Encouraging upstream experimentation and downstream coordination in a design and development game

James Campbell

Providence College*

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Abstract

Upstream players produce design ideas and downstream players select among these ideas to develop finished products. Design diversity is valuable at the upstream stage and coordination is valuable at the downstream stage, in the sense that this maximizes the sum of payoffs to all players. However, this outcome is not always realized since both the upstream and downstream players may have an individual incentive to use different strategies, so that coordination occurs too soon or not at all. This problem is associated with too much predictability or too little difference in the relative value of designs. We show that an intermediary whose interests align with the industry as a whole can solve either problem by selecting among designs in such a way that occasionally rewards inferior ideas, so long as the intermediary has enforcement power or can extract commitments from downstream players. We discuss the application of the model to technology standards, political primaries, and trend-driven industries.

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*Department of Economics, 1 Cunningham Square, Providence, RI 02906; jcampb10@providence.edu

1 Introduction

This paper presents a design and development game, which we analyze in general terms before considering its mapping to possible applications. Two upstream players select between two potential designs of uncertain quality, selecting what we might think of as prototypes, proposals, or technologies. Next, Nature reveals which of the two designs is superior. Finally, two downstream players select among the prototypes chosen upstream to develop into a finished product. Payoffs are chosen so that the sum of payoffs to these four players is largest when upstream players choose different designs (realizing the benefits of experimentation and discovery) and the downstream players choose the same design (realizing the benefits of coordination or compatibility).

The first main highlight of the analysis is that the joint payoff-maximizing outcome is not always realized in a subgame perfect Nash equilibrium of the game. Coordination may occur too soon or not at all in equilibrium, depending on the strength of the various incentives for each player. For example, if one design has a much higher ex ante chance of being superior than the other or if the difference in value between the superior and inferior designs is low, it is more likely that joint payoffs will not be maximized. In general, actions that elevate the status, salience, and unpredictability of the 'contest of ideas' among competing designs are valuable.

A new player is introduced in a modified version of the game. This player is an intermediary whose goal is to maximize joint payoffs, which in practice means creating the right incentives for upstream players to differentiate their prototype designs and for downstream players to herd on one design in their finished products. The intermediary's role is to nominate or select a design for the downstream players to follow, after Nature reveals the relative quality of the designs but before downstream players act.

This intermediary can improve upon the outcome of the original game in cases in which the joint payoff would not be maximized, again so long as the relative quality of the designs is not too predictable. Their selection process must put some small positive weight on selecting the 'wrong' prototype, in order to give the upstream players sufficient incentive to choose different designs. Since this would enhance the value created upstream, downstream players are willing to commit to follow the intermediary's selection in order to realize it. The second main highlight of the analysis is that it is reasonable to expect players in a design and development setting to willingly cede some decision-making power to intermediaries of this type. We may expect to observe intermediaries like this in some applications and anticipate their usefulness in others.

Finally, we present some specifications of the game in which there is vertical integration between one or more upstream-downstream pair. The third main highlight of the analysis is that there are unilateral incentives to vertically integrate in this setting, but ultimately at a cost to all players. Under vertical integration joint payoff-maximizing outcomes are harder to achieve and the intermediary's ability to improve outcomes is lessened relative to the unintegrated game.

When applying this framework to industrial organization, this implies a fresh set of considerations in antitrust enforcement in situations where compatibility or standards matter. Vertical consolidation may superficially appear to make standardization easier by aligning the incentives of upstream and downstream players. However, it can hinder the process of experimentation and coordination, and impede institutional solutions.

The general framework of the model may be applied to a variety of settings. Below we will consider in particular how the model may be applied and adapted to three examples:

Example 1: industry standard-setting bodies

Competing firms have engaged in research and development into a new generation of technology. All else being equal, it is better for all parties to resolve the question of which technology will become the new standard, since consumers may prefer to wait and see before they adopt either one speculatively. However, both parties would prefer that their own technology become the new standard. Standard-setting bodies with representatives from across the industry may be formed with various rules and mandates to make the decision.

Example 2: designing products with network effects

In industries such as computer software and fashion, consumers may enjoy network externalities in consumption of a product, so that their valuation of it depends on how many others are also using it. Although it may pay for the industry to experiment with different designs in order to discover which will be the most popular, it ultimately benefits all firms that there be resolution on one variety so that all may enjoy the fruits of the network externalities. A focal opinion leader or tastemaker may be tacitly empowered to shepherd the design process and help to coordinate consumers (or a particular niche of consumers) on a single product.

Example 3: selecting political candidates

In a political primary, a political party may unearth useful ideas, toughen up candidates, and generate press coverage. However, it may be important to coalesce around a single candidate before too long to conserve resources and consolidate support before the general election. Party insiders may use soft power or backroom deals to expedite the process of accord. Institutional rules may be created to formalize selection mechanisms.

These three examples all share the general structure of the design and development game. Naturally, there are significant differences among them, some of which affect how we may read the mapping from game to application. In particular, a key question is what type of intermediary could or does have enforcement or commitment power in each setting. In some examples we may view the intermediary player as descriptive of existing institutions and in others as a thought experiment for what kind of institution could improve design and development outcomes.

2 Related literature

It is well known that the possibility of making binding commitments can enhance players' payoffs in extensive-form games (following Schelling, 1960 and applications in industrial organization as in Dixit, 1982). In our model players may commit to following the recommendation of an intermediary whose interests are aligned with those of a social planner. This allows players to do better than in the equilibrium without commitment. While commitment is one key to the intermediary's role, in some cases the intermediary's recommendation shares some features with a randomization device as in the correlated equilibrium of Aumann (1974). In such cases, randomization in the intermediary's announcement creates the incentive for designers to diversify their choices to the benefit of all.

In the context of the application to technological compatibility, the implications of the model in this paper are consistent with Rysman and Simcoe (2008), which finds that standard-setting organizations do indeed have significant influence over technology adoption decisions in industries with incentives for coordinated systems innovation. In a theoretical treatment, Axelrod et al. (1995) considers the incentives to form institutional alliances in standard-setting problems and highlights a tension between the benefits of joining an alliance to achieve coordination and the competitive incentive to go it alone. This tension is central to the model here, but with added consideration of the incentives of the upstream parties who generate usable ideas.

Shapiro (2000) argues for principles in antitrust enforcement to facilitate the introduction of new technologies in a setting in which standard-setting and intellectual property protection are important considerations. Farrell et al. (2007) provides a review of the legal history of hold-up in standard-setting problems, another problem that may justify industry- or society-level intervention. The parameterization of the model in this paper has in mind, among other considerations, the transaction costs introduced by intellectual property disputes that increase the incentive for industry-level cooperation.

A rich literature has addressed the issue of coordination in the adoption of new technologies in the presence of network externalities, for example Farrell and Saloner (1985), Katz and Shapiro (1986) and Katz and Shapiro (1992). The analysis in this paper can be applied to this class of problem, since one aspect of the role of the intermediaries we consider is to assist with downstream coordination. In the context of the application of the model to systems competition, we also add consideration of the incentives of the producers of the technological ideas upstream. This reveals an additional way in which beneficial coordination can be hindered.

Gandal (2002) identifies two senses in which a standardization process may be inefficient. First, socially beneficial standardization may not be achieved, and second, a standard that is achieved may be worse than an available alternative. In a similar vein Choi (1996) provides an explanation for cases when market forces achieve standardization inefficiently late, and cases when ex ante standardization occurs inefficiently early. The model in this paper provides a novel mechanism for the failure to achieve efficient standards by considering the special problems of upstream-downstream design incentives. However, we also argue that the occasional adoption of inferior standards may be a feature and not a bug of interventions to benefit industry in the standard-setting process. This aspect of the analysis complements Cabral and Salant (2014), which demonstrates with a duopoly model the potential value of competing standards in fostering beneficial R&D expenditures. Although our model is quite different, the intermediary's role we propose shares a similar spirit.

The model in this paper has some similarity to the model of Church and Gandal (2000), which features two upstream and downstream firms, with incentives for compatibility. There are several differences in the settings of the two models, but also some revealing similarities in their characteristics. The model in this paper involves incentives for the two downstream players to coordinate, a role for an intermediary player to improve joint payoffs, and discretion for upstream players over design choices. Nevertheless, as discussed in more detail below in Section 6, vertical integration can arise in equilibrium of both models, with some common effects. The conclusions of that extension of our model are also complementary to Bresnahan and Greenstein (1999), which raises the question of how vertical consolidation may proceed in a world of platform competition. In general, in this paper's analysis vertical consolidation makes life more difficult for institutions that would seek to foster healthy design competition in an industry.

The conclusions drawn below are consistent with Shapiro and Varian (1999), which analyzes historical standard wars and highlights the importance of alliances and first-mover advantages. This paper shows the importance and potential role for industry-level institutions. It also provides a rationale for first-mover advantages since first movers have the chance to select ex ante likely 'winners' from the menu of possible designs.

A literature on patent pools includes contributions that focus on the potential for ex ante agreements to improve outcomes. For example, Llanes and Poblete (2014) shows that ex ante agreements can be an optimal policy for social welfare and require little specific information on the part of the standard-setting body. Although not tailored specifically to the question of patent pools, the results in this paper agree with these conclusions from the perspective of social payoffs. As discussed below, in this context coordinating agreements can be implemented to mutual benefit by intermediaries whether or not they are welfare-enhancing overall. An important point to note is that we will be agnostic about the effect on consumer welfare per se—the analysis here is robust to a net positive effect for consumers from standardization or a net negative effect due to increased market power for producers.

3 Model

There are two designers, D_1 and D_2, two retailers, R_1 and R_2, and Nature.[1] Later we will consider the case in which there are two vertically integrated designer-retailers. There are two possible designs A and B.

The order of play is as follows:

1. Nature chooses one of the designs to be 'superior'. Let the probability that nature chooses design A be $\alpha > \frac{1}{2}$. Nature's choice is not observed by any player.

2. Designer D_1 chooses a prototype design d_1, either A or B.

3. Designer D_2 observes the choice of designer D_1 and chooses a prototype design d_2, either A or B.

4. Nature's choice is revealed to all players.

[1]We denote the downstream players 'retailers' with a purview to market to the public in mind. Nevertheless, as discussed in the introduction, there are several possible interpretations of what the various players here actually do. For example, in the political primary application, the downstream players may be thought of as factions of the party promoting a candidate or platform to their constituents.

5. Retailer R_1 chooses a design r_1 from those chosen by the designers. That is, if the designers chose the same design, the retailer is restricted to choose that design, but if they chose different designs, the retailer can choose either one.

6. Retailer R_2 observes the choice of retailer R_1 and chooses a design r_2, with the same restrictions as retailer R_1.

Until we consider vertical integration below, there is no contracting between designers or between retailers. This could be, for example, because contracts that specify that two players use designs that are the same or different are unenforceable, or because of the difficulty or cost of litigation to settle disputes.

Nature provides a common prior belief of which design is more likely to be the superior one, but which design is actually realized as superior is not known until at least one prototype is made. The parameter α can then be thought of as capturing a commonly observed signal, maybe from underlying trends or market research. $\alpha = \frac{1}{2}$ would mean that the signal is uninformative, so that the designs are thought equally likely to be the superior, and higher α means a more informative signal. In Section 7 below we consider the incentive for players to acquire a better signal—to increase α.

The value generated by a design for its designers and retailers, and how it is split among them, depends on the number of designers who chose it and on the number of retailers who chose it. If the ex post inferior design is played by n_D designers and n_R retailers, it generates a total value of size $\pi_X(n_D, n_R)$; if the ex post superior design is played by n_D designers and n_R retailers, it generates a total value of size $\gamma\pi_X(n_D, n_R)$, where $\gamma > 1$ represents the premium in the value generated by the superior product.

We impose the following structure on π:

$$\pi(n_D, 0) = 0 \tag{1}$$

$$\pi(n_D, 2) > 2\pi(n_D, 1) \tag{2}$$

$$\pi(1, r) > \pi(2, r) \text{ for } r > 0 \tag{3}$$

Equation 1 says that a design that is not chosen by either retailer generates no value. Equation 2 says that a design that is chosen by both retailers generates more than twice the value of a design chosen by one retailer. This could reflect network effects in consumption or benefits to compatibility. Finally, equation 3 says that a design whose prototype is made by only one designer is more valuable than a design whose prototype is made by both designers. This could reflect fewer intellectual property disputes or a consumer preference for distinctive name brands.

To parameterize the model, we first normalize $\pi(2,2) = 1$. Let $\pi(1,2) = \rho$, with $\rho > 1$ a parameter reflecting the importance of diversity at the design stage. Let $\pi(1,1) = \tau$, with $\tau < \frac{1}{2}$, an inverse measure of the importance of coordination at the downstream stage.

The split of this value between designers and retailers again depends on the number of designers and retailers who chose design X. The share of value that flows to designers is $S_D(n_D, n_R)$, and the share to retailers is

$$S_R(n_D, n_R) \equiv 1 - S_D(n_D, n_R). \tag{4}$$

We put the following structure on how the value generated by a design is shared between designers and retailers: $S_D(2,2) < S_D(1,1) < S_D(1,2)$. That is, a larger share of the value generated by a product accrues to the designers' side if only one designer chose that design. This is motivated by bargaining power between the two sides: bargaining power for the designer is greatest when two retailers both choose to turn the designer's style into a finished product. Since $S_D(n_D, n_R) = 1 - S_R(n_D, n_R)$ this implies that $S_R(2,2) > S_R(1,1) > S_R(1,2)$. Finally, assume that the share of the value going to each side is split equally within that side. For example, if both designers and both retailers choose the same design—so that $n_D = 2$ and $n_R = 2$—then each designer receives a payoff of $\frac{1}{2}S_D(2,2)\pi(2,2)$ and each retailer receives a payoff of $\frac{1}{2}S_R(2,2)\pi(2,2)$.

On the interpretation of the payoffs in general, we can be flexible about precisely how the designer earns their payoff, depending on our application for the model. For example, for a designer's prototype to be chosen by two retailers could be interpreted in practice a range of possibilities for how the designer earns revenue, from those retailers directly paying a license fee or royalties to the designer to produce a finished product, to the retailers creating a product inspired by the designer's ideas and the designer's earnings increasing via the prestige of having pioneered a fashionable idea.

There is no ex post bargaining over surplus. This could be taken literally to reflect short decision-making windows and rapid turnaround times in design-driven industries. Or, in general, by parameterizing the split of surplus between the designer and retailer sides, we can accommodate situations in which renegotiation and coalition formation are impossible or constrained by considerations such as time, bargaining costs, or pre-existing contracts or norms. This also abstracts from possible hold-up problems. We therefore do not make precise assumptions on the structure of bargaining over surplus among the various parties. However, in the analysis below we highlight cases which are not renegotiation proof—reflecting a situation in which it is possible to freely negotiate shares among all parties after the downstream players have made their choices—and the implications of this for equilibrium outcomes.

4 Equilibria

The game described in section 3 has a unique subgame perfect Nash equilibrium; the equilibrium outcome is parameter dependent.

Some aspects of the equilibrium are the same regardless of the magnitude of parameters. In all cases the designer who selects first always chooses A, the design that is more likely to be superior, and if the designers chose different designs, the retailer that selects first always chooses the design that has been revealed in the design stage to be superior.

Beyond these common elements, there are three conditions that determine which outcome occurs in equilibrium:

$$\frac{\gamma\rho}{2\tau} > \frac{S_R(1,1)}{S_R(1,2)} \tag{5}$$

$$\frac{1}{2\gamma\rho}\left[\frac{\alpha\gamma}{1-\alpha}+1\right] < \frac{S_D(1,2)}{S_D(2,2)} \tag{6}$$

$$\frac{\alpha\gamma+(1-\alpha)}{2[\alpha\tau+(1-\alpha)\tau\gamma]} < \frac{S_D(1,1)}{S_D(2,2)} \tag{7}$$

If Equation 5 is satisfied, retailers prefer to match rather than mismatch. That is, in the case that both prototype designs were played, the retailer who chooses second prefers to match the first retailer and select the design that is revealed to be superior rather than mismatch and select the inferior design. If Equation 6 is satisfied, if the retailers will prefer to match on the superior design, then designer 2 prefers to mismatch and choose design B. If Equation 7 is satisfied, then if the retailers will mismatch when both designs are available, designer 2 prefers to mismatch and choose design B.

The following result characterizes the equilibrium of the game:

Proposition 1. *The game has a unique subgame perfect Nash equilibrium outcome in which:*

i. *Designers choose different designs and retailers both choose the design that is revealed to be* *superior if Equations 5 and 6 are both true.*

ii. *Both designers choose the design that is more likely to be superior either if Equation 5 is true and 6 is false, or if Equation 5 is false and 7 is false.*

iii. *The designers choose different designs and the retailers choose different designs if Equation 5 is false and 7 is true.*

Case i. generates the largest total value of $\rho\gamma$: both designs are produced in the prototype stage, and the design that proves to be superior is selected by both retailers. In case ii. the expected total value is $\alpha\gamma + (1 - \alpha)$: since both designers select the design that is more likely to be superior, both retailers must select this design. With probability α this design is the true superior and the value generated is γ, and with probability $(1 - \alpha)$ the other design is the true superior and the value generated is 1. Case iii. generates the smallest total value of $\tau\gamma + \tau$: both designs are produced in the prototype stage, and each is selected by one retailer. The true superior generates value $\tau\gamma$ and the inferior τ.

From the point of view of sum of payoffs to all four players, cases ii. and iii. represent two distinct problems which can arise. First, there may be insufficient design diversity: it can be the case that retailers are willing to herd on the superior design, which is valuable since a design that is 'pushed' by both retailers becomes standard and has its value inflated, but, given this, designers are not willing to produce both designs. This arises when the second designer prefers the guarantee of being selected when matching the first design over the *chance* of being the sole winner when mismatching. Thus only one design is available, and the value created is depressed both by the inferior design sometimes being selected and by the cost in value when a design cannot be attributed to a single 'winning' designer.

Second, there may be insufficient downstream coordination: it can be the case that retailers prefer to mismatch, regardless of which outcome is truly superior. This can occur when a retailer gains more in bargaining power when being the sole buyer of the inferior design than splitting the inflated value of the superior design with the other retailer. Note that in the case in which there can be ex post negotiation on how to divide value among designers and retailers, this problem cannot arise, and so case iii. would not be an equilibrium of the game with ex post negotiation. In the next sections we discuss how value-enhancing interventions may proceed in each of these two cases.

Comparative statics on Equations 5 and 6 allow us to describe factors that make it more likely that the joint payoff-maximizing case i. is realized in equilibrium. For the outcome that maximizes joint payoff to be realized in equilibrium:

i. downstream coordination must be sufficiently important (small τ),

ii. unique attribution of designs must be sufficiently important (large ρ),

iii. the premium to the superior design must be sufficiently large (large γ), and

iv. the true relative value of each design must be sufficiently unpredictable (α close to $\frac{1}{2}$).

Two relevant features of this 'recipe' foster the industry surplus-maximizing outcome.[2] First, when τ is smaller and γ is larger, the premium to downstream coordination over the downstream firms choosing different designs is higher. Thus the incentive of the downstream retailers to coordinate on choosing the design that is revealed to be superior in the design stage is increased, and outweighs any motivation to mismatch to obtain a larger share of the smaller surplus that would result from mismatching.

Second, when ρ is larger and α is smaller, the premium to design diversity is larger, but the signal received by the players about which design will be truly superior is less informative. This combination gives designers the incentive to mismatch and choose different designs, hoping to be the single designer responsible for the downstream design adopted by both retailers, rather than matching the design of the other designer and guaranteeing a share of the smaller total payoff that would result.[3] It is worth noting, however, that there can be conflicting effects when these parameters change. For example, higher γ increases the incentive of retailers to match, but also reduces the incentive of designers to mismatch, since there is a greater cost to playing a design that is then found to be inferior.

We may apply this result to political primary example mentioned earlier. Here, the value of upstream diversity of ideas captures the importance of the 'contest of ideas' view of the primary process, and the value of coordination downstream captures the importance of rallying around a single candidate before the general election. The conditions for the ideal outcome to prevail include also true ex ante uncertainty over which platform will truly be preferred by voters, and a competitive general election field that makes the premium to finding the best candidate or platform high. This

[2]Although we go on below to consider institutions that act as a commitment device, another role they may play could be to to influence these parameters to foster a culture that is beneficial for the industry.

[3]We return to the implications of high predictability in trends—high α—in Section 7 below.

is consistent with Adams and Merrill (2008) which finds that primaries are valuable to a party when candidate attributes that are unknown prior to the primaries are particularly salient. This application shows how institutional bodies may benefit from shaping the rules of the design and development game to favor uncertainty that fosters competition in the prototype stage.

5 Institutions as value-enhancing commitment devices

In our benchmark model, we show that the joint payoff-maximizing equilibrium outcome is not always realized. In this section we introduce a player who we call the *intermediary*, who can make pronouncements during the design-and-retail process that players may commit to follow. Of course, there are many and varied activities performed by critics, opinion leaders, industry bodies, and 'fixers' in general. We will abstract from these specific examples in order to focus on the commonalities of the role.[4]

We do not claim that the possible role we propose is either the only function of intermediaries or the only way that ideas progress from design to product. We will also abstract from a multiplicity of competing intermediaries. It would be consistent with our argument for there to be many players behaving in a similar way to the single institution in the model, particularly in applications in which the space of possible designs is large or the market is broken into distinct niches. Overall, the conclusion will be that that having an institution like this may improve outcomes when upstream or downstream inefficiency occurs.

We assume that the goal of the intermediary is to maximize joint payoff to all players. This is consistent with the player being either a benevolent planner, altruistically interested in the health of an industry, or a self-interested party who earns a payoff proportional to total payoff. An example of the latter case, in which the player does better when an industry is healthier, could be a media outlet or industry magazine that enjoys greater advertising revenue when the revenues earned by designers and retailers are higher.

Consider a situation in which after the designers have chosen designs, the intermediary announces one of the two designs to be the 'winner' (not necessarily the design that is superior). Do the retailers have incentive to cede power to the intermediary and commit in advance to select the design that the intermediary announces? Can this intervention by the intermediary be value-enhancing?

[4] Hsu et al. (2012) is an interesting recent example of an analysis in which critics act as intermediaries in an upstream-downstream relationship under uncertainty, although there the focus is on evaluation of quality and associated price agreements.

We formalize these questions by analyzing the following game:

1. Nature chooses one of the designs to be 'superior'. Let the probability that A is chosen be $\alpha > \frac{1}{2}$. Nature's choice is not observed by any player.

2. Intermediary I chooses (and commits to) a rule that will generate their announcement.

3. Retailer R_1 observes the decision of I and chooses whether to commit to follow the intermediary's announcement.

4. Retailer R_2 observes the decision of I and R_1 and chooses whether to commit to follow the intermediary's announcement.

5. Designer D_1 observes the choices of the intermediary and retailers and chooses a prototype design d_1, as before.

6. Designer D_2 observes the choice of the intermediary, retailers and designer D_1 and chooses a prototype design d_2, as before.

7. Nature's choice is revealed to all players.

8. The intermediary makes an announcement according to the announcement rule.

9. If R_1 committed to follow the announcement, she does so, or else chooses a design r_1, as before.

10. If R_2 committed to follow the announcement, she does so, or else observes the choice of retailer R_1 and chooses a design r_2, as before.

The announcement rule could in general take many forms, and in particular could specify that no announcement be made in some cases. Note that while it is natural to imagine that the intermediary would have some expertise in evaluating the quality of designs, we do *not* assume so here: everyone can see the true nature of the designs after the prototype stage. Thus the model will explain a possible role for an 'expert' even in the case in which there is no expertise.

5.1 Intervention to diversify designers

A particularly problematic combination occurs when downstream coordination is very important, the predictability of trends is high, and designers have little bargaining power relative to retailers. This combination increases the likelihood that Equation 5 is true and Equation 6 is false: retailers are happy to match on a design to exploit the value of coordination, but the predictability of the superior design means that no designer is willing to produce the likely inferior design. The result is that with probability $(1-\alpha)$ the superior product is not designed, and the value of unique attribution of a design is lost. This is case ii. of Proposition 1. In this case, if retailers choose to commit to following the recommendation of the intermediary (revealed after the design stage), it can encourage the designers to mismatch and increase the total value generated.

Consider the following announcement rule. The intermediary will make no announcement unless both retailers have committed to follow it. If both retailers commit, then when both designs are played by the designers, the intermediary will announce B whenever it is revealed to be superior (probability $1-\alpha$). The intermediary will announce B as the winner with a further probability β when A is revealed to be superior (where $\beta < \alpha$ by necessity). Finally, the intermediary and will announce A with the remaining probability. We call this the β-announcement plan.

If retailers follow this announcement, then if designers mismatch, the designer playing B would be selected as the 'winner' with probability $(1-\alpha+\beta)$, although sometimes with the inferior product. The designer playing A would be selected as the 'winner' with probability $(\alpha-\beta)$, always with the superior product. Under such a plan, the probability of the design ultimately chosen by both retailers being the true superior is $(1-\beta)$, which is higher than in the previous game. Further, the premium ρ for unique attribution of a design would always be realized where it was not before. Thus the total surplus generated for the industry increases from $\alpha\gamma + (1-\alpha)$ under the previous game to $(1-\beta)\gamma\rho + \beta\rho$.

Given this structure, it is possible that the intermediary can implement an outcome that increases the total sum of payoffs:

Proposition 2. *Consider the case in which both designers choose the design that is likely to be superior in the equilibrium of the game without an intermediary. In the game with an intermediary, there exists a β-announcement plan such that retailers commit to following the industry's announcement, designers choose different designs, and the joint payoff is greater than in the game without* *an intermediary, if*

$$\frac{1}{2\gamma\rho}\left[\frac{\gamma(\alpha\gamma+(1-\alpha))+(\alpha+(1-\alpha)\gamma)}{\alpha+(1-\alpha)\gamma}\right]<\frac{S_D(1,2)}{S_D(2,2)}. \tag{8}$$

Equation 8 implies that the intermediary must select β, the weight on B being chosen when it is the true inferior, to accomplish three things. First, β must be big enough that one designer must be willing to play design B, the likely inferior design, when the other plays A. Second, β must be small enough that one designer is willing to play design A when the other plays B. Third, β must be big enough that retailers prefer to commit to follow the announcement rather than play the equilibrium of the game without an intermediary. If Equation 8 is satisfied, then such a β exists.

It is important to note that if α is high, Equation 8 is more difficult to satisfy, and so the possibility of beneficial intervention is lowered. Recall that α captures the preciseness with which designers and retailers know which of the available designs is likely to be superior before seeing the prototypes—that is, higher α means that trends in what product is likely to be a hit with consumers are more predictable. In Section 4 we saw that, in the benchmark game without the intermediary, if trends are too predictable, there is insufficient incentive for designers to experiment, and so valuable design diversity is lost. The same intuition applies in the game with an intermediary. If trends are too predictable, the incentives for the designers to both select the likely superior design can be too strong for the intermediary to be able to overcome with this intervention.

The intermediary, with the objective of maximizing total payoff to all players, will choose the smallest possible β. This β is

$$\beta^*=\frac{S_D(2,2)}{S_D(1,2)}\left[\frac{\alpha\gamma+(1-\alpha)}{2\rho}\right]-(1-\alpha)\gamma. \tag{9}$$

The value created by the intermediary—the difference in surplus between the case with and without them—is larger when β is smaller. Equation 9 shows that β is smaller when a designer has more bargaining power as a 'sole winner' compared to when both designers choose the same design, the value to unique attribution of designs is high, and the predictability of the superior design is smaller.

By combining the conditions in Proposition 1 that define when there is a need for intervention to spread designers with the condition in Proposition 2 on when the intervention can be successful, we can completely characterize the conditions under which the intermediary using the β strategy can improve upon the equilibrium without this player in which designers choose the same design:

$$\frac{\gamma\rho}{2\tau} > \frac{S_R(1,1)}{S_R(1,2)}, \tag{10}$$

$$\frac{1}{2\gamma\rho}\left[\frac{\gamma(\alpha\gamma+(1-\alpha))+(\alpha+(1-\alpha)\gamma)}{\alpha+(1-\alpha)\gamma}\right] < \frac{S_D(1,2)}{S_D(2,2)} < \frac{1}{2\gamma\rho}\left[\frac{\alpha\gamma}{1-\alpha}+1\right]. \tag{11}$$

These conditions are more readily satisfied when γ is high (so that the premium to the superior design is high) and τ is low (so that coordination downstream is important). The effect of α is ambiguous: the left hand constraint in Equation 11 becomes tighter, but the right hand constraint relaxes at a faster rate as α increases. The reason for the ambiguity is that while, as we have just noted, if α is too high it is impossible for the intermediary to design a β-announcement plan that will spread out designers, it is also the case that higher α increases the need for intervention to spread out designers.

In the β-announcement plan, the intermediary is acting as a randomization device with commitment. The objective is to spread out the designers, achieving both the benefit from the designers mismatching and the benefit that the truly superior design is ultimately chosen by the intermediary more often. This conception of the intermediary's role includes the important aspect that the announcement must be idiosyncratic to some degree: sometimes the intermediary must seem contrarian, in the sense of picking a 'winning' design that is inferior to another possible design. The result is particularly stark in our simple model since we have a small set of available designs, a single winner selected, and the true nature of designs is publicly known after prototyping.

One way to translate this result into real-world settings with variety in standards is to think of the real-world intermediary as picking a *set* of winning designs alongside a general consensus on the designs from other experts. The analog of the β-announcement rule would be for that intermediary to include in the winning set some designs that the general critical consensus feels to be poor. The seeming arbitrariness or contrariness of some of the intermediary's choices relative to the critical consensus can be a way to encourage diversity and risk-taking by designers.

We may also note that it is not crucial for this result that the intermediary *consciously* selects a β-announcement rule. Any behavior by the intermediary that functions in the same way would have the same effect and so would also be capable of rationalizing the power and influence of the intermediary. For example, it may be the case that the intermediary strives always to select the truly superior design—as revealed at the design stage—but occasionally makes mistakes, or is occasionally blinded by her idiosyncratic tastes, so that she sometimes selects a truly inferior design. These behaviors are both consistent with the (conscious) choice of announcement rule made by the intermediary in our model, and so are capable of functioning in the same way to spread out the choices made by designers, as in Proposition 2. This raises the question of the optimal fallibility of the intermediary, which is outside the scope of this paper but may be quite relevant in some applications.

How the commitment to follow the intermediary's announcement is enforced is a question outside of the game structure. It may be that the intermediary has latent power over the players of this game; perhaps the retailers need access to the intermediary which can be denied if they commit and renege. Another possibility is that in a repeated version of this game, for the retailer to renege today could be punished in the game tomorrow. Both of these arguments have appeal in the context of industries with short product life-cycles: the design-and-development game then takes place repeatedly, increasing the chance for standard folk theorem arguments to support cooperation with the intermediaries in equilibrium. The literature on technology standard-setting problems has examined role of repeated game incentives, for example in sustaining 'fair, reasonable and non-discriminatory' royalty fee commitments (Llanes, 2017, Larouche and Schuett, 2017).

Finally, we reiterate that we have abstracted from any notion that the intermediary has special ability to evaluate prototypes or to influence the magnitude of payoffs directly—although these are very plausible in a real-world context and may be beneficial, we have shown that they are not necessary attributes for the intermediary to function as a commitment device.

5.2 Intervention to herd retailers

Next we consider a similar intervention by the intermediary that can improve the sum of payoffs in case iii. of Proposition 1. This is the case in which the designers chose different designs and the retailers chose different designs in equilibrium, which is the unique equilibrium outcome when Equation 5 is false and 7 is true.[5]

In this case it is again possible for a similar action by the intermediary to increase total industry surplus. However, the method is therefore quite different from the previous case of Proposition 2. The 'problem' in this case is that retailers would prefer to choose different designs than to herd on

[5]As we noted above, this problem can exist only in settings in which design choices and the division of surplus are not freely renegotiable after the design stage, since otherwise this possibility will not arise in equilibrium of the prototype and development game.

one. For this reason the intermediary's intervention cannot simply induce the retailers to choose the same design, but instead focuses on encouraging the designers to choose the same design. The intermediary can accomplish this with the following announcement rule: whenever at least one retailer commits to follow the intermediary's announcement, announce the likely superior design, A, whenever it is designed by at least one designer, regardless of which design is revealed to be truly superior. We call this the A-announcement plan.

Proposition 3. *Consider the case in which designers choose different designs and retailers choose different designs in the equilibrium of the game without an intermediary. In the game with an intermediary, there exists a unique equilibrium such that the intermediary uses the A-announcement plan, retailers commit to follow the intermediary's announcement and designers both choose the design that is more likely to be superior, and in turn the sum of payoffs is greater than in the game without an intermediary.*

Proposition 3 implies that there exists a value-enhancing role for the intermediary using the A-announcement plan if retailers' bargaining power is low in the case when two retailers carry the same design picked by a single designer, and retailers' bargaining power is high when they carry a design picked by both designers. Under these conditions, the second-mover retailer is always willing to commit to such a plan, and given this, the first-mover retailer is also willing to commit, and so designers are willing to both play design A. In Proposition 2, the intermediary's intervention was designed to spread out the designers by sometimes favoring the inferior design. In this case, the intervention is designed to herd the retailers on the likely superior in order to in turn herd the designers on the same. Absent the intermediary, the designers chose different designs because retailers chose different designs in the subsequent subgame, generating the worst-case total surplus. With retailers committing to follow the intermediary's announcement, designers are willing to match on the likely superior and avoid this worst-case. In this way the introduction of an intermediary eliminates the equilibrium outcome in which no design is coordinated on downstream.

The intermediary's announcement in equilibrium here will match the design that was identified in advance as more likely to be superior. The intermediary's recommendation will then in some sense confirm the prevailing sentiment, but it will *not* necessarily conform to the information that identifies which design is truly superior, a fact which is revealed after the design stage. In this sense the 'surprise' of an inferior design being announced is more prevalent in this intervention than in the case of the β intervention. The retailer's decision could even in this case occur at the same time as the intermediary's announcement, since it does not require waiting for the true superior to be revealed in the design stage. Like the intervention of Proposition 2, it is also not the case that the intermediary must be consciously choosing to enact this announcement rule. For example, it may be the case that the intermediary must commit to selecting a winning design *before* the designs are finalized, due to publishing constraints or relationships with designers, and so commits to selecting the likely superior design before the truth is known. This behavior is consistent with the announcement rule that was designed to herd the choices made by designers, and would justify the decision of downstream retailers to follow the announcement, just as the conscious choice of announcement rule would.

5.3 The intermediary's incentives

In the preceding sections we assume that the intermediary earns a payoff that is proportional to the total payoff to the four original players. Since the players here are using a commitment device that is non-deterministic—the intermediary retains the right to make whichever announcement she chooses in the announcement stage—in this sense it may be important that the intermediary is an insider. A proportional payoff could reflect higher sales of some auxiliary product offered by the intermediary or greater advertising expenditure in the intermediary's outlet. This naturally implies that the intermediary's strategic choice will match that of a benevolent planner in the same role.

The intermediary is not incorruptible in the one-shot game we have studied. It is possible that at least one of the players may have incentive to bribe the intermediary to influence the announcement after the retailers have committed to follow it. However, just as we argue above that a repeated version of the game would give the intermediary the means to discipline players who renege on commitments, repetition could similarly reduce the corruptibility of the intermediary, in both cases via traditional folk theorem arguments. The ability to sanction and be sanctioned over the long run is one possible reason why it is beneficial that influential intermediaries be long-lived in the industry.

Let us consider briefly a particular application of our model to trend-driven industries. A figure who matches the intermediary in the model is Anna Wintour, former editor-in-chief of *Vogue*, a fashion outlet. Although the fashion industry is vast and has many influential figures, Wintour has historically stood above others. As R.J. Cutler, producer of the movie *The September Issue*, puts it:

> You can make a film in Hollywood without Steven Spielberg's blessing, and you can publish software without Bill Gates's blessing, but you can't succeed in fashion without Anna's blessing. (Levine, 2011)

Winter has been heavily involved in promoting and guiding the work of designers, for example by founding and chairing the judging panel of the CFDA/Vogue Fashion Fund, a competition whose prize includes "business mentoring" (CFDA, 2014). Boosting new designers to prevent stagnation is a strategy that would be good for the overall health of the industry, and thus in this way Wintour fits the role of the intermediary in fostering design diversity.

At the same time, she was able to use her platform as an editor to influence downstream coordination in the products pushed as fashionable. Fashion product cycles are short and frequent, highlighted by 'fashion weeks' at which designers showcase styles for the upcoming season and buyers for couture clothing retailers make deals to sell designers' products. This increases the urgency of forming an industry-wide consensus on what the 'hot' products will be. Wintour's editorial role gave her a pulpit to influence retailers' choices and the latent power to punish deviators in this repeated game setting.

The one-shot with an intermediary that we have presented relies on commitment to a rule by the intermediary and commitment by downstream players to conform. In this fashion application punishment strategies admitted by repetition of the game are a plausible enforcement mechanism for this commitment. In other applications, for example technology standard-setting, the game may be played too infrequently for this to be effective, and we may expect to see or require formalized agreements to arise to generate commitment.

6 Vertical consolidation

In this section we consider an extension of the benchmark model in which designers and retailers are vertically integrated. That is, rather than two designers and two retailers, the players are two hybrid designer-retailers. This can represent either (unmodeled) contractual agreements between retailers and designers, or the case in which a single entity performs both functions. We consider two separate cases: case one, the retail arm of each hybrid will be restricted to use the design produced by its design arm; case two, the retail arm will be free to 'switch' and adopt a different design from the one created by its own design arm.

We can formalize the first case as follows:

1. Nature chooses one of the designs to be 'superior'. Let the probability that A is chosen be $\alpha > \frac{1}{2}$. Nature's choice is not observed by any player.

2. Designer D_1 chooses a prototype design $d_1 \in \{A, B\}$.

3. Designer D_2 observes the choice of designer D_1 and chooses a prototype design $d_2 \in \{A, B\}$.

4. Nature's choice is revealed to all players.

5. Designer D_1 retails $r_1 = d_1$.

6. Designer D_2 retails $r_2 = d_2$.

Proposition 4. *In the game with two hybrid designer-retailers who are restricted to retail their own design, the unique equilibrium has both players design and retail A, the likely superior design.*

Vertical consolidation with retail commitment thus removes in equilibrium the best and worst outcomes from the case with separate designers and retailers. The outcome in which different design prototypes are produced and retailers mismatch is never realized in equilibrium of the game with consolidation, and the case in which different design prototypes are produced and retailers herd is immediately ruled out by assumption. The incentive to mismatch at the design stage is lower once the designer is consolidated with a retailer. Whereas before a designer may have preferred to mismatch, reducing total surplus in order to increase her *share* of the surplus, there is now no such incentive. Consolidation thus mitigates the risk of drawing unfavorable parameters and ending up in the worst-case, at the cost of sometimes missing out on the higher payoff of the best-case.

However, the intermediary in the game of Propositions 2 and 3 is not only able to eliminate the worst-case outcome in the setting with unconsolidated players, but also preserve and enhance the range of parameters such that higher industry surplus, with a diversity of designs and then herding by retailers, can be realized. In this sense, vertical consolidation as an aid to coordination and commitment is inferior to the role of intermediary in the unconsolidated industry.

Next consider a game with consolidated players who can 'switch' from the design they prototyped at the retail stage:

1. Nature chooses one of the designs to be 'superior'. Let the probability that A is chosen be $\alpha > \frac{1}{2}$. Nature's choice is not observed by any player.

2. Designer D_1 chooses a prototype design $d_1 \in \{A, B\}$.

3. Designer D_2 observes the choice of designer D_1 and chooses a prototype design $d_2 \in \{A, B\}$.

4. Nature's choice is revealed to all players.

5. Designer D_1 chooses a design $r_1 \in \{d_1, d_2\}$.

6. Designer D_2 observes the choice of designer D_1 and chooses a design $r_2 \in \{d_1, d_2\}$.

Proposition 5. *In the game with two hybrid designer-retailers who are not restricted to retail their own design, there exists an unique equilibrium that is parameter dependent:*

i. *Designer 1 chooses design A, designer 2 chooses design B, and both retail the true superior design if*

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) < \left[\frac{1}{2}S_R(1,2) + (1-\alpha)S_D(1,2)\right]\rho\gamma, \tag{12}$$

and either

$$S_R(1,2) > \frac{2\tau\gamma}{\rho}, \text{ and} \tag{13}$$

$$\frac{1}{2}S_R(1,2) + S_D(1,2) < \frac{1}{2}S_R(1,2)\gamma, \tag{14}$$

or

$$\frac{2\tau}{\rho\gamma} < S_R(1,2) < \frac{2\tau\gamma}{\rho}. \tag{15}$$

ii. *Designer 1 chooses design A, designer 2 chooses design B, and both retail A if*

$$S_R(1,2) > \frac{2\tau\gamma}{\rho}, \tag{16}$$

$$\frac{1}{2}S_R(1,2) + S_D(1,2) > \frac{1}{2}S_R(1,2)\gamma, \text{ and} \tag{17}$$

$$S_R(1,2)\rho > 1. \tag{18}$$

iii. *Both designers choose design A in all other cases.*

In one respect this outcome is similar to the outcome of Proposition 4, the case in which switching was not possible. The worst-case outcome from the unconsolidated game is again eliminated: since the hybrid designer-retailer earns both the designer and retailer's share of surplus, there is no incentive for a designer-retailer to mismatch at the retail stage in order to increase her share of surplus. However, in the case with switching, the outcome that maximizes total payoff can occur in equilibrium, although the conditions for it are more restrictive than with unconsolidated designers (as in Proposition 1). This is because the loss to a designer-retailer from choosing a distinct design that might not be revealed superior by Nature can be outweighed by the extra surplus they enjoy when a diversity of designs was produced.

In the game with consolidated designer-retailers and possible switching, it is again the case that an intermediary acting similarly to before can increase industry surplus. Again we consider a structure such that both retailers can precommit to follow the intermediary's announcement. While before the intermediary had to favor the true inferior design in making announcements, it can be sufficient to improve on the equilibrium outcome here for the intermediary to simply announce the true superior product, whichever it may be. The intermediary then acts as a pure commitment device; precommitment to the true superior constrains the designer-retailers in subgames in which they learn that their design is inferior. This makes mismatched designs followed by herding in the retail stage an equilibrium outcome for a greater range of parameters than in the game absent an intermediary. Formally:

Proposition 6. *In the game with two hybrid designer-retailers who are not restricted to retail their own design, consider the case in which both designers select A in the game without an intermediary. Further suppose the intermediary's announcement plan is to announce the true superior design whenever it has been played and when both designer-retailers have committed to follow the announcement, and to make no announcement otherwise. If*

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) < [S_R(1,2) + (1-\alpha)S_D(1,2)]\,\rho\gamma, \tag{19}$$

then the unique equilibrium in the subgame following the intermediary's announcement plan has both designer-retailers commit to follow the intermediary's announcement, choose different designs, and retail the true superior design.

Note that this is not in general the best the intermediary can do: it is possible, at least in some cases, for the intermediary to enact a β-announcement plan as before. We have omitted this case for ease of exposition.

6.1 Incentives for vertical integration

In this section we demonstrate that it can be the case that a retailer-designer pair can do better by integrating (again either contractually or by a designer retailing its own design) than they would under the intermediary's β-announcement plan in the unconsolidated industry. This in turn can lead the second retailer-designer pair to consolidate, and thus leave industry surplus lower than before, resulting in the equilibrium of Proposition 4 or Proposition 5.

Consider a game similar to the original case except that designer D_2 is consolidated with retailer R_2, who sells the design produced by D_2.

Proposition 7. *In the game in which designer 2 and retailer 2 are consolidated and sell the design produced by designer 2, then if*

$$\frac{S_R(1,1)}{S_R(1,2)} < \frac{\rho}{2\tau\gamma} \tag{20}$$

and

$$S_D(1,2) + \frac{1}{2}S_R(1,2) > \frac{\alpha\gamma + (1-\alpha)}{2\rho(\alpha + (1-\alpha)\gamma)}, \tag{21}$$

the unique equilibrium has the designers produce different designs and the retailers both retail the design produced by designer 2.

In this equilibrium, whatever design is played by the first designer, the second designer will choose the other, which in turn will be selected by both retailers. The payoff to the consolidated $D_2 - R_2$ is higher in this case than the payoff earned by the pair in the equilibrium of Proposition 2, the intermediary's β-announcement plan. The incentive for vertical consolidation is therefore not ruled out by the intermediary's intervention to increase industry surplus.

This leaves designer D_1 unselected, and with a payoff of zero. There are two possibilities. It can be the case that there is incentive for the second pair D_1 and R_1 to consolidate, or it can be the case that retailer R_1 prefers this equilibrium to consolidation, leaving D_1 effectively defunct. We can therefore see preventing such a sequence of consolidation as another potential role for the intermediary.

In sum, there is an incentive for upstream and downstream firms to vertically integrate, but that this can create a cascade of vertical integration that leaves all worse off than before. We may say informally that vertical integration is a 'safe' choice for a designer and retailer, since it gives an middling payoff with certainty, ruling out the possibility of larger gains or losses. This contrasts with an unintegrated industry with an intermediary, in which total industry surplus is always weakly higher than in the baseline case. Under vertical integration the intermediary can still perform a similar role as in the unintegrated industry, but with less effectiveness.

The conclusions in the analysis of vertical integration here are complementary to Church and Gandal (2000), which demonstrates that predatory vertical mergers to shut down competing technology can be an equilibrium outcome of a game with systems competition. The setting and precise incentives for vertical integration are a little different, but the spirit of the result is quite similar. In both cases product variety may ultimately suffer from the possibility and incentive for vertical integration.

7 Incentive to predict trends

In all versions of the model discussed in earlier sections, it is the case that at least one player has private incentive to enhance the precision with which the true superior design can be identified—that is, to increase α. For example, in the β-announcement equilibrium, designer 1 'wins' the design tournament with probability $(\alpha - \beta)$, which is increasing in α. However, another pervasive feature of the model is that as this precision increases, the incentive for designers to differentiate in the design stage is undermined. Eventually, the equilibrium selection effect is to push the game away from the joint payoff-maximizing outcome, and to make the value-enhancing intervention by the intermediary more difficult. The private incentive to acquire information thus can at best conflict with social incentives, and at worst be counterproductive even for the party acquiring the information.

In contrast, a primitive assumption in our analysis was a set of possible designs—the set $\{A, B\}$—that was of the same order of magnitude as the set of designers. We can think of this as capturing a 'narrowing down' of the designs that are under general consideration, implying that other designs outside this set are generally known to be inferior to those in the set. This rules out a case in which the true superior design may go 'undiscovered' even with maximal differentiation by designers.

The tension between these two considerations implies a social sweet spot for information acquisition: narrowing down the set of possible designs to a manageable size is good for joint payoffs, but narrowing down too far undermines the design tournament and is bad for joint payoffs. In some applications, the emergence of trends can seem somewhat arbitrary, particularly in situations where the value of downstream coordination among consumers is driven by herd behavior (in the sense of Bikhchandani et al., 1992 and Banerjee, 1992), and so there is a lot of leeway for coordinating institutions to make pronouncements without being constrained by objectively verifiable product characteristics. Our model suggests that too much herding too soon in the design process can be counterproductive for design-and-development outcomes.

8 Conclusion

In this paper we investigate the role of intermediaries in settings that which ideally see the proposal of diverse design ideas and coordination on development of just one of these ideas. We consider a process of upstream players developing prototypes and downstream players choosing among these prototypes, and show that in general the sum of payoffs is not maximized by this process. There are two broad reasons. One is that upstream designers may prefer to produce the same design as each other rather than differentiating their prototypes, which guarantees the designer a share of the market but reduces valuable diversity in the design stage. Another is that downstream retailers may prefer to select different designs to sell rather than coordinate on a standard design, which increases the retailer's bargaining power over its design but sacrifices valuable standardization.

In both cases intervention by an intermediary can help increase the sum of payoffs in the game. The intermediary can make public pronouncements on which prototype the retailers should select, after the designs are revealed but before retailers select among them. We show that retailers have incentive to commit to follow these recommendations, and that this can raise payoffs. Depending on circumstance, the intermediary's optimal recommendations can include various strategies. For example, if more design diversity is needed, the intermediary may occasionally recommend an *inferior* design to retailers, to encourage designers to make varied prototypes. If, however, more coordination by retailers on a particular design is needed, the intermediary may commit to recommending a particular design in advance in order to induce all designers to focus on it, thus preventing retailers from selecting different designs.

This intermediary's role is robust to vertical integration among design and retail operations within the industry. Nevertheless, another implication of our analysis is that vertical consolidation among designers and downstream firms can be good for the consolidating players but socially harmful by discouraging both design diversity at the prototyping stage and coordination at the retail stage. Overall efficiency and beneficial intervention by the intermediary are therefore harder to achieve after vertical consolidation. A similar effect occurs with the incentive for designers and retailers to acquire better information about the value of different designs in advance. This information is valuable for an individual player but again is socially harmful, since it reduces the incentive for designers to choose different designs.

In sum, the model we have developed suggests one justification for the level of power possessed by prominent intermediaries who act as coordinators in settings that rely on competitive prototyping and development. These players have a stake in the game but the source of their influence can seem mysterious. We show that their value extends beyond any talent they have in evaluating designs or in swaying consumers. Even without these talents, these players can still improve outcomes by acting as a 'smart' commitment device for the various players, who may then be willing to cede power to such a player, to the benefit of all.

Finally, we may note that we have been flexible about the interpretation of payoffs. In applications with marketable products, consumer welfare is an open question in the analysis in this paper. It is possible that coordination may be a net benefit or a net cost to consumers, depending, for example, on whether the benefits of network externalities outweigh the costs of increased market power for producers or the loss of product diversity. The interaction between explicit specifications of consumer behavior and the incentives for upstream and downstream firms may give fresh insight to specific applications of the model.

References

Adams, J. and Merrill, S. (2008). Candidate and party strategies in two-stage elections beginning with a primary. *American Journal of Political Science*, 52(2):344–359.

Aumann, R. J. (1974). Subjectivity and correlation in randomized strategies. *Journal of Mathematical Economics*, 1(1):67–96.

Axelrod, R., Mitchell, W., Thomas, R. E., Bennett, D. S., and Bruderer, E. (1995). Coalition formation in standard-setting alliances. *Management Science*, 41(9):1493–1508.

Banerjee, A. V. (1992). A simple model of herd behavior. *The Quarterly Journal of Economics*, 107(3):797–817.

Bikhchandani, S., Hirshleifer, D., and Welch, I. (1992). A theory of fads, fashion, custom, and cultural change as informational cascades. *The Journal of Political Economy*, 100(5):992–1026.

Bresnahan, T. F. and Greenstein, S. (1999). Technological competition and the structure of the computer industry. *The Journal of Industrial Economics*, 47(1):1–40.

Cabral, L. and Salant, D. (2014). Evolving technologies and standards regulation. *International Journal of Industrial Organization*, 36:48 – 56. Standards, Intellectual Property & Innovation.

CFDA (2014). CFDA/Vogue Fashion Fund. CFDA.com. `http://cfda.com/programs/the-cfdavogue-fashion-fund`. Accessed 22 May 2014.

Choi, J. (1996). Standardization and experimentation: Ex ante vs. ex post standardization. *European Journal of Political Economy*, 12(2):273–290.

Church, J. and Gandal, N. (2000). Systems competition, vertical merger, and foreclosure. *Journal of Economics & Management Strategy*, 9(1):25–51.

Dixit, A. (1982). Recent developments in oligopoly theory. *The American Economic Review, Papers and Proceedings*, 72(2):12–17.

Farrell, J., Hayes, J., Shapiro, C., and Sullivan, T. (2007). Standard setting, patents, and hold-up. *Antitrust Law Journal*, 74(3):603–670.

Farrell, J. and Saloner, G. (1985). Standardization, compatibility, and innovation. *The RAND Journal of Economics*, 16(1):70–83.

Gandal, N. (2002). Compatibility, Standardization, and Network Effects: Some Policy Implications. *Oxford Review of Economic Policy*, 18(1):80–91.

Hsu, G., Roberts, P. W., and Swaminathan, A. (2012). Evaluative schemas and the mediating role of critics. *Organization Science*, 23(1):83–97.

Katz, M. L. and Shapiro, C. (1986). Technology adoption in the presence of network externalities. *The Journal of Political Economy*, 94(4):822–841.

Katz, M. L. and Shapiro, C. (1992). Product introduction with network externalities. *The Journal of Industrial Economics*, 40(1):55–83.

Larouche, P. and Schuett, F. (2017). Repeated interaction in standard setting. https://sites.google.com/site/schuettflorian/larouche_schuett-repeated_standards.pdf. Accessed 31 July, 2017.

Levine, J. (2011). Brand Anna. WSJ Magazine. https://www.wsj.com/articles/SB10001424052748704893604576200722939264658. Accessed 4 August 2017.

Llanes, G. (2017). Ex-ante Agreements, FRAND Commitments, and Technology Choice in Standard Setting Organizations. http://www.gllanes.com/sso.pdf. Accessed 31 July, 2017.

Llanes, G. and Poblete, J. (2014). Ex ante agreements in standard setting and patent-pool formation*. *Journal of Economics & Management Strategy*, 23(1):50–67.

Rysman, M. and Simcoe, T. (2008). Patents and the performance of voluntary standard-setting organizations. *Management Science*, 54(11):1920–1934.

Schelling, T. (1960). *The Strategy of Conflict*. Harvard University Press, Cambridge.

Shapiro, C. (2000). Navigating the patent thicket: Cross licenses, patent pools, and standard setting. *Innovation Policy and the Economy*, 1:119–150.

Shapiro, C. and Varian, H. R. (1999). The art of standards wars. *California Management Review*, 41(2):8–32.

A Proofs

Proposition 1

Proof. We proceed by backward induction. In the final stage, retailer R_2 chooses a design $r_2 \in \{d_1, d_2\}$. If $d_1 = d_2$, this is degenerate and $r_2 = d_1 = d_2$. There are two further cases:

i. $d_1 \neq d_2$ and R_1 chose the design that was revealed to be superior. If R_2 also chooses the superior design, R_2 earns $\frac{1}{2}S_R(1,2)\gamma\rho$. If R_2 chooses the inferior design, R_2 earns $S_R(1,1)\tau$. Thus R_2 chooses to match R_1 and play the superior design if

$$\frac{\gamma\rho}{2\tau} > \frac{S_R(1,1)}{S_R(1,2)}, \tag{22}$$

and chooses the inferior design otherwise.

ii. $d_1 \neq d_2$ and R_1 chose the design that was revealed to be inferior. If R_2 also chooses the inferior design, R_2 earns $\frac{1}{2}S_R(1,2)\rho$. If R_2 chooses the superior design, R_2 earns $S_R(1,1)\gamma\tau$. Thus R_2 chooses to match R_1 and play the inferior design if

$$\frac{\rho}{2\gamma\tau} > \frac{S_R(1,1)}{S_R(1,2)}, \tag{23}$$

and chooses the superior design otherwise.

This completes the cases for the final stage.

In the preceding stage, retailer R_1 chooses a design $r_1 \in \{d_1, d_2\}$. Again if $d_1 = d_2$, this is degenerate and $r_2 = d_1 = d_2$. If $d_1 \neq d_2$, there are three possible cases:

i. If equations 22 and 23 are both true, then R_2 will play $r_2 = r_1$ for any r_1. R_1 prefers to select the true superior design if

$$\frac{1}{2}S_R(1,2)\gamma\rho > \frac{1}{2}S_R(1,2)\rho. \tag{24}$$

Since $\gamma > 1$, this condition is always satisfied.

ii. If equation 22 and 23 are both false, then R_2 will play $r_2 \neq r_1$ for any r_1. R_1 prefers to select the true superior design if

$$S_R(1,1)\gamma\tau > S_R(1,1)\tau. \tag{25}$$

Since $\gamma > 1$, this condition is always satisfied.

iii. If equation 22 is true and 23 is false, then R_2 will play $r_2 = r_1$ if r_1 is the true superior design, and R_2 will play $r_2 \neq r_1$ if r_1 is the true inferior design. R_1 prefers to select the true superior design if

$$S_R(1,2)\gamma\rho > S_R(1,1)\tau. \tag{26}$$

This is identical to equation 22 which is true in this case.

It cannot be that equation 22 is false while 23 is true, since for this to be the case would require

$$\frac{\rho}{2\gamma\tau} > \frac{\gamma\rho}{2\tau}, \tag{27}$$

which cannot be since $\gamma > 1$. Therefore the three cases are exhaustive, and retailer R_1 will always select the true superior design whenever both designs are available.

In the preceding stage, designer D_2 must choose a design $d_2 \in \{A, B\}$. There are four possible cases:

i. If $d_1 = A$ and equation 22 is true, then if D_2 plays A, D_2 will earn an expected payoff of $\alpha\left[\frac{1}{2}S_D(2,2)\gamma\right] + (1-\alpha)\left[\frac{1}{2}S_D(2,2)\right]$. If D_2 plays B, D_2 will earn $(1-\alpha)\left[S_D(1,2)\gamma\rho\right]$. Thus D_2 will match D_1 and play A if

$$\frac{1}{2\gamma\rho}\left[\frac{\alpha\gamma}{1-\alpha} + 1\right] > \frac{S_D(1,2)}{S_D(2,2)}. \tag{28}$$

ii. If $d_1 = B$ and equation 22 is true, then if D_2 plays A, D_2 will earn an expected payoff of $\alpha\left[S_D(1,2)\gamma\rho\right]$. If D_2 plays B, D_2 will earn $\alpha\left[\frac{1}{2}S_D(2,2)\right]+(1-\alpha)\left[\frac{1}{2}S_D(2,2)\gamma\right]$. Thus D_2 will play A if

$$\frac{S_D(1,2)}{S_D(2,2)} > \frac{1}{2\gamma\rho}\left[\frac{(1-\alpha)\gamma}{\alpha}+1\right]. \tag{29}$$

This condition is true always.

iii. If $d_1 = A$ and equation 22 is false, then if D_2 plays A, D_2 will earn an expected payoff of $\alpha\left[\frac{1}{2}S_D(2,2)\gamma\right]+(1-\alpha)\left[\frac{1}{2}S_D(2,2)\right]$. If D_2 plays B, D_2 will earn $\alpha\left[S_D(1,1)\tau\right]+(1-\alpha)\left[S_D(1,1)\gamma\tau\right]$. Thus D_2 will match D_1 and play A if

$$\frac{\alpha\gamma+(1-\alpha)}{2\left[\alpha\tau+(1-\alpha)\gamma\tau\right]} > \frac{S_D(1,1)}{S_D(2,2)}. \tag{30}$$

iv. If $d_1 = B$ and equation 22 is false, then if D_2 plays A, D_2 will earn an expected payoff of $\alpha\left[S_D(1,1)\gamma\tau\right]+(1-\alpha)\left[S_D(1,1)\tau\right]$. If D_2 plays B, D_2 will earn $\alpha\left[\frac{1}{2}S_D(2,2)\right]+(1-\alpha)\left[\frac{1}{2}S_D(2,2)\gamma\right]$. Thus D_2 will play A if

$$\frac{S_D(1,1)}{S_D(2,2)} > \frac{\alpha+\gamma(1-\alpha)}{2\left[\alpha\gamma\tau+(1-\alpha)\tau\right]}. \tag{31}$$

This completes the second designer's stage.

Finally the preceding stage is the first in which designer D_1 must choose $d_1 \in \{A,B\}$.

i. If equations 22 and 28 are both true, then if D_1 plays A, D_2 will match and D_1 earns $\alpha\left[\frac{1}{2}S_D(2,2)\gamma\right]+(1-\alpha)\left[\frac{1}{2}S_D(2,2)\right]$. If D_1 plays B, D_2 will play A and the retailers will both select the true superior, so that D_1 earns $(1-\alpha)S_D(1,2)\gamma\rho$. Thus D_1 will prefer to play A if

$$\frac{1}{2\gamma\rho}\left[\frac{\alpha\gamma}{1-\alpha}+1\right] > \frac{S_D(1,2)}{S_D(2,2)}. \tag{32}$$

This is equation 28, which is true in this case and so D_1 plays A for sure.

ii. If equation 22 is true and 28 is false, then D_2 will mismatch either choice by D_1 and the retailers will both select the true superior. D_1 thus earns $\alpha S_D(1,2)\gamma\rho$ by selecting A and $(1-\alpha)S_D(1,2)\gamma\rho$ by selecting B. Since $\alpha > \frac{1}{2}$, D_1 prefers to play A.

iii. If equation 22 is false, 30 is true, and 31 is false, then D_2 will match if $d_1 = A$ and will match if $d_1 = B$, and both retailers must then select the only available design. D_1 thus earns $\alpha\left[\frac{1}{2}S_D(2,2)\gamma\right]+(1-\alpha)\left[\frac{1}{2}S_D(2,2)\right]$ by selecting A and $\alpha\left[\frac{1}{2}S_D(2,2)\right]+(1-\alpha)\left[\frac{1}{2}S_D(2,2)\gamma\right]$ by selecting B. Since $\alpha > \frac{1}{2}$, D_1 prefers to play A.

iv. If equation 22 is false, 30 is false, and 31 is true, then D_2 will mismatch if $d_1 = A$ and will mismatch if $d_1 = B$, and retailers will select different designs. D_1 thus earns $\alpha\left[S_D(1,1)\gamma\tau\right]+(1-\alpha)\left[S_D(1,1)\tau\right]$ by selecting A and $\alpha\left[S_D(1,1)\tau\right]+(1-\alpha)\left[S_D(1,1)\gamma\tau\right]$ by selecting B. Since $\alpha > \frac{1}{2}$, D_1 prefers to play A.

v. If equation 22 is false, 30 is true, and 31 is true, then D_2 will match if $d_1 = A$ and mismatch if $d_1 = B$, and retailers will select different designs if possible. D_1 thus earns $\alpha\left[\frac{1}{2}S_D(2,2)\gamma\right]+$

$(1-\alpha)\left[\frac{1}{2}S_D(2,2)\right]$ by selecting A and $\alpha\left[S_D(1,1)\tau\right]+(1-\alpha)\left[S_D(1,1)\gamma\tau\right]$ by selecting B. Thus D_1 will prefer to play A if

$$\frac{\alpha\gamma+(1-\alpha)}{2\left[\alpha\tau+(1-\alpha)\gamma\tau\right]} > \frac{S_D(1,1)}{S_D(2,2)}. \tag{33}$$

This is equation 30, which is true in this case.

It cannot be that equation 30 is false and 31 is false, since for this to be the case would require

$$\frac{\alpha\gamma+(1-\alpha)}{2\left[\alpha\tau+(1-\alpha)\gamma\tau\right]} < \frac{\alpha+\gamma(1-\alpha)}{2\left[\alpha\gamma\tau+(1-\alpha)\tau\right]}, \tag{34}$$

which cannot be since $\gamma > 1$. These cases are therefore exhaustive.

We can thus completely characterize the outcome in equilibrium in this game. D_1 plays A, the likely superior product. D_2 plays A if equation 22 is true and 28 is true, or if 22 is false and 30 is true, or else plays B. If $d_1 = d_2$ then on the equilibrium path both retailers play this design trivially. If $d_1 \neq d_2$, then R_1 plays the product that is revealed to be the true superior, and R_2 plays the true superior if equation 22 is true, and the true inferior otherwise. This completes the proof. □

Proposition 2

Proof. Note that if both retailers do not commit to follow the intermediary's recommendation, then the unique SPNE outcome of the game with the intermediary is identical that of the game without the intermediary.

Consider the case in which both retailers have committed to follow the intermediary's recommendation, and say that the intermediary has announced a parameter β. In this case all that follows the designers' choices is deterministic. In the stage in which designer D_2 must choose a design, there are two cases.

i. If D_1 picked A, then D_2 earns a higher payoff by selecting B than A if

$$(1-\alpha)S_D(1,2)\gamma\rho+\beta S_D(1,2)\rho \geq \frac{1}{2}\alpha S_D(2,2)\gamma+\frac{1}{2}(1-\alpha)S_D(2,2) \tag{35}$$

$$\beta \geq \frac{S_D(2,2)}{S_D(1,2)}\left[\frac{\alpha\gamma+(1-\alpha)}{2\rho}\right]-(1-\alpha)\gamma. \tag{36}$$

Denote this β as $\underline{\beta}_D$.

ii. If D_1 picked B, then D_2 earns a higher payoff by selecting A than B if

$$(\alpha-\beta)S_D(1,2)\gamma\rho > \frac{1}{2}\alpha S_D(2,2)+\frac{1}{2}(1-\alpha)S_D(2,2)\gamma \tag{37}$$

$$\beta < \alpha-\frac{S_D(2,2)}{S_D(1,2)}\left[\frac{\alpha+\gamma(1-\alpha)}{2\gamma\rho}\right]. \tag{38}$$

Denote this β as $\bar{\beta}_D$.

Next consider the preceding stage in which D_1 must choose a design. There are four possible cases.

i. Equations 36 and 38 are both satisfied. In this case D_2 will mismatch in either case, and so different designs will be played.

ii. Equations 36 and 38 are both not satisfied. In this case D_2 will match the design chosen by D_1, and so the same design will be played.

iii. Equation 36 is satisfied and 38 is not. In this case D_2 will match when D_1 plays B and mismatch when D_1 plays A. D_1 therefore prefers to play A if

$$(\alpha - \beta)S_D(1,2)\gamma\rho > \frac{1}{2}\alpha S_D(2,2) + \frac{1}{2}(1-\alpha)S_D(2,2)\gamma, \tag{39}$$

that is, if Equation 38 is satisfied, a contradiction. Thus in this case D_1 and D_2 each play B.

iv. Equation 38 is satisfied and 36 is not. In this case D_2 will match when D_1 plays A and mismatch when D_1 pays B. D_1 therefore prefers to play A if

$$(1-\alpha)S_D(1,2)\gamma\rho + \beta S_D(1,2)\rho < \frac{1}{2}\alpha S_D(2,2)\gamma + \frac{1}{2}(1-\alpha)S_D(2,2), \tag{40}$$

that is, if Equation 36 is not satisfied. Thus in this case D_1 and D_2 each play A.

To induce the designers to select different designs therefore requires that β satisfy both Equations 36 and 38. For there to exist a β such that both are satisfied requires that

$$\frac{S_D(2,2)}{S_D(1,2)}\left[\frac{\alpha\gamma + (1-\alpha)}{2\rho}\right] - (1-\alpha)\gamma < \alpha - \frac{S_D(2,2)}{S_D(1,2)}\left[\frac{\alpha + \gamma(1-\alpha)}{2\gamma\rho}\right] \tag{41}$$

$$\frac{1}{2\gamma\rho}\left[\frac{\alpha\gamma^2 + 2(1-\alpha)\gamma + \alpha}{\alpha + (1-\alpha)\gamma}\right] < \frac{S_D(1,2)}{S_D(2,2)}. \tag{42}$$

Since industry surplus is greater only in the case in which the designers select different designs, and since surplus in that case is decreasing in β, we can rule out $\beta > \underline{\beta}_D$ as dominated by $\beta = \underline{\beta}_D$ for the intermediary.

Next return to the retailers' decision to commit to follow the intermediary's announcement. For the retailers to earn a higher payoff under the β regime than in the equilibrium of the game without the intermediary (and, equivalently, the equilibrium in any subgame in which both retailers do not commit to follow the intermediary's recommendation) requires:

$$(1-\beta)\frac{1}{2}S_R(1,2)\gamma\rho + \beta\frac{1}{2}S_D(1,2)\rho > \alpha\frac{1}{2}S_R(2,2)\gamma + (1-\alpha)\frac{1}{2}S_R(2,2) \tag{43}$$

$$\beta < \frac{\gamma}{\gamma-1} - \frac{S_R(2,2)}{S_R(1,2)}\left[\frac{\alpha\gamma + (1-\alpha)}{\rho(\gamma-1)}\right] \tag{44}$$

Denote this β as $\bar{\beta}_R$. If β is below this threshold and also successfully induces the designers to mismatch, each retailer prefers to commit given that the other commits to follow the intermediary's announcement. For this to be the case it must be that $\underline{\beta}_D < \bar{\beta}_R$:

$$\frac{S_D(2,2)}{S_D(1,2)}\left[\frac{\alpha\gamma + (1-\alpha)}{2\rho}\right] - (1-\alpha)\gamma < \frac{\gamma}{\gamma-1} - \frac{S_R(2,2)}{S_R(1,2)}\left[\frac{\alpha\gamma + (1-\alpha)}{\rho(\gamma-1)}\right] \tag{45}$$

$$\frac{1}{2\gamma\rho}\left[\frac{(\gamma+1)(\alpha\gamma + (1-\alpha))}{\gamma + \gamma(\gamma-1)(1-\alpha)}\right] < \frac{S_D(1,2)}{S_D(2,2)}. \tag{46}$$

Thus if 8 and 46 are satisfied, the unique SPNE outcome of the game with the intermediary sees the intermediary set $\beta = \underline{\beta}_D$, the retailers commit to follow the intermediary's announcement, and the retailers choose different designs. Since the left hand side of equation 8 is greater than the left hand side of 46, the latter condition is satisfied whenever the former is. □

Proposition 3

Proof. As with Proposition 2, if neither retailer commits to follow the intermediary's recommendation, then the unique SPNE outcome of the game with the intermediary is identical that of the game without the intermediary. We know also that if only one retailer has committed to follow the intermediary's A recommendation, the other retailer will always prefer to choose B if it is available (since Equation 5 is false), and therefore the designers will choose different designs (since equation 7 is true).

If both retailers have committed to follow the intermediary's announcement, then play following the designers' choices is deterministic. Consider the choice of designer D_2. There are two cases:

i. If D_1 picked A, then the intermediary will announce A and retailers will select A. D_2 thus earns zero by choosing B (since $\pi(1,0) = 0$ by assumption) and earns a positive payoff by choosing A.

ii. If D_1 picked B, then D_2 earns a higher payoff by selecting A than B if

$$S_D(1,2)\rho(\alpha\gamma + (1-\alpha)) > \frac{1}{2}S_D(2,2)(\alpha + (1-\alpha)\gamma) \tag{47}$$

$$\frac{S_D(1,2)}{S_D(2,2)} > \frac{\alpha + (1-\alpha)\gamma}{2\rho(\alpha\gamma + (1-\alpha)}. \tag{48}$$

This is true for any parameters in the assumed ranges.

Next consider the choice of designer D_1 in the preceding stage. Since D_2 will choose A in either case, and since the intermediary will announce A whenever it is played, D_1 will earn zero by choosing B (again since $\pi(1,0) = 0$ by assumption) and will earn a positive payoff by choosing A. Thus both designers will choose A in equilibrium of the subgame following retailers committing to follow the intermediary's recommendation.

Next consider to the retailers' decision to commit to follow the intermediary's announcement. First consider the decision by retailer R_2. There are two cases:

i. If R_1 did not commit, then if R_2 commits, the outcome in the following subgame will be for designers to choose different designs and retailer R_1 to select design B. If R_2 does not commit, then as in the game without the intermediary, both designs will be played by the designers and R_2 will ultimately play the true inferior design. R_2 thus prefers to commit since

$$S_R(1,1)\tau(\alpha\gamma + (1-\alpha)) > S_R(1,1)\tau. \tag{49}$$

ii. If R_1 did commit, then if R_2 commits, the outcome is as above with both designers playing A. If R_2 does not commit, the outcome in the following subgame will be for designers to choose different designs and retailer R_1 to select A. Since Equation 5 is false, R_2 will then prefer to play B. R_2 thus prefers to commit since

$$\frac{1}{2}S_D(2,2)(\alpha\gamma + (1-\alpha)) > S_R(1,1)\tau(\alpha + (1-\alpha)\gamma). \tag{50}$$

Thus R_2 prefers to commit to follow the intermediary's recommendation regardless of whether R_1 commits. The decision for R_1 in the preceding stage is therefore identical to case ii., and so R_1 prefers to commit. The unique equilibrium in the game in which the intermediary announces A whenever it is played is for both retailers to commit to follow the recommendation, and all parties to play A throughout.

Finally note that since Equation 7 is true, then retailers prefer to mismatch than to match on the true superior product when both designs are available. Since the equilibrium in any subgame in which both retailers do not commit to follow the intermediary's recommendation has designers mismatch and retailers mismatch, this means that there cannot be an equilibrium in the game with an intermediary in which the retailers commit to follow the intermediary's recommendation if both designs will go on to be played in equilibrium of the subsequent subgame. Thus the intermediary can do no better than the plan to announce A whenever it is played. □

Proposition 4

Proof. Since the designer-retailers are restricted to retail the same design, everything following the design stage is deterministic. In stage 3, D_2 chooses a design. There are two cases.

The first case is $d_1 = A$. If $d_2 = A$, D_2 earns $\frac{1}{2}(\alpha\gamma + (1-\alpha))$, while if $d_2 = B$, D_2 earns $\alpha\tau + (1-\alpha)\tau\gamma$, which is certainly lower. Thus $d_2 = A$ is the best response by D_2 if $d_1 = A$.

The second case is $d_1 = B$. If $d_2 = A$, D_2 earns $\alpha\tau\gamma + (1-\alpha)\tau$, while if $d_2 = B$, D_2 earns $\frac{1}{2}(\alpha + (1-\alpha)\gamma)$. Thus $d_2 = A$ is the best response by D_2 iff $2\tau > \frac{\alpha+(1-\alpha)\gamma}{\alpha\gamma+(1-\alpha)}$.

In stage 2, D_1 chooses a design. If $d_1 = A$, then $d_2 = A$ and D_1 earns $\frac{1}{2}(\alpha\gamma + (1\alpha))$. If $d_1 = B$, then if $d_2 = A$ D_1 earns $\alpha\tau + (1-\alpha)\tau\gamma$, while if $d_2 = B$ D_1 earns $\frac{1}{2}(\alpha + (1-\alpha)\gamma)$. Both payoffs are less than the payoff to $d_1 = A$. Thus the unique subgame perfect Nash equilibrium outcome is for both designers to play A. □

Proposition 5

Proof. In the last stage D_2 selects $r_2 \in \{d_1, d_2\}$. If $d_1 = d_2$ this is degenerate. If $d_1 \neq d_2$ there are four cases:

i. d_1 is revealed to be the true superior and $r_1 = d_1$. In this case $r_2 = d_2$ yields a higher payoff than $r_2 = d_1$ for D_2 if

$$\tau > \frac{1}{2}S_R(1,2)\gamma\rho. \tag{51}$$

ii. d_1 is revealed to be the true inferior and $r_1 = d_1$. In this case $r_2 = d_2$ yields a higher payoff than $r_2 = d_1$ for D_2 if

$$\tau\gamma > \frac{1}{2}S_R(1,2)\rho. \tag{52}$$

iii. d_1 is revealed to be the true superior and $r_1 = d_2$. In this case $r_2 = d_2$ yields a higher payoff than $r_2 = d_1$ for D_2 if

$$\left[\frac{1}{2}S_R(1,2) + S_D(1,2)\right]\rho > \left[S_R(1,1)\gamma + S_D(1,1)\right]\tau. \tag{53}$$

iv. d_1 is revealed to be the true inferior and $r_1 = d_2$. In this case $r_2 = d_2$ yields a higher payoff than $r_2 = d_1$ for D_2 if

$$\left[\frac{1}{2}S_R(1,2) + S_D(1,2)\right]\rho\gamma > \left[S_R(1,1) + S_D(1,1)\gamma\right]\tau, \tag{54}$$

which is true always.

In the preceding stage, D_1 selects $r_1 \in \{d_1, d_2\}$. If $d_1 = d_2$ this is degenerate. If $d_1 \neq d_2$ there are two cases:

i. d_1 is the true superior.

a) Equations 51 and 53 are true. In this case $r_1 = d_1$ yields a higher payoff than $r_1 = d_2$ for D_1 if

$$\tau\gamma > \frac{1}{2}S_R(1,2)\rho, \tag{55}$$

which is true since 51 is true.

b) Equations 51 and 53 are false. In this case $r_1 = d_1$ yields a higher payoff than $r_1 = d_2$ for D_1 if

$$\left[\frac{1}{2}S_R(1,2) + S_D(1,2)\right]\rho\gamma > \left[S_R(1,1) + S_D(1,1)\gamma\right]\tau, \tag{56}$$

which is true always.

c) Equation 51 is true and 53 is false. In this case $r_1 = d_1$ yields a higher payoff than $r_1 = d_2$ for D_1 if

$$\tau\gamma > \left[S_R(1,1) + S_D(1,1)\gamma\right]\tau, \tag{57}$$

which is true always.

d) Equation 51 is false and 53 is true. In this case $r_1 = d_1$ yields a higher payoff than $r_1 = d_2$ for D_1 if

$$\left[\frac{1}{2}S_R(1,2) + S_D(1,2)\right]\rho\gamma > \frac{1}{2}S_R(1,2)\rho, \tag{58}$$

which is true always.

Thus when d_1 is the true superior, if Equation 51 is true, the retailers mismatch by playing their own designs; if 51 is false, the retails match on d_1.

ii. d_1 is the true inferior.

a) Equation 52 is true. In this case $r_1 = d_1$ yields a higher payoff than $r_1 = d_2$ for D_1 if

$$\tau > \frac{1}{2}S_R(1,2)\rho\gamma, \tag{59}$$

that is, if 51 is true.

b) Equation 52 is false. In this case $r_1 = d_1$ yields a higher payoff than $r_1 = d_2$ for D_1 if

$$\left[\frac{1}{2}S_R(1,2) + S_D(1,2)\right]\rho > \frac{1}{2}S_R(1,2)\rho\gamma. \tag{60}$$

Thus when d_1 is the true superior, retailers match on d_2 if Equation 51 is false and 52 is true, or if Equations 52 and 60 are false. Retailers match on d_1 if Equation 52 is false and 60 is true. Retailers mismatch by playing their own designs if Equations 51 and 52 are true.

In the preceding stage, D_2 selects $d_2 \in \{A, B\}$. There are two possible cases:

i. $d_1 = A$.

a) Equations 51 and 52 are true. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) > \tau(\alpha + (1-\alpha)\gamma), \tag{61}$$

which is true always.

b) Equations 51 and 52 are false and 60 is true. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) > \alpha\left[\frac{1}{2}S_R(1,2)\gamma\rho\right] + (1-\alpha)\left[\frac{1}{2}S_R(1,2)\rho\right] \tag{62}$$

$$S_R(1,2)\rho < 1. \tag{63}$$

c) Equations 51, 52 and 60 are false. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) > \alpha\left[\frac{1}{2}S_R(1,2)\gamma\rho\right] + (1-\alpha)\left[\frac{1}{2}S_R(1,2)\gamma\rho + S_D(1,2)\gamma\rho\right] \tag{64}$$

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) > \frac{1}{2}S_R(1,2)\gamma\rho + (1-\alpha)S_D(1,2)\gamma\rho. \tag{65}$$

d) Equation 51 is false and 52 is true. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if 65 is true.

These cases are exhaustive for $d_1 = A$.

ii. $d_1 = B$.

a) Equations 51 and 52 are true. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if

$$\tau(\alpha\gamma + (1-\alpha) > \frac{1}{2}(\alpha + (1-\alpha)\gamma). \tag{66}$$

b) Equations 51 and 52 are false and 60 is true. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if

$$\alpha \left[\frac{1}{2}S_R(1,2)\rho\right] + (1-\alpha)\left[\frac{1}{2}S_R(1,2)\rho\gamma\right] > \frac{1}{2}(\alpha + (1-\alpha)\gamma), \tag{67}$$

that is, if Equation 63 is false.

c) Equations 51, 52 and 60 are false. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if

$$\alpha \left[\frac{1}{2}S_R(1,2) + S_D(1,2)\right]\gamma\rho + (1-\alpha)\left[\frac{1}{2}S_R(1,2)\gamma\rho\right] > \frac{1}{2}(\alpha + (1-\alpha)\gamma), \tag{68}$$

which is true always.

d) Equation 51 is false and 52 is true. In this case $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_1 if

$$\alpha \left[\frac{1}{2}S_R(1,2) + S_D(1,2)\right]\gamma\rho + (1-\alpha)\left[\frac{1}{2}S_R(1,2)\gamma\rho\right] > \frac{1}{2}(\alpha + (1-\alpha)\gamma), \tag{69}$$

which is true always.

These cases are exhaustive for $d_1 = B$.

Finally, in the preceding stage D_2 selects $d_2 \in \{A, B\}$.

a) Equations 51, 52 and 66 are true. In this case D_2 will play A for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1.

b) Equations 51 and 52 are true and 66 is false. In this case D_2 will play $d_2 = d_1$ for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1.

c) Equations 51 and 52 are false and 60 and 63 are true. In this case D_2 will play $d_2 = d_1$ for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1.

d) Equations 51, 52 and 63 are false and 60 is true. In this case D_2 will play $d_2 \neq d_1$ for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1.

e) Equations 51, 52 and 60 are false and 65 is true. In this case D_2 will play $d_2 = d_1$ if $d_1 = A$ and $d_2 \neq d_1$ if $d_1 = B$, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1 since Equation 65 is true.

f) Equations 51, 52, 60 and 65 are false. In this case D_2 will play $d_2 \neq d_1$ for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1.

g) Equation 51 is false and 52 and 65 are true. In this case D_2 will play $d_2 = d_1$ if $d_1 = A$ and $d_2 \neq d_1$ if $d_1 = B$, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1 since Equation 65 is true.

h) Equations 51 and 65 are false and 52 is true. In this case D_2 will play $d_2 \neq d_1$ for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$ for D_1.

Thus in the unique subgame perfect Nash equilibrium:

1. $d_1 = A$, $d_2 = B$, and the players herd on the true superior product in the retail stage either if Equations 51, 52, 60 and 65 are false, or if Equations 51 and 65 are false and 52 is true.

2. $d_1 = A$, $d_2 = B$, and the players herd on A in the retail stage if Equations 51 and 63 are false and 60 is true.

3. $d_1 = A$, $d_2 = A$ in all other cases.

□

Proposition 6

Proof. Say that both designer-retailers have committed to follow the intermediary's announcement. Play in the retail stage is therefore deterministic provided that at least one designer-retailer plays the true superior product. In the second design stage, D_2 chooses $d_2 \in \{A, B\}$. There are two cases:

i. $d_1 = A$. $d_2 = B$ yields a higher payoff than $d_2 = A$ for D_2 if

$$\left[\frac{1}{2}S_R(1,2) + (1-\alpha)S_D(1,2)\right]\rho\gamma > \frac{1}{2}(\alpha\gamma + (1-\alpha)). \tag{70}$$

ii. $d_1 = B$. $d_2 = A$ yields a higher payoff than $d_2 = B$ for D_2 if

$$\left[\frac{1}{2}S_R(1,2) + \alpha S_D(1,2)\right]\rho\gamma > \frac{1}{2}(\alpha + (1-\alpha)\gamma). \tag{71}$$

In the preceding stage, D_1 chooses $d_1 \in \{A, B\}$. There are three cases:

i. Equations 70 and 71 are true. In this case D_2 will play B regardless of the choice by D_1. D_1 thus prefers to choose A since Equation 71 is true.

ii. Equations 70 and 71 are false. In this case D_2 will play $d_2 = d_1$ regardless of the choice by D_1. D_1 thus prefers to choose A.

iii. Equation 70 is false and 71 is true. In this case D_2 will play A regardless of the choice by D_1. D_1 thus prefers to choose A since Equation 70 is false.

Thus if Equation 70 is false, the unique equilibrium in the design subgame is for both to play A; if Equation 70 is true, the unique equilibrium in the design subgame is $d_1 = A$, $d_2 = B$.

In the preceding stage, D_2 chooses whether to commit to follow the intermediary's announcement. If D_1 has not committed, this choice by D_2 is irrelevant. If D_1 has committed, D_2 commits if she will earn a higher payoff in the subgame following commitment, which is (weakly) true in all cases: if Equation 70 is false, the equilibrium outcome is identical in the cases with and without commitment; if Equation 70 is true, the equilibrium outcome is mismatched designs in the subgame with commitment and matched designs in the subgame without commitment. Since Equation 70 is true in the latter case, D_2 earns a greater payoff by committing than not.

In the preceding stage, D_1 chooses whether to commit to follow the intermediary's announcement. D_1 commits if she will earn a higher payoff in the subgame following commitment, which is (weakly) true in all cases: if Equation 70 is false the reason is identical to that of D_2; if Equation

70 is true, the equilibrium outcome is mismatched designs in the subgame with commitment and matched designs in the subgame without commitment. Since Equation 70 is true in the latter case, this implies that Equation 70 is true and so D_1 earns a greater payoff by committing than not. □

Proposition 7

Proof. In final retail stage $r_2 = d_2$ by assumption. In the preceding stage R_1 chooses $r_1 \in \{d_1, d_2\}$. If $d_1 = d_2$ this is degenerate. If $d_1 \neq d_2$ there are two cases:

i. d_1 is the true superior. If R_1 chooses $r_1 = d_1$, he will be alone on the true superior design; if $r_1 = d_2$ he will match R_2 on the true inferior design. R_1 thus earns a higher payoff by playing d_1 if

$$S_R(1,1)\tau\gamma > \frac{1}{2}S_R(1,2)\rho. \tag{72}$$

ii. d_1 is the true inferior. If R_1 chooses $r_1 = d_1$, he will be alone on the true inferior design; if $r_1 = d_2$ he will match R_2 on the true superior design. R_1 thus earns a higher payoff by playing d_1 if

$$S_R(1,1)\tau > \frac{1}{2}S_R(1,2)\rho\gamma. \tag{73}$$

In the preceding stage, D_2 chooses $d_2 \in \{A, B\}$.

i. $d_1 = A$.

a) Equations 72 and 73 are both true. $d_2 = A$ yields a higher payoff than $d_2 = B$ if

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) > \tau(\alpha + (1-\alpha)\gamma), \tag{74}$$

which is true always.

b) Equations 72 and 73 are both false. $d_2 = A$ yields a higher payoff than $d_2 = B$ if

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) > \alpha\left[S_D(1,2) + \frac{1}{2}S_R(1,2)\right]\rho + (1-\alpha)\left[S_D(1,2) + \frac{1}{2}S_R(1,2)\right]\rho\gamma. \tag{75}$$

c) Equations 72 is true and 73 is false. $d_2 = A$ yields a higher payoff than $d_2 = B$ if

$$\frac{1}{2}(\alpha\gamma + (1-\alpha)) > \alpha\tau + (1-\alpha)\left[S_D(1,2) + \frac{1}{2}S_R(1,2)\right]\rho\gamma. \tag{76}$$

ii. $d_1 = B$.

a) Equations 72 and 73 are both true. $d_2 = A$ yields a higher payoff than $d_2 = B$ if

$$\tau(\alpha\gamma + (1-\alpha)) > \frac{1}{2}(\alpha + (1-\alpha)\gamma). \tag{77}$$

b) Equations 72 and 73 are both false. $d_2 = A$ yields a higher payoff than $d_2 = B$ if

$$\alpha\left[S_D(1,2)+\frac{1}{2}S_R(1,2)\right]\rho\gamma+(1-\alpha)\left[S_D(1,2)+\frac{1}{2}S_R(1,2)\right]\rho>\frac{1}{2}(\alpha+(1-\alpha)\gamma), \tag{78}$$

which is true always.

c) Equations 72 is true and 73 is false. $d_2 = A$ yields a higher payoff than $d_2 = B$ if

$$\alpha\left[S_D(1,2)+\frac{1}{2}S_R(1,2)\right]\rho\gamma+(1-\alpha)\tau>\frac{1}{2}(\alpha+(1-\alpha)\gamma). \tag{79}$$

In the preceding stage, D_1 chooses $d_2 \in \{A, B\}$.

a) Equations 72, 73 and 77 are true. In this case $d_2 = A$ for any d_1. $d_1 = A$ yields a higher payoff than $d_1 = B$ if

$$\frac{1}{2}S_D(2,2)(\alpha\gamma+(1-\alpha))>\tau(\alpha+(1-\alpha)\gamma)S_D(1,1). \tag{80}$$

b) Equations 72 and 73 are true and Equation 77 is false. In this case, d_2 will match d_1 for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$.

c) Equations 72 and 73 are false and Equation 75 is true. In this case d_2 will play A for any d_1, and if $d_1 \neq d_2$, d_1 will not be retailed. Thus $d_1 = A$ yields a higher payoff than $d_1 = B$.

d) Equations 72, 73 and 75 are false. In this case d_2 will mismatch d_1 for any d_1 and retailers will never retail d_1. Thus both A and B yield a payoff of zero for D_1.

e) Equations 72, 76 and 79 are true and Equation 73 is false. In this case $d_2 = A$ for any d_1. $d_1 = A$ yields a higher payoff than $d_1 = B$ if

$$\frac{1}{2}S_D(2,2)(\alpha\gamma+(1-\alpha))>\tau(1-\alpha)\gamma S_D(1,1). \tag{81}$$

e) Equations 72 and 79 are true and Equations 73 and 76 are false. In this case d_2 will mismatch d_1 for any d_1. Since d_1 will be retailed only if it is the true superior, $d_1 = A$ yields a higher payoff than $d_1 = B$.

f) Equations 72 and 76 are true and Equations 73 and 79 are false. In this case d_2 will match d_1 for any d_1, and so $d_1 = A$ yields a higher payoff than $d_1 = B$.

This completely characterizes equilibrium strategies. Thus if Equations 72 and 75 are false, the equilibrium outcome is for designers to mismatch and retailers to herd on the design chosen by D_2. In particular, it is an equilibrium outcome for d_1 to choose B, d_2 to choose A, and both retailers to choose d_2. □