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The Pitfalls of Subsystem Integration: When Less Is More

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In various industries end-product manufacturers acquire core subsystems from upstream technology provider firms and focus primarily on efficient end-product integration. We examine the strategic interactions between a technology firm that introduces a new subsystem and the respective end-product manufacturers ("integrators"). We analyze how the fraction of end-product functionalities prepackaged into the subsystem impacts the optimal introduction strategy and the relative value appropriation power across the industries. Offering a subsystem that performs many end-product functions has a dual effect on the provider's profits. On the positive side, the provider extracts a higher *ease-of-use* rent from the integrators because of the easier/cheaper integration. On the negative side, such subsystems may curtail the adopters' ability for competitive differentiation and render adoption less valuable. We discuss the role of subsystem functionality in value appropriation in technology markets, and we highlight the perils of subsystem overintegration.

Key words: technology introduction; technology licensing; technological value appropriation; subsystem functionality
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1. Introduction

Many industries exhibit a trend of disintegration over time. They start off vertically integrated, and gradually they evolve toward a multitier disintegrated structure (Christensen 1994, Christensen et al. 2002). In such vertically disintegrated value chains, the downstream manufacturers assume the role of end-product integrators; they assemble and integrate many of the end-product subsystems, be it large components or process technologies, which are developed and introduced by upstream technology providers. These new disintegrated industrial structures pose a new set of challenges for the participating firms.

The following example illustrates a key challenge that upstream technology providers and downstream integrators face, the former when they introduce a new subsystem technology, and the latter when they adopt it. In the mid-1980s, one such disintegrated value chain consisted of approximately 30 large carpet mill companies (the downstream tier), who used key (process) technologies developed by an upstream tier of technology providers (such as DuPont). These carpet mill companies were competing on both price and end-product performance with relatively low margins. During this time, DuPont Chemicals, a leading innovator in chemical and bio-based process technologies, introduced a novel process technology, named Stainmaster. Stainmaster allowed the carpet mills to significantly enhance the stain resistance of their carpets, an important performance dimension for the large volume carpet market. DuPont introduced the Stainmaster technology as a highly integrated offering, where much of the adopter's process steps were specified in the licensing agreement. Even the end-product branding had to be uniform and utilize the title Stainmaster (Miller 2005).

The performance improvement in the Stainmaster products was unquestionable (Mello et al. 2006, p. 192). Together with an intense advertising campaign, Stainmaster became a "must have" feature of any carpet. DuPont aggressively pushed Stainmaster, which was ultimately adopted by nearly all large downstream integrators. Although the full-fledged solution of Stainmaster reduced the cost and uncertainty of an adopter's integration effort, the restrictions to customize the offerings also resulted in limited ability to differentiate end products. Indeed, according to a senior manager at DuPont, their large-scale rollout combined with the highly integrated nature of the technology sparked more intense price competition, reducing the already thin profit margins of carpet mills (Miller 2005). This period also recorded a rapid and intense consolidation of the carpet mills industry. Several mills exited in bankruptcy, the downstream industry became more concentrated, and DuPont's ability to appropriate value (henceforth, *value appropriation power*) diminished. The lesson from the Stainmaster experience was not lost at DuPont. Indeed, one of the members of DuPont's senior management team framed a key goal for future technology introductions as follows: "enough value [should be] left on the table for licensees" and "[make] doubly sure that the licensees could transform the technology into differentiated products" (Miller 2005).

The preceding example is an instance that motivates the core trade-off explored in this paper: the technology provider may be ill-served by a highly integrated subsystem even when the subsystem reduces the risk/cost of integration, because highly integrated subsystems place limitations on downstream competitive differentiation. This trade-off arises because of a subsystem effect that is different from the more traditional view discussed in the literature, whereby subsystems are assumed to determine either the end-product marginal cost or their performance (Kauffman et al. 2000). Instead, the Stainmaster example suggests an alternative design dimension that may play an equally important and complementary role: the amount of end-product functions (integration) offered by subsystems.

Our argument about the potential negative implications from subsystem integration, although likely to be qualitatively true in general, has greater economic significance in some industrial contexts than in others. For example, in some industrial markets, such as electronics, dominant technology providers like Intel have shown an increasing tendency toward offering highly integrated, full-fledged subsystems (compared to piecemeal solutions). In these contexts, the level of integration not only alters the integration costs/risks (our key concern in this paper) but may also play a role in determining the end-product performance, and therefore, the downstream user's profitability (Kamien and Tauman 1984, 1986). It is possible, therefore, for a firm to find that the possible upside of offering superior end-product performance (identified in past literature, for instance, see Kamien and Tauman 1984) through greater subsystem integration is sufficiently large and outweighs the downside we identify from reduced integration risk/costs.

Elsewhere, a single large downstream integrator (e.g., IBM Global Services) may dominate the end-product market. After a unique transformation into a service solutions company, IBM has leveraged the hardware or software subsystems (upstream technology) very carefully to grow and retain market share. Indeed, their focus on carefully managing their upstream providers is cited as a core element of their approach.[1] Although a complete enumeration of all the issues that determine a provider's design choices lies beyond the scope of our study, we attempt to characterize how the potential pitfalls or benefits of subsystem integration depend on (i) the subsystem contribution to the end-product performance as well as (ii) the heterogeneous capabilities of the downstream integrators. In that regard, our study examines the moderating role of subsystem integration choices on the *relative value appropriation power*[2] between the upstream provider and downstream integrators.

We consider a business setting where a technology provider offers a *subsystem* that adds value to adopting integrator firms in one (or both) of two possible ways: (i) integration benefits such as the reduction of the cost/time/uncertainty of the adopter's integration process, which we term "ease-of-integration" benefits, or (ii) higher end-product performance. We refrain from distinguishing between subsystems that are component technologies or process technologies, and we build on Ulrich's (1995) definition of functionality to accommodate the case of process technologies as follows: a subsystem is defined as a collection of functions and integration activities,[3] and the subsystem *"functionality"* is the metric that summarizes the fraction of end-product functions and integration activities embedded in the subsystem.

Motivated by the earlier DuPont example, we assume that the upstream provider enjoys a monopoly position, but that the downstream industrial setting is competitive. We also extend our base model to allow heterogeneous capabilities among the integrators, and thus explore the constraints that the competitiveness in the downstream industry impose on the provider's value appropriation power. Moreover, our analysis also examines the role of different fee structures—fixed upfront licensing fees and variable (royalties) fees—in determining the provider's value appropriation power.

We explore two main research questions:

(1) How does the subsystem functionality affect the relative value appropriation power between the subsystem provider and the downstream industry?

(2) What *introduction strategy* should the technology provider undertake?

[1] We thank the associate editor for offering this example.

[2] Our use of the term "relative value appropriation power" reflects the fact that in several industrial settings the value appropriated by the upstream provider might be smaller, and therefore her power to appropriate diminishes, despite the fact that the ex ante conditions for the downstream integrators are the same. Note that this usage is distinct from the economic interpretation of power in terms of bargaining outcomes resulting from splitting the total value across the different markets.

[3] Integration activities are the steps associated with integrating the particular subsystem into the complete product.

In answering the first question, we find that, ceteris paribus, greater functionality in a subsystem has two opposing effects on the upstream provider's value appropriation power. On the positive side, the provider may be able to obtain a larger ease-of-integration premium from the integrators. On the negative side, greater functionality may curtail the downstream ability to competitively differentiate, especially when the subsystem is widely adopted. Thus, greater functionality may make a subsystem less attractive for the integrators, and consequently reduce upstream provider's relative value appropriation power. The result highlights an important, cautionary message for technology providers on the potential pitfalls of overintegration, especially when the subsystem is targeted at multiple integrators. At the same time, the result also reveals the nonmonotonic effect of functionality on upstream value appropriation power and on the market share that the subsystem can garner. Note that such nonmonotonicity in profits and market share that directly emerges from the negative effect of functionality identified earlier, is in contrast to most, if not all, previous models of technology introduction, where a superior technology performance can only serve to enhance a provider's value appropriation power (Kamien and Tauman 1984, 1986; Kamien 1992; Erat and Kavadias 2006).

Our results also reveal valuable insights about the implications of a subsystem on the downstream industry: even when a subsystem diminishes integration costs and risks, or enhances the end-product performance substantially, it may not be widely adopted, as a result of the strategic interactions among the integrators. Interestingly, the subsystem technology might result in an increase in the downstream industry's power to appropriate value whereby many integrators with similar integration capabilities intensely compete, and are transformed into fewer integrators that are more capable, and ultimately dominate the end-product market. We also find that heterogeneity between the integrators may restrict the number of adopters who benefit from the subsystem offered, and therefore diminish the provider's value appropriation power. These insights reveal the complex interplay between design factors and industry level factors and thereby add to the extant literature on this topic (Baldwin and Clark 1999, Fixson and Park 2008).

At a much more operational level, we show how the subsystem introduction strategy, i.e., the optimal number of integrators to target, and the fee structure that a provider employs, depend on subsystem functionality. For very low and very high functionality levels, the provider should optimally offer the subsystem to a limited number of integrators. Furthermore, mixed fee structures, employing both a fixed and a royalty component, are optimal when the technology provider targets the subsystem to multiple integrators. These results offer normative support to past empirical findings on the prevalence of such mixed fee structures (Rostoker 1984) and add to the growing stream of literature that has identified plausible conditions that favor the superiority of volume-based fees (see, for instance, Wang 1998, Sen and Tauman 2007).

2. Literature Review

Two main areas in the academic literature explore different aspects of our research question: (i) the new product development literature examines the effect of product architecture on the firm's strategic decisions, and (ii) the patent-licensing literature from economics and strategy examines the implications of market (and technology) characteristics to technology introduction.

2.1. The Effects of Product Architecture on Firm Strategy

Ulrich (1995) defines the *product architecture* as "the scheme by which the function of a product is allocated to its physical components" (Ulrich 1995, p. 419). Building on this definition, we conceptualize a subsystem as a collection of functions and integration activities, and the subsystem functionality as the metric summarizing the fraction of end-product functions and integration activities embedded in the subsystem.

It has long been recognized that the product architecture has important implications to a firm's operational performance on dimensions including flexibility, efficiency, and profitability (Baiman et al. 2001, Krishnan and Gupta 2001, Dana 2003, Ülkü and Schmidt 2011). Recently, Fixson and Park (2008) developed a conceptual framework based on an in-depth case study that examines the role of architectural choices in the structure of upstream and downstream tiers across the bicycle (components) value chain. The majority of these studies focus on how design and architectural dimensions affect a firm's product strategy (e.g., intertemporal price discrimination, upgradeability, product variety, etc.) and the upstream industry structure (Fixson and Park 2008).

A related, yet distinct, stream of research in strategy argues that the product and process architectures may influence the value of intraorganizational and interorganizational coordination and governance mechanisms, thereby influencing a firm's long-term profitability. Within this stream, Sanchez and Mahoney (1996) theorize that modularity in architectures facilitate loose coupling, and thus have the potential to reduce the cost and difficulty of adaptive coordination, thereby increasing the strategic flexibility of firms to respond to environmental change. Thus, modularity in architectures should not be just related to firm performance (Worren et al. 2002) but should also serve as a substitute for extensive coordination and control routines, both within an organization and between organizations in alliances (Tiwana 2008). In a recent study, Cabigiosu and Camuffo (2012) enrich this proposition by hypothesizing that because the need to share information is minimized with highly modular designs, the positive impact of information sharing on supply chain performance is itself negatively moderated by the modularity of the product designs employed in the supply chain.

Although we examine a specific attribute of the product architecture, namely, the functionality of the subsystem technology, our emphasis is complementary to these past studies. Specifically, we seek to understand how the functionality of a technology subsystem offered by one upstream economic entity (the provider) to multiple downstream entities (the integrators) determines their respective value appropriation (profits) and more broadly the structure of the downstream tier (i.e., resultant asymmetries among the integrators).

2.2. Technology Introduction and Patent Licensing

Since the pioneering work of Arrow (1962), a number of studies have analyzed when and how innovations (intellectual property rights) are licensed. This stream of literature has mainly focused on market side drivers, and it has viewed technology as a unidimensional factor that improves the end-product performance or reduces its marginal cost.

Early work in this stream, by Kamien and Tauman (1984, 1986) and Katz and Shapiro (1985), examines the case of an upstream innovator who licenses cost-reducing innovations to downstream competing firms. They find that upstream innovators obtain limited value through royalty licensing mechanisms.[4] Kamien (1992) offers a comprehensive survey of this stream of literature.

There are very few empirical studies of licensing agreements for the case of upstream innovators, possibly because of the difficulty to obtain detailed data about licensing agreements. The few available studies note that volume-based royalties are a key element of most licensing agreements despite the theoretical prediction of their suboptimality. For instance, Rostoker (1984) finds that the fixed-price *plus* volume royalty is the most frequently used (46%), followed by pure volume-based royalties (39%). These empirical regularities have spurred a number of important inquiries, e.g., the role of information asymmetry (Gallini and Wright 1990), risk sharing (Bousquet et al. 1998), etc. These extensions show that volume-based royalties may alleviate two-sided moral hazard and optimally split the innovation risk between risk-averse parties. We add to this stream of literature by demonstrating that royalties may also benefit the innovator by moderating the downstream competition.

Starting with Shapiro (1985), research has expanded the context of licensing to include the case of licensing among competitors within an industry, i.e., the innovator is no longer an outsider and may actually compete in the same product market as the licensee. Within this stream, Arora and Fosfuri (2003) examine the case of an incumbent firm licensing to her competitor and identify two drivers for the innovator's profits: (i) a revenue effect, resulting from the license fees, and (ii) a rent dissipation effect, resulting from the licensee who is a competitor possessing a superior (or equal) cost structure. Although we examine a different context, through a suitable interpretation of the rent dissipation effect, our results expand the scope of their findings to the case where the innovator is an upstream technology provider. In addition, our explicit consideration of the integration process allows us to identify the role of the upstream technology on the revenue and rent dissipation effects.

Recently, researchers have examined the product development and marketing implications of (optimal) licensing decisions. They have attempted to operationalize both the demand side (i.e., market potential) and the supply side (i.e., cost of technological development) of licensing decisions. Erat and Kavadias (2006) examine the effects from offering subsystem performance enhancements (defined as the subsystem contribution to the end-product performance) on an upstream provider's licensing decisions. They find that higher current subsystem performance prompts the provider to at least keep or even expand the number of licensees. Furthermore, aligned with the extant literature, they find that the provider revenues increase in the subsystem performance. In contrast, in our model, a highly integrated subsystem, through its potential to intensify downstream competition (by limiting the downstream competitive differentiation), may result in a decrease in the provider's revenues. Stated differently, a technology provider may ultimately hurt the downstream adopters (and hence herself) by trying to be helpful and offering a highly integrated subsystem. This contrast illustrates the different effects of the two design dimensions of the subsystem, i.e., end-product performance contribution (examined in Erat and Kavadias 2006) versus subsystem functionality examined in our study.

Overall, past studies have concentrated on the end-product performance effects of technologies and have ignored that a subsystem technology may also be valued for its integration effects. Our study highlights

[4] For instance, in the case of risk-neutral agents with complete information, Kamien and Tauman (1986) show that volume-based royalties are inferior to fixed-price licenses.

this additional dimension of *integration-related* effects, and outlines the different set of challenges that influence the introduction strategy for such subsystem technologies. Thus, we complement past studies by explicitly accounting for the effect of subsystem functionality on the uncertainty/cost of the integration process.

3. Model Setup

A monopolist technology firm introduces a subsystem $\mathscr{C}$ to a downstream market of n integrators. The subsystem $\mathscr{C}$ offers functionality f, i.e., the fraction of end-product integration functions/activities prepackaged into the subsystem. We assume that a part (if not all) of the technologies embedded in the subsystem are protected by patents, and therefore other firms cannot replicate the same subsystem. For tractability, we consider a duopoly in the downstream market, i.e., $n = 2$.

If an integrator adopts the subsystem offered by the provider, his[5] integration process and end-product performance may both be impacted. First, consider the effect on the integration process. A downstream integrator, upon adoption of the subsystem $\mathscr{C}$, may undertake further development and integration. We consider a model where at the end of the "integration period," the integrators are either (i) unsuccessful in their integration efforts and revert back to the existing (status quo) subsystem, say $\overline{\mathscr{C}}$, or (ii) successful and utilize the new subsystem $\mathscr{C}$ in their end product.[6]

Each integrator i ($i = 1, 2$) can successfully integrate the subsystem $\mathscr{C}$ into his end product with probability $p(f)$ after incurring cost $C_i(f)$. We assume that the probability of successful integration is identical across the two integrators, to keep the analysis straightforward. Still, to account for industrial settings close to our example of IBM Global Services, we capture heterogeneous capabilities among the downstream integrators through the heterogeneous integration costs. We parameterize this heterogeneity by defining $C_1(f) = C(f) - \kappa$ and $C_2(f) = C(f) + \kappa$, respectively, ($\kappa \geq 0$). Hence, a nonzero κ allows us to represent different degrees of heterogeneity and value appropriation power among the upstream and downstream industries.

A subsystem that offers lower functionality necessitates greater integration/development efforts by the integrator firm, because the integrator needs to employ alternative subsystems and components in order to ensure end-product performance. Thus, lower functionality creates a more complex and costly integration process, so that the integrator needs to invest more resources (Clark 1989) and is less certain about the integration success because of the potential for numerous subsystem interactions (Schilling 2000). Hence, it is likely that $p(f)$ is a nondecreasing function of f, and that $C(f)$ is a nonincreasing function of f. Specifically, we assume that there is a nondecreasing nonnegative function $\phi(f)$ (≤ 1) such that[7]

Assumption A.0.1. $p(f) = \phi(f)$.

Assumption A.0.2. $C(f) = K(1 - \psi\phi(f))$, *where* K *and* $\psi \leq 1$ *are nonnegative constants*.

Second, the adoption and successful integration of the subsystem into the end product may offer an additional well-understood benefit, namely, enhanced *end-product performance*. Note that we conceptualize the end-product performance as a key competitive dimension in an industry, varying from industry to industry. In some contexts marginal cost may be the basis for competition, whereas in others it may be technology performance such as power consumption or battery life. Let an integrator's end-product performance be $P(\overline{\mathscr{C}})$ when he utilizes the existing subsystem, and $P(\mathscr{C})$ when he uses the newly offered subsystem. In general the end-product performance depends on various design features of the subsystem. Consistent with our research question, we limit our focus only on the effect of subsystem functionality on end-product performance. Therefore, we define the performance of the end product that uses the subsystem $\mathscr{C}$ as $P(\mathscr{C}) = P(f)$.

Let $\Pi(P_i, P_j)$ be the payoff to integrator i ($i = 1, 2$) when his end product exhibits performance P_i and the competitive offering (that is j's end product, $j = 3 - i$) has performance P_j. The structure of the profit function $\Pi(\cdot, \cdot)$ subsumes the market mechanism that allocates profits to the competing integrators. Instead of assuming a specific form for the market mechanism (e.g., Cournot competition), we adopt an axiomatic approach to modeling competition between integrators, and we assume an intuitive structural property that any reasonable market mechanism would satisfy.

[5] We refer to downstream integrators as "he" and the technology provider as "she."

[6] For ease of exposition, we have discretized the development/integration process and consider a single "integration period." Still, in Online Appendix 2.3 (available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1381624), we show that our results are generalizable to settings with continuous integration time.

[7] Although we only require that $\phi(\cdot)$ is a nondecreasing nonnegative function, there are also alternate plausible conditions under which our results hold. For instance, it may be shown that our results hold if the point elasticity of the marginal change in costs is never greater than the point elasticity of the marginal change in probability (i.e., $C''(f)/C'(f) \leq p''(f)/p'(f)$). A particular case where this last condition holds is when $p(f)$ and $C(f)$ are convex. Even when the previous condition is violated, and $C(f)$ and $p(f)$ are arbitrary nonincreasing and nondecreasing functions, respectively, our main structural results, including Propositions 1 and 2, and Corollaries 1 and 2 hold.

Assumption A.1. *$\Pi(P_i', P_j) - \Pi(P_i, P_j)$ is nonincreasing in P_j for all $P_i' > P_i$; i.e., $\partial^2\Pi(P_i, P_j)/\partial P_i \partial P_j < 0$.*

In economic terms, the performances are "substitutes," i.e., $\Pi(P_i, P_j)$ is submodular in (P_i, P_j) (Topkis 1978). Intuitively, the marginal benefit from a superior performance is greater if the competitor lags significantly in performance.[8]

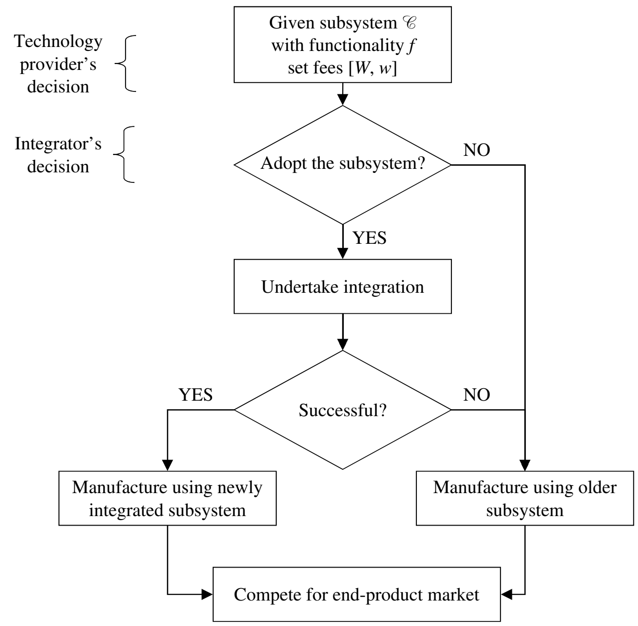
Without loss of generality, we normalize the performance of end products currently offered by both the integrators (i.e., before any adoption decisions) to $P(\bar{\mathscr{C}}) = 1$. For notational convenience, define (i) $a(P) = \Pi(P(\mathscr{C}), P(\mathscr{C}))$, (ii) $b(P) = \Pi(P(\mathscr{C}), 1)$, (iii) $c(P) = \Pi(1, P(\mathscr{C}))$, (iv) $d = \Pi(1, 1)$. That is, $a(P)$ is the payoff to an integrator when both he and his competitor employ the subsystem $\mathscr{C}$; $b(P)$ is the payoff when only he employs subsystem $\mathscr{C}$; $c(P)$ when only his competitor employs subsystem $\mathscr{C}$; and d when neither of the integrators employs the new subsystem $\mathscr{C}$. Let $S(P) = a(P) - c(P)$, and $F(P) = b(P) - d$. Thus, $S(P)$ ($F(P)$) represents the incremental benefit of the adopter when his competitor has (not) adopted the same subsystem.

Finally, given the integration-related and end-product performance-related benefits that the subsystem offers, the technology provider sets the adoption fees $\bar{W}$ for the specific subsystem $\mathscr{C}$. In general, the fee $\bar{W} = [W, w]$ may be composed of two parts: a fixed one-time payment, W, paid upon adoption, and a per-unit royalty, w, paid for each unit of the end product sold.

The sequence of decisions (Figure 1) for the upstream and downstream parties is as follows. In the first stage, the technology provider sets the fees $\bar{W}$ for a specific subsystem $\mathscr{C}$. Given the fee, the integrators decide based on anticipated profits, whether or not to adopt the subsystem. Next, the integrators commence additional development efforts to integrate the acquired subsystem into their end product (at cost $C(f) - \kappa$ or $C(f) + \kappa$) and are successful with probability $p(f)$. In case of success, the integrator utilizes subsystem $\mathscr{C}$ in their end product, whereas in case of failure he reverts to the older (status quo) subsystem $\bar{\mathscr{C}}$. End products are then competitively sold and generate revenues as per the $\Pi(P_i, P_j)$ mechanism. The basic notation and assumptions of our model setup are summarized in Table 1.

[8] It is possible that the integrators compete on several dimensions, with end-product performance being only one of them. In Online Appendix 2.2 (available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1381624), we discuss how our assumptions map onto quite complex competition models and we demonstrate that Assumption A.1 is indeed quite general and is satisfied by a wide variety of economic models of competition, including traditional quantity-based competition, differentiated Bertrand models of price competition, vertical differentiation models, etc. Furthermore, although submodularity is a relatively weak assumption, we also describe how a significantly weaker set of assumptions is adequate to obtain our main results.

Figure 1 Timeline of Decisions



4. Subsystem Functionality, the Optimal Introduction Strategy, and Value Appropriation

This section presents our core result: the role of the subsystem's functionality on the provider's value appropriation, and on her optimal introduction strategy. The effect of enhancing the end-product performance is fairly well understood (Erat and Kavadias 2006). Hence, in the first step in our analysis, we "shut off" this mechanism by explicitly assuming that the end-product performance is unaffected by the functionality of the underlying subsystem $\mathscr{C}$. This allows us to offer clear contrast between our analysis and that offered in Erat and Kavadias (2006). Thus, the performance obtained by integrator i, P_i, although possibly dependent on broader subsystem characteristics, is assumed to be independent of f. We relax this assumption in §5.1.

Assumption B.1. *$P(\mathscr{C})$ is independent of f.*

We also assume that the value appropriation power in the downstream market is minimal; the integrators possess identical capabilities and cost structures, and their costs of integration are identical.[9] We consider more general settings in §5.2. For now,

Assumption B.2. *$\kappa = 0$; i.e., $C_1(f) = C_2(f) = C(f)$.*

Finally, we assume that the subsystem licensing fee $\bar{W}$ is composed of only the single fixed one-time

[9] It is a straightforward argument that when all downstream integrators are symmetric in their integration capabilities, they possess minimal appropriation power, because they face maximum competition.

Table 1 **List of Variables and Key Assumptions in the Model**

Variable	Name	Assumption	
f	Functionality		
$p_i = p = p(f)$	Likelihood of integration success	A.0.1	$p(f) = \phi(f)$ is nondecreasing
$C_1 = C(f) - \kappa$	Integration costs	A.0.2	$C(f) = K(1 - \psi\phi(f))$; $K, \psi \geq 0$
$C_2 = C(f) + \kappa$			
P	End-product performance	A.0.3	$P(f)$ is nondecreasing in f
$\Pi(P_i, P_j)$	Integrator i's payoffs	A.1	submodular
$\bar{W} = [W, w]$	Subsystem adoption fees		

payment. Our assumption reflects industrial settings where providers avoid more complex forms, such as royalties, perhaps because of significant costs such as monitoring for compliance, etc. We relax this assumption in §5.3. For now,

Assumption B.3. $w = 0$.

Whenever the meaning is apparent, we suppress the notations and use p, C, S, and F for $p(f)$, $C(f)$, $S(P)$, and $F(P)$, respectively. Furthermore, we follow Erat and Kavadias (2006) and define the different introduction strategies that may arise.

Definition 1. An introduction strategy where the technology provider sets fees such that
- both integrators adopt the subsystem, termed a *saturation* strategy;
- only one integrator adopts the subsystem, termed a *niche* strategy;
- none of the integrators adopt the subsystem, termed a *no-sale* strategy.

Next, we define a metric that both allows us to capture the probabilistic nature of the integration process and its ex post outcomes and facilitates the explanation of the intuition behind our main result.

Definition 2. The *degree of differentiation potential* is the probability that the integrators sell end products whose performances differ.

Degree of differentiation potential (DDP)

$$= \begin{cases} 0 & \text{if introduction strategy is no-sale,} \\ p & \text{if introduction strategy is niche,} \\ 2p(1-p) & \text{if introduction strategy is saturation.} \end{cases}$$

When neither integrator adopts the subsystem (no-sale), then ex post both will sell end products that have status performance 1, thus making the differentiation 0. When only one adopts the subsystem (niche strategy), then the nonadopter always has ex post end-product performance of 1, whereas the adopter has ex post performance P with probability p, and with remaining probability $1 - p$ has ex post performance 1. Stated differently, under a niche strategy, there is a likelihood p that the ex post performance of the two downstream integrator's end product would be different. In a similar manner, even when both integrators adopt the new subsystem (saturation strategy), the integration uncertainty results in a nonzero likelihood that their end products exhibit different ex post performances. Specifically, the end-product performances can be different only when one integrator fails his integration process and the other succeeds, which happens with probability $2p(1-p)$.

Proposition 1 describes the (optimal) licensing fee that the provider charges contingent on the number of integrators she targets.

Proposition 1. *The provider optimally employs the saturation strategy by setting the fee at* $W = W_s - C$, *where*

$$W_s = pF - p^2(F - S),$$

or she may optimally pursue the niche strategy by setting the fee at $W = W_n - C$, *where*

$$W_n = pF.$$

The corresponding provider payoffs are $\pi_s = 2(W_s - C)$ *and* $\pi_n = W_n - C$. *The overall optimal introduction strategy is saturation (niche) iff* $\pi_s > \max\{0, \pi_n\}$ ($\pi_n > \max\{0, \pi_s\}$).

Note that because the integrators are symmetric (homogeneous) (Assumption B.2), the niche strategy (when $W = W_n - C$) corresponds to two distinct equilibria, one in which integrator 1 licenses and integrator 2 does not, and another in which integrator 2 licenses and integrator 1 does not. Admittedly, the nonuniqueness of equilibria may in general raise a concern for the need for potential equilibrium refinements. However, given that our focus is on the provider's optimal decisions, the issue of which equilibrium emerges, albeit theoretically interesting, is less relevant; this is because irrespective of the equilibrium chosen, the technology provider gains the same revenues, and hence is indifferent between them.

Proposition 1 reveals an interesting insight: The technology provider's revenue under the saturation strategy is *not* monotonically increasing with the likelihood of successful integration p. Specifically, for very high values of p, the marginal value of p may fail to be positive. This result is somewhat unusual[10] because for $p > 1/2$, the likelihood of integration failure *and* the integration uncertainty (measured by the variance $p(1-p)$) decrease with an increase in p. Thus, we show that the provider's revenues may in fact decrease when the uncertainty in the integration process and even the likelihood of integration failure are lower.

The impact of p on the provider's profitability is explained as follows: the higher p indicates a higher likelihood that an adopter is successful in her integration effort. However, under a saturation strategy, the higher p also implies that her competitor has the same greater likelihood of being successful. In that case, the potential for a differentiated outcome (Definition 2) decreases as p increases. This lower potential of a differentiated outcome makes it less likely that any one integrator obtains the high "monopolist" payoffs, and most likely that both integrators obtain the duopoly payoffs. As a result, the integrators have less incentives to adopt the subsystem, and thus may be induced to adopt only through lower fees. Viewed from the perspective of the technology provider, this suggests that although an easier to integrate subsystem (higher p) is valued by any given individual integrator (upon exclusive access), the same subsystem could be less valuable to the downstream market as a whole. Thus, an easier to integrate subsystem decreases the value appropriation power of the upstream provider even when the downstream industry is fiercely competitive (symmetric firms).

There is an additional interesting connection between our finding and the rent dissipation effect, an important driver identified from past research examining why and when firms license technologies to their competitors (Arora and Fosfuri 2003). Rent dissipation in these contexts refers to the reduction in the licensor's profits because the licensee is a competitor in the end-product market. Note that in our case the licensor does not compete with the licensee. Still, the fact that multiple licensees compete for the same end-product market, combined with the fact that very high p results in an exceedingly low possibility of a differentiated outcome, results in a situation where the integrator's rents are reduced. Thus, by reinterpreting the rent dissipation as a probabilistic effect that depends on the actual integration outcome, we may expand the scope of the Arora and Fosfuri (2003) results to cases where the innovator is an outsider and the outcome of the integration process is uncertain.

Corollary 1. 1. *There exists a threshold* $(=F/(2\cdot(F-S)))$ *for the likelihood of successful integration* p *such that above the threshold, the provider revenues under a saturation strategy decrease in* p.

2. *There exists a threshold* $(=\phi^{-1}((F+K\psi)/(2(F-S))))$ *for the subsystem functionality* f *such that above the threshold, the provider revenues under the saturation strategy decrease in* f.

Corollary 1 summarizes an important managerial insight obtained from Proposition 1. Introduction of a subsystem with a greater likelihood of successful integration (higher p), and/or with a lower integration cost (lower C), may not be a beneficial value appropriation strategy. Easier integration has an important side effect: it reduces the potential for differentiation, and therefore increases the downstream competition intensity.

The next proposition characterizes the optimal introduction strategy as a function of the two key integration-related benefits of a subsystem: lower likelihood of integration failure and lower integration cost. In addition, the proposition states the role of subsystem functionality on the introduction strategy.

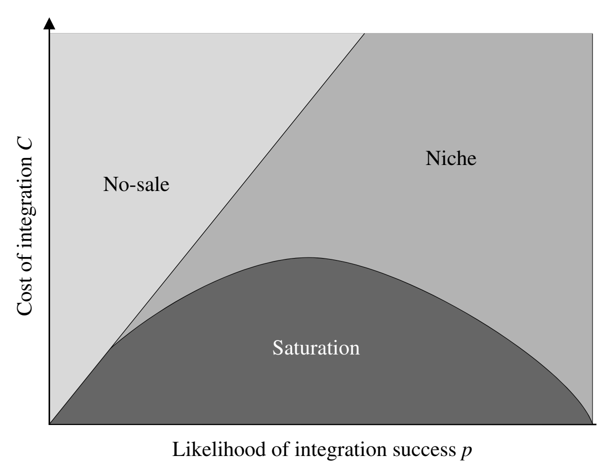
Proposition 2. 1. *There exist thresholds on the likelihood of successful integration* p^0, p^1, *and* p^2 *such that for* $p < p^0$ *no-sale is optimal, for* $p^0 \le p < p^1$ *a niche strategy is optimal, for* $p^1 \le p \le p^2$ *a saturation strategy is optimal, and for* $p^2 \le p$ *a niche strategy is optimal.*

2. *There exist thresholds on integration costs* C^0 *and* C^1 *such that for* $C < C^0$ *a saturation strategy is optimal, for* $C^0 \le C < C^1$ *a niche strategy is optimal, and for* $C \ge C^1$ *no-sale is optimal.*

3. *There exist thresholds on the subsystem functionality* $0 \le f_0 \le f_1 \le f_2 \le 1$ *such that the provider finds it optimal to* (i) *undertake the niche strategy if* $f \in [f_0, f_1]$ *or* $f \in [f_2, 1]$, (ii) *undertake the saturation strategy if* $f \in [f_1, f_2]$, *and* (iii) *not offer the subsystem to any of the integrators if* $f \in [0, f_0]$.

Figure 2 plots the optimal introduction strategy contingent on the likelihood of successful integration

Figure 2 **Regions Corresponding to Different Levels of Integration Uncertainty and Cost**



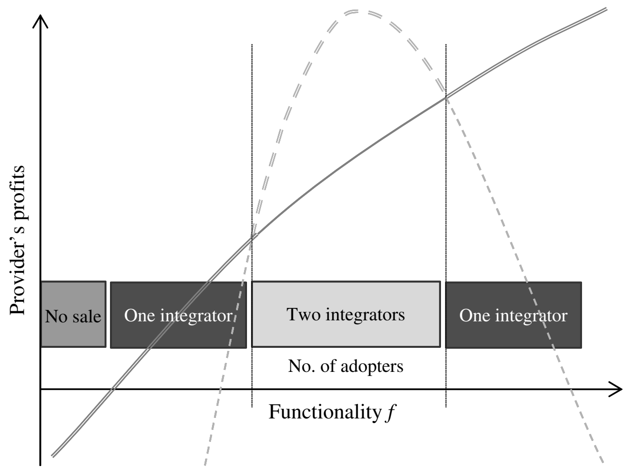
[10] We thank one of the reviewers for pointing this out.

p and the integration cost C. For very low likelihood of successful integration, the expected adoption benefit to an integrator is also very low. Hence, the only way the provider may induce an integrator to adopt the subsystem is through a negative license fee, i.e., a form of "subsidy." This would result in negative profits, so the provider does not introduce the subsystem. As the likelihood of successful integration takes on moderate values, the expected benefit from adoption increases. Consequently, the provider offers the subsystem to more and more integrators. However, for very high likelihood of successful integration, every adopter can successfully integrate the technology into their end product, and as a result, the degree of potential differentiation between them decreases and the competitive intensity increases. Following the reasoning of Corollary 1, this effect dilutes the value the provider appropriates from saturation relative to the niche strategy.

The impact of the integration cost on the optimal introduction strategy is intuitive. Integration costs directly reduce the license fee that a given integrator is willing to pay. Under the saturation strategy, the revenue loss to the provider because of high integration costs is greater compared to her revenue loss under the niche strategy (in the former case, the integration cost affects more integrators compared to the latter case). Thus, for very high costs, the provider optimally adopts a niche strategy (or chooses not to introduce the subsystem). As the costs become lower, it becomes feasible to offer the subsystem to multiple integrators (saturation strategy).

It is interesting to compare our results with prior findings on the optimal licensing of technologies that reduce the adopter's marginal cost. A key finding emerges from that literature: breakthrough technologies that significantly lower marginal costs result in fewer licensees compared to moderate improvements (Sen and Tauman 2007). If we interpret the reduction of integration costs as a technology effect, then we see that our result suggests the exact opposite: drastic reduction in integration costs results in *more* licensees. This contrast stems from the different role that a one-time fixed integration cost plays compared to the role played by the variable manufacturing costs. Specifically, a reduction in integration costs directly reduces an adopter's cost structure, independent of whether or not a competitor adopts the subsystem. In that regard, the adoption decision carries a constant (competition-independent) value. Instead, a reduction in the adopter's manufacturing costs (examined in past literature) allows the adopter to compete more effectively, but its value becomes lesser when her competitor also has the same lower manufacturing costs. Thus, our result indicates that taking a more operational perspective on the technology introduction benefits, e.g., manufacturing cost reduction versus integration cost reduction, has dramatically different managerial implications for the optimal introduction strategies.

Figure 3 **Provider's Profit and Optimal Introduction Strategy Contingent on Subsystem Functionality**



Notes. The solid (dashed) curve represents the profit when pursuing the niche (saturation) strategy. The maximum of the two curves gives the provider's optimal profit.

Figure 3 illustrates the technology provider's profits and her optimal introduction strategy contingent on the subsystem functionality. Higher functionality diminishes the integration cost and the likelihood of an integration failure. As a result, the provider targets more integrators. However, beyond a certain threshold, additional functionality leads to such a low likelihood of an integration failure that *every* adopting integrator would be successful in the integration process. As a result, the lower potential differentiation between the integrators dilutes the overall value the provider may appropriate through a saturation strategy. Consequently, the provider can offer a subsystem with very high functionality only to a subset of integrators so as to induce some downstream differentiation and to retain her value appropriation power.

In summary, our core results reveal the subtle dynamics across upstream and downstream industries. In industrial settings where the downstream industry is relatively more competitive, the subsystem functionality becomes an important lever that determines the value appropriation power of the upstream subsystem provider. Overintegration might lead to a decline of the value appropriation power, and eventual loss, a situation that echoes our introductory Stainmaster account. However, alternative strategies may allow the provider to avoid the overintegration trap. For example, subsystems that affect the end-product performance, and subsequently the end-product market potential, might still induce downstream integrators to adopt.[11] We explore some of these alternative strategies in the next section.

5. Extensions

Our analysis thus far has focused on a core insight: the effect of subsystem functionality on the potential for differentiation among the adopters, and consequently the value appropriation power that the subsystem grants to the downstream and upstream industries. However, our initial analysis has assumed away some of the complex realities in several industrial contexts. In this section we enrich the base model to examine the robustness of our core result. Moreover, we discuss how the value appropriation power shifts across the upstream and the downstream industries.

We examine three important extensions: (i) an industrial setting where subsystem functionality affects the end-product performance and therefore the downstream competition (Assumption B.1); (ii) the case where the downstream market may exhibit higher value appropriation power because of the possibility of a dominant integrator (Assumption B.2); and (iii) the case where technology might be offered through more involved licensing arrangements such as the volume-based royalty fees often found in practice (Assumption B.3). Although our extensions yield greater confidence in the robustness of our core insight, they also help delineate the settings where subsystem functionality plays a more important role rather than less important.[12]

5.1. Value Appropriation: The Role of the Subsystem Performance Contribution

The subsystem functionality may affect the end-product performance. For instance, in integrated circuits a prepackaged number of functions within a subsystem (IC) often results in less power losses, higher transmission speed, and therefore overall better performance. Consider modifying the base-case model by relaxing Assumption B.1 to now assume that $P(f)$ is nondecreasing in f. The assumption that performance is nondecreasing in functionality is relatively intuitive. In DuPont's Stainmaster process technology, the explicitly defined (and rigidly controlled) production process implied a better performance for the end product of the carpet mills. Note that the structure of $P(f)$ allows us to capture the importance of functionality in determining the end-product performance. When the subsystem functionality has minimal impact on end-product performance (e.g., a subsystem with a peripheral role in the end-product architecture), then $P(f)$ would be nearly constant in f. In contrast, when the subsystem functionality enhances the end-product performance, we would expect a steeply increasing functional form.

Given that the end-product performance determines the end-product market mechanism, we need to specify in greater detail the effects of $P(f)$ on an integrator's rents. We assume that the competition mechanism $\Pi(\cdot, \cdot)$ satisfies the following additional properties:

Assumption A.2. *$\Pi(P_i, P_j)$ is increasing ($\partial\Pi/\partial P_i > 0$) and concave in P_i ($\partial^2\Pi/\partial P_i^2 < 0$).*

Assumption A.3. *$\Pi(P_i, P_j)$ is decreasing ($\partial\Pi/\partial P_j < 0$) and convex in P_j ($\partial^2\Pi/\partial P_j^2 > 0$).*

Assumption A.2 states that higher end-product performance leads to larger profit. However, this profit exhibits decreasing marginal returns in the performance. Assumption A.3 states that an integrator's own profit decreases when his competitor's end product realizes superior end-product performance (post integration). Furthermore, this decrease in profit is likely to flatten out when the competitor's superiority is very high. Both of these assumptions are intuitive.[13]

Finally, the end-product performance affects the relative benefit from adopting the subsystem, as follows:

Assumption A.4. *$F(P) - S(P)$ is increasing and convex in P.*

Assumption A.1 immediately implies that the marginal benefit one obtains from being the only one with the subsystem (i.e., $F(P)$) is greater than the marginal benefit one obtains from the subsystem when the competitor adopts the same subsystem ($S(P)$). Assumption A.4 states that the difference $F(P) - S(P)$ increases in the end-product performance, and that the rate of increase is increasing as well.[14]

[11] We thank the associate editor for framing these alternatives in a succinct way.

[12] Note that we do not relax all assumptions at once. Section 5.1 relaxes Assumption B.1, but retains Assumptions B.2 and B.3. Similarly, §5.2 (§5.3) relaxes only Assumption B.2 (B.3).

[13] It is straightforward to show that these assumptions are satisfied by many economic models of competition such as quantity-based competition, differentiated Bertrand models of price competition, market-share attraction models, etc. However, it is interesting to note that these assumptions fail to support one specific type of competition mechanism, namely, vertical differentiation models. We thank one of the reviewers for pointing this out.

[14] This technical assumption primarily allows mathematical tractability. It is relatively unimportant for the validity of our main results, as we demonstrate through a numerical example in Online Appendix 2.1 (available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1381624). Also, a simple argument shows the internal consistency in our assumptions: suppose that the converse of A.4 is true; i.e., $F(P) - S(P)$ is nonincreasing for all P. By definition that $F(1) - S(1) = 0$. Because we have assumed that $F(P) - S(P)$ is nonincreasing, this implies that $F(P) - S(P) \leq 0$. However, by Assumption A.1 we know that $F(P) - S(P) \geq 0$. This results in a contradiction.

The economic intuition behind A.4 is that as end-product performance gets higher there should be more incentives for an integrator to seek exclusivity in the subsystem usage, i.e., the subsystem becomes a bigger contributor to competitive differentiation (Sen and Tauman 2007).

Proposition 3. 1. *There exist thresholds on end-product performance P^0, P^1, and P^2 such that for $P < P^0$ no-sale is optimal, for $P^0 \le P < P^1$ a niche strategy is optimal, for $P^1 \le P \le P^2$ a saturation strategy is optimal, and for $P^2 \le P$ a niche strategy is optimal.*

2. *There exist thresholds on the subsystem functionality $0 \le \hat{f}_0 \le \hat{f}_1 \le \hat{f}_2 \le 1$ such that the provider finds it optimal to* (i) *undertake the niche strategy if $f \in [\hat{f}_0, \hat{f}_1]$ or $f \in [\hat{f}_2, 1]$,* (ii) *undertake the saturation strategy if $f \in [\hat{f}_1, \hat{f}_2]$, and* (iii) *not offer to any of the integrators if $f \in [0, \hat{f}_0]$.*

The first part of our proposition, unsurprisingly, echoes past findings in the literature (Sen and Tauman 2007) regarding the impact of end-product performance on the introduction strategy and the value appropriation power of the upstream provider. When a subsystem offers high performance, the provider finds it optimal to target more integrators. However, when the performance improvement is extremely large, i.e., $P \gg 1$, an integrator with exclusive access can become a (near) monopolist and dominate the end-product market. This insight explains why, for extremely large performance improvements, the provider appropriates higher value from licensing exclusive rights (niche strategy), and allows the adopter to become a near monopolist.

It is interesting, though, that high subsystem functionality via its effect on end-product performance becomes an attractive design choice. Recall from our discussion in §4 that when functionality affects only the integration uncertainty/costs, a high functionality (overintegration) diminishes the provider's value appropriation power and her revenues, because it decreases the potential for downstream differentiation. Thus, to mitigate the revenue decrease, the upstream provider pursues a niche strategy. Stated differently, the upstream provider could benefit from decreasing the subsystem functionality and pursuing a saturation strategy. However, when functionality affects the end-product performance, a relatively high subsystem functionality makes the niche strategy more profitable compared to the saturation strategy. Higher subsystem functionality disproportionately increases the integrator's benefit from being a near monopolist under a niche strategy (*end-product performance effect*) and decreases the likelihood of being a monopolist under a saturation strategy (*differentiation potential effect*).

Therefore, in industrial settings where the subsystem functionality shapes the end-product performance, and consequently the end-product market competition, we find that the upstream provider may reduce her value appropriation power by offering over-integrated subsystems. Our finding offers a potential explanation for the severity of the challenges during the DuPont Stainmaster introduction. DuPont insisted on pursuing a saturation strategy with Stainmaster, a technology that offered both superior end-product performance and high subsystem functionality; indeed, these are the exact conditions under which our results support the superiority of pursuing a niche strategy.

5.2. Value Appropriation: The Role of Downstream Integrator Heterogeneity

A reality in many downstream industries is that the integrators have heterogeneous capabilities (e.g., integration costs), and that some integrators tend to be more dominant than the rest. We relax Assumption B.2 (i.e., $\kappa = 0$), and we assume a nonzero cost differential parameter κ that captures the downstream heterogeneity in integration capabilities. The integration costs for the two integrators are $C(f) - \kappa$ and $C(f) + \kappa$, respectively. We also discuss a different source of heterogeneity, namely, an a priori end-product advantage for the dominant integrator. The existence of a heterogeneous downstream market allows us to capture settings where the downstream industry enjoys a higher (relative) power in value appropriation (settings close to our earlier reference to the IBM Global Services).

The baseline results about the dependence of introduction strategy on the functionality (illustrated in Figure 3) remain robust. The following proposition clarifies how the regions become larger or smaller, and how the core trade-off is moderated by heterogeneity in the downstream market.

Proposition 4. *The subsystem introduction strategy and the ex post downstream industry structure are affected as follows by greater ex ante heterogeneity among downstream integrators:*

- *fewer no-sale settings,*
- *more niche settings,*
- *fewer saturation settings.*

Heterogeneity, in our model, enhances the integration ability of one of the integrators while reducing the other's integration ability. The provider appropriates more revenues with a harder to integrate subsystem (i.e., lower functionality), because the integrator with the lowest cost can still profitably adopt the subsystem, whereas the weaker integrator cannot pay significant fees for the subsystem. As such, the no-sale region diminishes, and the saturation strategy becomes less attractive. Instead, the existence of a dominant downstream integrator constrains the upstream provider to "do business" only with him, and it favors lower ranges for the subsystem functionality. In that regard, the upstream value appropriation power is reduced. Indeed, our finding is consistent with observations in technology markets with dominant integrators (e.g., IBM Global Services and its ability to integrate multiple externally sourced information technology modules in its offerings); these dominant downstream integrators are able to dictate the level of integration to some of their technology providers.[15]

The previous effect of downstream heterogeneity on the upstream value appropriation power is independent of the type of heterogeneity: the provider always ends up transacting with one of the integrators. Yet, it is interesting to note that the upstream provider may not always benefit from transacting with the a priori dominant integrator. If the integrators exhibit heterogeneous ex ante end-product performances ($P_1(\overline{\mathscr{C}}) \neq P_2(\overline{\mathscr{C}})$), then the provider licenses to the integrator with the lower a priori end-product performance.[16] This intriguing difference is explained as follows: Under differing integration costs, the more capable integrator is willing to pay the most for the subsystem, because he has a lower integration cost; with end-product performance heterogeneity, the lower capability integrator is willing to pay the most for the subsystem, because his status quo performance is lower (i.e., higher marginal benefit from adoption). Hence, when the heterogeneity is in the integration costs, the provider should, under a niche strategy, target the more capable integrator; whereas when the heterogeneity is in the end-product performances, the provider should, under a niche strategy, target the less capable integrator.

Our finding allows us to shed more light on the drivers of the upstream value appropriation power. Downstream heterogeneity limits the upstream power as it imposes a niche strategy with an associated range for the subsystem functionality (see Figure 3). At the same time, depending on the type of a priori downstream heterogeneity, we find that the upstream provider may either enhance the level of downstream heterogeneity, or she may reduce it. In the former case, the upstream provider may lose her value appropriation power in the long run, whereas in the latter she may level competition downstream and retain her value appropriation power.

[15] Needless to say, our result, although consistent with low levels of integration found in certain technology markets with large integrators, is not the unique explanation. For instance, as one anonymous reviewer pointed out, the sheer heterogeneity of the end-product market and the ability of the integrator to pick and choose from multiple modules to develop a customized end product may have the same effect.

[16] A complete proof is available from the authors, but the proof logic is identical to that of Proposition 4.

5.3. Value Appropriation: The Role of Licensing Mechanisms

In §4 we assume the provider licenses the subsystem for a fixed one-time payment. The assumption allowed us to abstract away from the complex technology transfer arrangements often found in practice, and isolate the effect of the subsystem's functionality. However, in actual technology markets, many subsystem technology providers employ volume-based fees (royalties) in addition to fixed fees (Rostoker 1984, Arora et al. 2004). In this section, we examine the robustness of our key insights, in the presence of richer licensing structures.

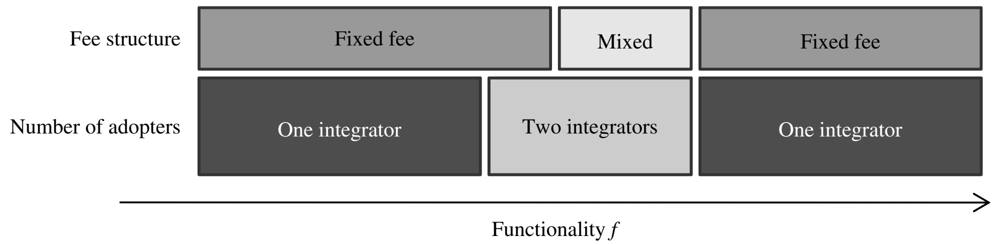
Recall that the general fee structure is $\overline{W} = [W, w]$, where W is the fixed-price component and w the per-unit fee (royalty). We relax Assumption B.3 and we assume that $w \geq 0$. Unlike the sunk-cost nature of the fixed fee W, a nonzero per unit fee w may affect the integrator's revenues $\Pi(\cdot, \cdot)$, because it directly affects the per-unit costs incurred (upon successful integration). Hence, for our analysis to carry through, we adjust the underlying notation for the payoffs $\Pi(\cdot, \cdot)$. Because these changes are for the most part intuitive, we describe them in Online Appendix 2.1, and we report here only the key results with respect to the introduction strategies and the respective upstream and downstream value appropriation power.

Proposition 5. *A royalty fee is suboptimal when the technology provider undertakes the niche strategy. However, when the technology provider undertakes the saturation strategy, she may benefit from charging a royalty* $w > 0$.

Proposition 5 makes an important point: An upstream provider will choose to calibrate her value appropriation power through complex licensing mechanisms only under certain settings. Specifically, the provider will never employ a royalty fee under a niche strategy. Intuitively, under a niche strategy, the familiar phenomenon of double marginalization makes its appearance, and it drives the adopter's revenue to decrease as the royalty (cost per unit) increases. Thus, the provider finds it beneficial not to use a volume-based fee under a niche strategy.

Volume-based royalties, on the other hand, are desirable only when the provider intends to offer the subsystem to multiple integrators. In a setting where technology is assumed to reduce manufacturing cost, Kamien and Tauman (1986) find that with complete information and risk-neutral firms, pure fixed-price contracts always dominate pure volume-based royalties. Sen and Tauman (2007) extend this model along one important dimension, namely, they allow mixed license structure with both fixed fees and royalties. They find that a provider may employ

Figure 4 Regions When Fees May Also Include Volume-Based Royalties



positive royalties when she licenses a cost-reducing innovation to many downstream firms. Our result extends these findings to the case of subsystem technologies that alter the integration risk/costs. It illustrates the *necessity* of a saturation strategy for the volume-based royalties to be optimal. The economic intuition is as follows: Whereas a royalty results in double marginalization when coupled with a niche strategy, the same royalty may be used to enhance the provider's relative value appropriation power, when coupled with a saturation strategy. Royalties inflate the per-unit cost for the entire industry, and therefore induces the downstream integrators to adjust their competitive actions to retain/increase revenues. The latter increase, which may increase overall industry revenues, is then appropriated by the provider using fixed fees. This insight has a significant managerial implication: licensing mechanisms not only serve as levers to appropriate value, but they can also regulate the power an upstream industry has to appropriate the value. Thus, the two mechanisms, volume-based royalties and fixed fees, are not substitutes but serve complementary roles.

The next proposition extends Propositions 2 and confirms the qualitative insights about the determinants of the provider's optimal introduction strategy.

Proposition 6. *The effects of the likelihood of successful integration (p), the integration costs (C), and the subsystem functionality (f) on the optimal number of integrators remain unchanged even when the provider has the flexibility to use royalties in addition to fixed fees. The region defining the saturation strategy becomes larger.*

The robustness of the structure of the thresholds governing the optimal introduction strategy (shown in Figures 2 and 3) validates that the key determinant of the provider's optimal introduction strategy is the subsystem functionality and not the type of licensing fee used. At the same time, some second-order effects exist. Specifically, our results indicate that royalties result in a larger saturation region for the following reason: Recall that for very high functionality f, the provider switches away from a saturation strategy to a niche because of the lower differentiation potential associated with the saturation strategy (see Proposition 2). However, the problem of lower differentiation potential can be mitigated by employing royalties to moderate the competition between the integrators, and thus to prevent the created value from dissipating.

Finally, the next proposition characterizes the dependence of royalty on the functionality f. Note that Propositions 6 and 7 together allow us to characterize the optimal introduction strategy (i.e., the number of integrators to whom the provider offers the subsystem and the type of fee structure she utilizes) contingent on the subsystem functionality. Figure 4 graphically illustrates this result.

Proposition 7. *There exists thresholds f_v and f'_v such that volume-based royalties are optimal if and only if $f'_v \geq f \geq f_v$.*

Proposition 7 states that any royalty fee shall be employed only for moderate values of functionality. The result follows directly from our previous discussion on the differentiation potential. The firm can employ royalties to mitigate the rent dissipation effect (Arora and Fosfuri 2003). However, beyond some level of subsystem functionality, royalties are inadequate to mitigate rent dissipation, and hence the provider resorts to restricting access to the technology (i.e., selling to fewer integrators).

6. Discussion and Conclusions

In this paper, we develop an analytical model that examines the optimal introduction strategies for a new subsystem technology in an industrial business-to-business (B2B) setting. Past studies have primarily focused on the performance contribution of such subsystem technologies to the end product. We focus on a different dimension, namely, the subsystem functionality that may influence both the end-product performance and the subsystem integration process. We define the subsystem functionality as the number of end-product functions included in the subsystem.

Our analysis suggests a strong effect of functionality to both the introduction strategy and the relative value appropriation power of the upstream technology provider. High functionality has a dual effect on the provider's profits. On the positive side, the provider extracts larger ease-of-integration rents from the adopters. Subsystems are easier to integrate because of lower integration costs/uncertainty. On the negative side, the subsystem curtails the integrator's ability to differentiate from competition. Stated differently, when the subsystem is introduced through mass adoption (i.e., saturation strategy), the provider finds it beneficial to offer less functionality. Less functionality allows all the downstream adopters to sufficiently differentiate from each other. Our result sends a cautionary message to technology providers on the potential pitfalls of overintegration, and highlights the need to conduct a more holistic assessment—the direct gains from the obvious positive effect and the indirect losses from overintegration—when managing this important design dimension.

The identified trade-off is robust to a set of potential circumstances that may alter the appropriation power of the upstream technology provider. Thus, even when one downstream firm dominates in terms of either performance or integration cost, the upstream provider needs to calibrate the subsystem functionality jointly with the introduction strategy to retain his value appropriation power. In other words, there is always a sufficiently high level of functionality that renders a mass adoption strategy suboptimal.

In addition, our study brings forward two important findings: first, the role of licensing structures in managing the influence of subsystem functionality on downstream competition. Second, the fact that the type of heterogeneity among downstream integrators may enable the use of functionality as a means to diminish or strengthen the upstream appropriation power. Specifically, the technology provider can potentially undertake a saturation strategy, even when the subsystem functionality is high, with royalties that change the cost structure of adopting firms. Royalties manage the downstream competition, whereas fixed component of fees allow her to appropriate the integrator surplus. This result identifies the complementary nature of the two value appropriation levers (fixed fee and royalties). It adds to the literature discussion that has identified plausible conditions where royalties are optimal in licensing agreements (Wang 1998, Sen and Tauman 2007).

Our results also serve to complement recent studies that examine the degree to which upstream decisions affect the downstream competition intensity, and therefore the value appropriation power across the different tiers in a value chain. Ghosh and John (2009), in a study examining B2B contexts where original equipment manufacturers (OEMs) procure subsystems from outside vendors, find that an OEM is less likely to procure a branded component when the component does not allow significant (ex post) differentiation of the end product. Thus, it appears that OEMs that integrate technology subsystems into their end products account not only for the end-product performance implications of the subsystem, but also the differentiation-related competitive advantage that the subsystem brings once adopted and integrated.

Although our findings suggest that the trade-off we propose, and its normative implications, have some descriptive power, we hasten to add that the general question of whether or not integrators and providers consider the influence of design factors on their competitive advantage can be answered only through an empirical study. The anecdotal evidence we offered about DuPont's Stainmaster technology allows us to conjecture that the theoretical model we have laid out, and the few propositions it yielded, may offer a reasonable starting point to undertake an empirical examination of how the adoption patterns and the fee structures depend on the design characteristics. Although further work needs to be undertaken to turn these implications into testable hypotheses, we summarize the more interesting (in our opinion) propositions emerging from our model:

P1: *Functionality has a positive effect on the provider's profit if she is a niche player.*

P2: *Functionality has a weaker effect on the provider's profit if she is a saturation player compared to the case where she is a niche player.*

P3: *Royalties would be associated with wide adoption (saturation) strategy.*

P4: *Controlling for provider's introduction strategy, royalties would be associated with moderate functionality subsystems.*

Throughout this study, we have focused on one design characteristic—functionality—and modeled its influence on the "integration process specific" value provided to an adopter by the subsystem. Still, it is doubtless that other managerial actions (such as customization) may allow a technology provider to perhaps even selectively affect the value that a subsystem offers. Our model may provide a useful framework for studying such additional managerial decisions. Finally, much of the extant literature in technology introduction, to our knowledge, has used noncooperative game theoretic frameworks, with the implicit assumption that either the provider or the adopter have market power (i.e., Stackelberg leaders). Although this assumption does allow one to gain an initial understanding, given the repeated nature of interactions in such technology markets, we believe it is necessary to view both technology introduction and development as a collaborative endeavor between the provider and the adopter, and possibly as an outcome of a negotiated joint decision. These questions await future research.

Acknowledgments

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Appendix

Recall that we defined the payoffs to the integrator (who is the row player) contingent on the integration outcome as given in Table A.1. For instance, we defined $\Pi(P(\mathscr{C}), 1)$, the payoffs to the row player when the outcome of his integration is success, and the outcome of his competitor's integration process is failure, as b (i.e., the cell {*SUCCESS*, *FAIL*}).

Proof of Proposition 1. Based on Table A.1, we may evaluate the expected payoffs to integrators *conditional* on their adoption decisions (i.e., decisions whether or not to license the subsystem). Table A.2 gives this net expected payoff (to the row player). We illustrate this for one of the quadrants of Table A.2.

Consider the value in the cell $\{A, A\}$, which denotes the expected payoffs to the row player when both he and his competitor decide to adopt the subsystem. Specifically, if the integrator and his competitor choose to adopt the subsystem, there are a total of four different possibilities for the integration outcome: (i) both are successful, which occurs with probability p^2 and yields payoff a; (ii) both are unsuccessful, which occurs with probability $(1-p)^2$ and yields payoff d; (iii) the integrator is successful while his competitor fails, which occurs with probability $p(1-p)$ and yield payoffs b; or (iv) the integrator fails while his competitor is successful, which occurs with probability $(1-p)p$ and yields payoffs c. Hence, the expected payoff is given by $p^2a+p(1-p)b+(1-p)pc+(1-p)^2d$; after netting out the license fee W and the integration cost $C(f)$, this yields the value given in the cell $\{A, A\}$ in Table A.2.

Therefore, once the provider sets a particular fee W, the two integrators play the adoption game that has the expected payoffs given in Table A.2. For ease of exposition, denote the value in the cell $\{A, A\}$ as V_{AA}, $\{N, A\}$ as V_{NA}, $\{A, N\}$ as V_{AN}, $\{N, N\}$ as V_{NN}, and with some abuse of notation denote $C(f)$ simply as C.

Table A.1 Payoffs (to Row Player) After Integration

	SUCCESS	*FAIL*
SUCCESS	a	b
FAIL	c	d

Table A.2 Net Expected Payoffs (to Row Player)

	A	N
A	$p^2a+p(1-p)(b+c)+(1-p)^2d-C(f)-W$	$pb+(1-p)d-C(f)-W$
N	$pc+(1-p)d$	d

Note. A and N denote the adopt and not-adopt strategies, respectively.

We characterize how the Nash equilibria of the adoption game depends on the license fee W next.

If one's competitor does not adopt, then one's best response is to adopt iff $V_{AN} \geq V_{NN}$, i.e., iff $pb+(1-p)d-C-W \geq d$, i.e., iff $W \leq p(b-d)-C$.

Similarly, if one's competitor adopts, then one's best response is to adopt iff $V_{AA} \geq V_{NA}$, i.e., iff $p^2a+p(1-p)\cdot(b+c)+(1-p)^2d-C-W \geq pc+(1-p)d$, i.e., iff $W \leq p(b-d)-p^2((b-d)-(a-c))-C$.

Also note that by Assumption A.1, $\Pi(P, P)-\Pi(1, P) \leq \Pi(P, 1)-\Pi(1, 1)$; i.e., $a-c \leq b-d$.

Hence, when $W \leq p(b-d)-p^2((b-d)-(a-c))-C$, then regardless of the competitor's action, one's dominant strategy is to adopt the subsystem, which implies that when $W \leq p(b-d)-p^2((b-d)-(a-c))-C$, the unique Nash equilibrium is that both adopt.

Similarly, if $p(b-d)-p^2((b-d)-(a-c))-C < W \leq p(b-d)-C$, then if the competitor does not adopt, then the integrator would prefer to adopt, but if the competitor adopts, then the integrator would prefer not to adopt. Hence, there are two Nash equilibria $\{A, N\}$ and $\{N, A\}$.

Finally, when $W > p(b-d)-C$, then irrespective of the competitor's action, one's dominant strategy is not to adopt the subsystem, which implies that the only Nash equilibrium is one where neither adopts.

Thus, a profit maximizing provider will set license fee $W_n = p(b-d)-C$ so as to induce only one integrator to adopt (niche strategy), and will set $W_s = p(b-d)-p^2\cdot((b-d)-(a-c))-C$ to induce both integrators to adopt (i.e., the saturation strategy). □

Proof of Corollary 1.

Claim 1: The provider's revenue under saturation strategy is

$$\begin{aligned}\pi_s &= 2(W_s-C)\\ &= 2(pF-p^2(F-S)-C), \quad \text{where } F=b-d \text{ and } S=a-c\\ \frac{d\pi_s}{dp} &= 2(F-2p(F-S))\\ &\geq 0 \text{ iff } p<\frac{F}{2(F-S)}.\end{aligned}$$

Hence, the revenue under the saturation strategy $\pi_s(p)$ is decreasing in the likelihood of integration success p for $p > F/(2(F-S))$. □

Claim 2: The provider's revenue under saturation strategy is

$$\begin{aligned}\pi_s &= 2(W_s-C)\\ &= 2(pF-p^2(F-S)-C), \quad \text{where } F=b-d \text{ and } S=a-c\\ &= 2(pF-p^2(F-S)-K(1-\psi p))\\ &\qquad \text{since } C(f)=K(1-\psi\phi(f)) \text{ and } p(f)=\phi(f)\\ &= 2(p(F+\psi K)-p^2(F-S)-K)\\ \frac{d\pi_s}{df} &= 2(F+\psi K-2p(F-S))\frac{1}{dp(f)/df}\\ &\leq 0 \text{ when } p>\frac{F+\psi K}{2(F-S)},\\ &\qquad \text{i.e., when } f>\phi^{-1}\left(\frac{F+\psi K}{2(F-S)}\right). \quad \square\end{aligned}$$

Before proving Proposition 2, we state the following simple auxiliary lemma. The proof is trivial and is given in Online Appendix 2.2.

Lemma 1. *If $F(x)$ is convex, then there exist x_1, x_2 such that* $\{F(x) \le 0\} \Leftrightarrow \{x \in [x_1, x_2]\}$.

Proof of Proposition 2. The profits under the saturation and niche strategies are given by π_s and π_n, respectively, where

$$\pi_n = pF - C,$$
$$\pi_s = 2(pF - p^2(F-S) - C).$$

Let

$$G(p, C, P) = \pi_n - \pi_s = 2p^2(F-S) - pF + C.$$

Then, saturation is superior to niche iff $G(p, C, P) \le 0$.

Claim 1: To prove the claim, observe that $G(p, C, P)$ is convex in p. Hence, by Lemma 1, there exists p^1 and p^2 such that $\{G(p, \ldots) \le 0\} \Leftrightarrow p \in [p^1, p^2]$. That is, there exists p^1 and p^2 such that saturation is superior to niche iff $p \in [p^1, p^2]$.

Niche is superior to no-sale iff $pF - C \ge 0$. That is, there exists a threshold $p^0 = C/F$ such that niche is superior to no-sale iff $p \ge p^0$. Furthermore, since $pF - C \ge pF - 2p^2(F-S) - C$, if saturation is superior to niche, then niche must be superior to no-sale. That is, $p^0 \le p^1$.

Hence, since $p^0 \le p^1 \le p^2$, when $p < p^0$, no-sale is superior to niche, which is superior to saturation; when $p^0 \le p < p^1$, niche is superior to no-sale, and niche is superior to saturation; when $p^1 \le p \le p^2$, saturation is superior to niche, which is superior to no-sale; and when $p > p^2$, niche is superior to saturation, and niche is superior to no-sale. □

Claim 2: To prove the claim, observe that saturation is superior to niche iff $C \le C^0$, where $C^0 = pF - 2p^2(F-S)$. Furthermore, niche is superior to no-sale iff $pF - C \ge 0$, i.e., there is a threshold $C^1 = pF$ such that niche is superior to no-sale iff $C \le C^1$. Lastly, observe that $C^1 \ge C^0$.

Hence, when $C \le C^0$, saturation is superior to niche, and niche is superior to no-sale; i.e., when $C \le C^0$ saturation is the optimal strategy. When $C^0 < C \le C^1$, niche is superior to saturation, and niche is superior to no-sale; i.e., when $C^0 < C \le C^1$, niche is the optimal strategy. Lastly, when $C > C^1$, niche is superior to saturation, and no-sale is superior to niche; hence, no-sale is the optimal strategy. □

Claim 3: Recall that we defined

$$G(p, C, P) = \pi_n - \pi_s = 2p^2(F-S) - pF + C.$$

Saturation is superior to niche iff $G(p, C, P) \le 0$.

Furthermore, recall that $p(f) = \phi(f)$ and $C(f) = K(1 - \psi\phi(f))$, where $\phi(\cdot)$ is a nondecreasing function. Unlike in Claims 1 and 2, we cannot simply apply Lemma 1 to find the appropriate thresholds for f because the function $G(\cdots)$ may not be convex in f.

However, a change of variable allows us to apply the Lemma. Specifically, $C(f) = K(1 - \psi\phi(f)) = K(1 - \psi p(f))$. Hence, $G(p, C, P) = 2p^2(F-S) - pF + K(1-\psi p)$. This function is convex in p, which implies that saturation is superior to niche iff $p \in [p^1, p^2]$. Furthermore, since $p = \phi(f)$ is nondecreasing in f, this implies that saturation is superior to niche iff $f \in [\phi^{-1}(p^1), \phi^{-1}(p^2)]$.

Niche is superior to no-sale iff $pF - C \ge 0$. That is, niche is superior to no-sale iff $pF - K(1 - \psi p) \ge 0$. Thus, there exists a threshold $p^0 = K/(F + K\psi)$ such that niche is superior to no-sale iff $p \ge p^0$. Furthermore, since $pF - C \ge pF - 2p^2(F-S) - C$, if saturation is superior to niche, then niche must be superior to no-sale. That is, $p^0 \le p^1$. Last, since $p = \phi(f)$ is nondecreasing in f, this implies that niche is superior to no-sale iff $f \ge \phi^{-1}(p^0)$.

Now as with Claims 1 and 2, we may easily see with $f_0 = \phi^{-1}(p^0)$, $f_1 = \phi^{-1}(p^1)$, $f_2 = \phi^{-1}(p^2)$, that no-sale is optimal when $f < f_0$, niche when $f \in [f_0, f_1] \cup [f_2, 1]$, and saturation when $f \in [f_1, f_2]$. □

Proof of Proposition 3.

Claim 1: Consider $G(P, \cdots) = p(2p(F-S) - F) + C$. Function $-F(P)$ is convex in P since $F(P)$ is concave in P (by Assumption A.2). Also, by Assumption A.4, $F(P) - S(P)$ is convex in P. Hence, $G(P, \cdots)$ is convex in P.

Thus, by Lemma 1, there exist P^1 and P^2 such that $\{G(P, \cdots) < 0\} \Leftrightarrow \{P^1 < P < P^2\}$. That is, saturation strategy is optimal iff $P^1 < P < P^2$.

Niche strategy is optimal under two cases—$P < P^1$ and $\pi_n > 0$, and $P > P^2$ and $\pi_n > 0$. Recall that $\pi_n = p_S p_I F(P) - C$, where $F(P) = b(P) - d$. By Assumption A.2, $b(P)$ is increasing in P. Hence, there is a threshold P^0 such that $\{\pi_n > 0\} \Leftrightarrow \{P > P^0\}$. Furthermore, $P^1 \ge P^0$ (because at the point P^1 where saturation becomes preferable to niche, $\pi_n > 0$). Hence, niche is optimal iff $P^0 < P < P^1$ or $P > P^2$.

The remaining case is $P < P^0$, for which no-sale is optimal. □

Claim 2: We prove this proposition in three steps.

Step 1. We will treat P as a purely exogenous variable, allowing us to directly use Claim 3 of Proposition 2 and Claim 1 of Proposition 3 to obtain the three thresholds for P and f denoted by P_0, P_1, P_2 and f_0, f_1, f_2, respectively, such that saturation is optimal iff $f \in (f_1, f_2)$ and $P \in (P_1, P_2)$, no-sale is optimal iff $f < f_0$ and $P < P_0$, and niche is optimal otherwise.

Step 2. In Lemma 3, we will characterize the sensitivity of these thresholds. This allows us to analytically derive the shape of the different optimal regions in the (P, f) space.

Step 3. We will endogenize the P variable by explicitly accounting for the dependence between P and f, and show that a different set of three thresholds exist for f.

Step 1:

When P is assumed to be an exogenous variable independent of f, Claim 3 of Proposition 2 and Claim 1 of Proposition 3 directly imply the existence of the required thresholds. For completeness, these are restated as the next lemma.

Lemma 2. 1. *There exist thresholds* $0 \le f_0(P) \le f_1(P) \le f_2(P) \le 1$ *such that the provider finds it optimal to* (i) *undertake the niche strategy if* $f \in [f_0, f_1]$ *or* $f \in [f_2, 1]$, (ii) *undertake the saturation strategy if* $f \in [f_1, f_2]$, *and* (iii) *not to offer the subsystem if* $f \in [0, f_0]$.

2. *There exist thresholds* $1 \le P_0(f) \le P_1(f) \le P_2(f)$ *such that the provider finds it optimal to* (i) *undertake the niche strategy if* $P \in [P_0, P_1]$ *or* $P \in [P_2, \infty)$, (ii) *undertake the saturation strategy if* $P \in [P_1, P_2]$, *and* (iii) *not to offer the subsystem if* $P \in [1, P_0]$.

Step 2:

Lemma 3. 1. *The thresholds* $f_0(P), f_1(P), f_2(P)$ *are nonincreasing in* P.

2. *The thresholds* $P_0(f), P_1(f), P_2(f)$ *are nonincreasing in* f.

Proof of Lemma 3. To show that $f_0(P)$ is nonincreasing in P, consider $P_2 > P_1$ and assume the converse, i.e., let $f_0(P_2) > f_0(P_1)$. Choose any $f \in (f_0(P_1), f_0(P_2))$. Since $f > f_0(P_1)$, the point $[f, P_1]$ cannot be in the no-sale region. Since $f < f_0(P_2)$, the point $[f, P_2]$ must be in the no-sale region (by Lemma 2). Thus, there exists an f such that as P increases (i.e., we go from P_1 to P_2, where $P_2 > P_1$), we switch into no-sale region from saturation or niche region. This is obviously false by Lemma 2. Hence, $f_0(P_2) \le f_0(P_1)$ for all $P_2 > P_1$; that is $f_0(P)$ is nonincreasing.

The proofs for the sensitivity of all other thresholds are similar and are available from the authors.

Step 3:

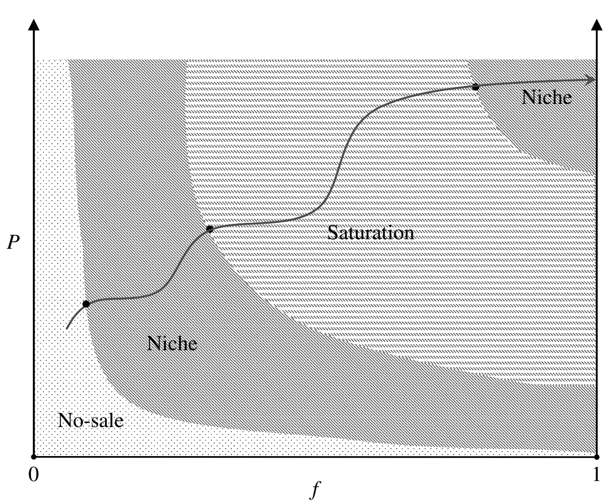
In this step, we offer the proof of the main claim (Claim 3). In Steps 1 and 2 we proved the existence of thresholds on P and f, and their sensitivity. This allows us to analytically construct the optimality regions in the (P, f) space. They are shown in Figure A.1.

Consider the case where P depends on f, specifically, $P = P(f)$ is nondecreasing in f. Now consider the curve in Figure A.1, which plots the function $P(f)$. Since $P(f)$ is always nondecreasing and because the thresholds on P, namely, $P_0(f), P_1(f), P_2(f)$ are always nonincreasing (by Lemma 3), this implies that they intersect at most once. Hence, it must be the case that when P is endogenous and determined by $P(f)$, as f increases, the optimal strategy switches from no-sale to niche to saturation to niche. □

Proof of Proposition 4. Recall that κ represents the downstream cost heterogeneity. A nearly identical proof as given for Proposition 1 can be given to show that $W_n = pF - C + \kappa$ and that $W_s = pF - p^2(F - S) - C - \kappa$. Hence, the difference between niche and saturation is given by $W_n - 2W_s = 3\kappa + 2p^2(F - S) - pF + C$.

Because this is increasing in κ, this implies that niche is superior to saturation for more cases. In the same manner,

Figure A.1 **Regions in the (f, P) Space and the Function $P(f)$**



note that the difference between saturation and no-sale, i.e., $W_s - 0$ is decreasing in κ. Hence, saturation is worse than no-sale in more cases.

Similarly, because the difference between niche and no-sale $W_n - 0$ is increasing in κ, niche is superior to no-sale in more cases. Combining these we get that as κ increases, niche increases, saturation decreases, and no-sale region decreases. □

Because we need to develop some additional notations, we defer the proof of Corollary 5, Proposition 2, and Proposition 7 to Online Appendix 2.1.

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