, $\gamma\le 1-\beta/\beta'$, where w-types charge the first-best bundle price. With fewer informed consumers ($\gamma>1-\beta/\beta'$), however, bundling alone cannot signal w-types. To signal, w-types increase the bundle price p_{WB} from the first-best price $p^*_{WB}=1/(2\beta)$ such that $\pi^*_{NU}(0)=\pi_{NB}(p_{WB};q=1)$; that is, the price of the bundle option is a part of the signal. Solving the equation, we have $p_{WB}=\bar p^*_{WB}>p^*_{WB}$, where

$$\bar p^*_{WB}=\frac{\beta+\sqrt{[\beta-\beta'(1-\gamma)+(\beta'-\beta)\theta(1-\gamma)](1-\beta/\beta')\beta\theta}}{2\beta[\beta+(\beta'-\beta)\theta(1-\gamma)]}.\tag{C.7}$$

Differentiating Equation (C.7) with respect to γ and θ, we have

$$\frac{\partial\bar p^*_{WB}}{\partial\gamma}=\frac{\beta(\beta'-\beta)\theta(\bar p^*_{WB})^2}{\sqrt{[\beta-\beta'(1-\gamma)+(\beta'-\beta)\theta(1-\gamma)](1-\beta/\beta')\beta\theta}}\ge 0,\tag{C.8}$$

$$\frac{\partial\bar p^*_{WB}}{\partial\theta}=\frac{(1-\beta/\beta')[1-4\beta'\beta(1-\gamma)(\bar p^*_{WB})^2]}{4\sqrt{[\beta-\beta'(1-\gamma)+(\beta'-\beta)\theta(1-\gamma)](1-\beta/\beta')\beta\theta}}\ge 0.\tag{C.9}$$

Claim 4. *Given* $\gamma>1-\beta/\beta'$, $4\beta'\beta(1-\gamma)(\bar p^*_{WB})^2<1$.

Proof. Let $g(\gamma)=4\beta'\beta(1-\gamma)(\bar p^*_{WB})^2$. Clearly, $g(1)=0<1$, and $g(\gamma=1-\beta/\beta')=1$. Note that $g'(\gamma)=4\beta'\beta\bar p^*_{WB}[-\bar p^*_{WB}+2(1-\gamma)\cdot(\partial\bar p^*_{WB}/\partial\gamma)]$. For $\gamma\ge 1-\beta/\beta'$, $g'(\gamma)=0$ has two unique solutions: $\gamma_1=1-\beta/\beta'$ and $\gamma_2=1+\beta/[(\beta'-\beta)\theta]>1$. Thus, $g(\gamma)<1$ for any $\gamma\in(1-\beta/\beta',1]$. Q.E.D.

From Equation (C.8), with a larger γ (i.e., more uncertainty), n-types have more incentive to mimic w-types, so the signaling distortion increases. From Equation (C.9), when the number of h increases, n-types have more incentive to attract h by mimicking w-types, causing larger signaling distortion.

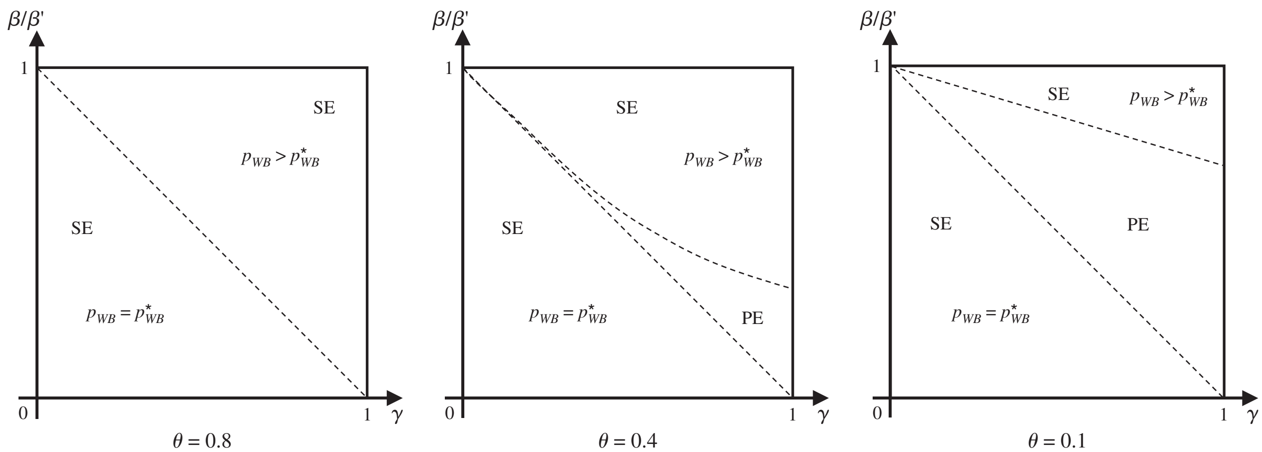
Last, a separating equilibrium requires w-types to have no incentive to unbundle. Therefore, $\pi^*_{WB}(\bar p^*_{WB};q=1)\ge\pi_{WU}(p^*_{NC},p^*_{NA};q=0)$, where $\pi^*_{WB}(\bar p^*_{WB};q=1)=\bar p^*_{WB}(1-\beta\bar p^*_{WB})$ and $\pi_{WU}(p^*_{NC},p^*_{NA};q=0)=[\beta'-\gamma\theta(\beta'-\beta)]/(4\beta'\beta)$; that is,

$$\begin{aligned}&2\sqrt{\left[-1+\frac{\gamma}{1-J}+\theta(1-\gamma)\right]J\theta}\\&\quad+(\theta\gamma+1)[1-\theta(1-\gamma)]J-(1-\gamma\theta)\theta(1-\gamma)\ge 0,\end{aligned}\tag{C.10}$$

where $J=\beta/\beta'$. Figure C.1 shows separating and pooling equilibria with three different θ's from Equation (C.10).

For $\gamma\le 1-\beta/\beta'$ (i.e., a sufficient number of informed), bundling signals w-types without signaling distortion. However, for $\gamma>1-\beta/\beta'$, w-types should increase their bundle price to signal because n-types' benefits of mimicking increases. Then, with a large number of h who do not value n-type add-ons, n-types still find bundling (mimicking) less profitable than unbundling (targeting). Thus, there is no pooling equilibrium; see Figure C.1 for $\theta=0.8$. With a small number of h, however, n-types become similar to w-types, making it difficult for w-types to signal. Thus, pooling equilibria exist; see Figure C.1 for $\theta=0.4$ and $\theta=0.1$. In this case, when $\beta/\beta'\approx 1$ or $\beta\approx\beta'$, that is, add-on margins are sufficiently small, n-types can gain only small add-on profits from mimicking; hence, w-types can signal their type by bundling.

Figure C.1. Separating and Pooling Equilibria



Note. SE and PE denote separating equilibria and pooling equilibria, respectively, and $p^*_{WB} = 1/2\beta$.

Social Welfare Analysis

Given $\gamma \le 1 - \beta/\beta'$, for w-types, consumer surplus is given by

$$CS_{WB}(1) = \int_{1/(2\beta)}^{1/\beta} \beta[\nu - 1/(2\beta)]\,d\nu = 1/(8\beta), \tag{C.11}$$

$$CS_{WU}(q) = \gamma\theta(1-q)/(8\beta') + [1 - \gamma\theta(1-q)]/(8\beta), \tag{C.12}$$

for a separating and pooling equilibrium, respectively. From Equations (C.11) and (C.12),

$$\Delta CS_W = CS_{WB}(1) - CS_{WU}(q) = (\beta' - \beta)\gamma\theta(1-q)/(8\beta'\beta) \ge 0. \tag{C.13}$$

From Equation (C.13), consumer surplus is higher at the separating equilibrium because bundle signals help consumers make better choices.

For n-types, Equation (C.14) shows consumer surplus in a pooling equilibrium

$$CS_{NU}(q) = \frac{\theta(1-\gamma q)}{8\beta'} + \gamma\theta q \int_{1/(2\beta')}^{1/\beta'} \beta'[\nu - 1/(2\beta)]\,d\nu + \frac{1-\theta}{8\beta}. \tag{C.14}$$

Equation (C.15) reveals that the difference in consumer surplus between signaling ($q = 0$) and pooling is positive for n-types

$$\Delta CS_N = CS_{NU}(0) - CS_{NU}(q) = \frac{(\beta' - \beta)\gamma\theta q}{4\beta'\beta} \ge 0. \tag{C.15}$$

At a pooling equilibrium, uninformed h who believe the add-on is of the w-type lose their surplus when those consumers buy n-type add-ons they will not value. The loss in consumer surplus increases when consumers are less price sensitive to w-type bundles (a smaller β); that is, uninformed h with a bias in their beliefs pay more for n-type bundles. Therefore, with signaling, consumer surplus increases for n-types.

Given a bundle signal, w-types gain profits from uninformed h who believe the add-on is n-type while n-types lose profits from uninformed h who believe the add-on is w-type. Finally, Equation (C.16) shows that the bundle signal increases social welfare for w-types because both consumers and sellers benefit. However, for n-types, signaling may not influence social welfare because n-types lose their profits from uninformed h with a bias, while those consumers correctly infer add-on types from the bundle/unbundle signal, increasing their surplus

$$\begin{aligned} SW_W(q) &= CS_{WB}(1) - CS_{WU}(q) + \pi^*_{WB}(1) - \pi^*_{WU}(q) \\ &= \frac{3(\beta' - \beta)\gamma\theta(1-q)}{8\beta'\beta} \ge 0, \\ SW_N(q) &= CS_{NU}(0) - CS_{NU}(q) + \pi^*_{NU}(0) - \pi^*_{NU}(q) = 0. \end{aligned} \tag{C.16}$$

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