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The Ecosystem Penalty: Value Creation Technologies and Incentive Misalignment

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Abstract

When are the incentives of a business ecosystem’s participants aligned with its growth? How is the technology of value creation affecting this alignment? To answer these questions we formally model how value creation determines value capture in a business ecosystem. We find that alignment is typically imperfect compared to an integrated benchmark, highlighting an “ecosystem penalty” whereby participants’ returns to value creation are lower than that of the ecosystem. The occurrence of this penalty depends on whether the technology is loosely coupled (value additive in inputs), exhibits bottlenecks (value constrained by the weaker input), or is strongly supermodular (value multiplicative in inputs). Contrary to conventional wisdom, we find it can be severe for the participants who are constraining the system the most.

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1 INTRODUCTION

Scholars and practitioners have been widely adopting an ecosystem lens to understand how firms supply complements to contribute a value proposition to final users (Adner and Kapoor, 2010; Jacobides, Cennamo, and Gawer, 2018; Kapoor, 2018). Investments by its participants are key to a business ecosystem development and survival (Ethiraj, 2007; Hannah and Eisenhardt, 2018; Kapoor and Agarwal, 2017). If complementors do not invest to boost value creation, consumers will fail to purchase the ecosystems offering. Yet the ecosystem literature lacks a comprehensive account of the relationship between the structure of an ecosystem and its participants' incentives to invest in value creation. While complementarities define ecosystems (Adner, 2017; Baldwin 2018; Jacobides et al. 2018, Kapoor, 2018), we know less about how some specific types of complementarities matter to the incentives of their participants.

Starkly different technologies of value creation with different types of underlying complementarities can be at play in ecosystems. For instance, in mobile phone-based ecosystems, some apps (e.g., email apps), provide additional value without depending on advances from the hardware. Others, such as an augmented reality app, depend heavily on advances in the performance of the hardware in computing power and sensors. In the former case, the components' value creation is loosely coupled, in the latter case, the components of value creation are tightly coupled and value creation is constrained by the least performing component in the manner of a bottleneck. However, we do not have a clear understanding of the implications of such variation for an ecosystem participants' incentives to further overall value creation. One reason is that we lack a formal theory of value capture in ecosystems that accounts for their fundamental features and links those to their participants' private returns.

As a result, some fundamental questions about firm strategy in business ecosystems are left unanswered: Are ecosystems providing sufficient investment incentives to their participants? How are value creation technologies shaping these incentives? How are other characteristics of ecosystems, such as within-component and between-component competition affecting investment incentives?

We answer these questions by offering a formal model of value creation and value capture in

a business ecosystem, and accounting for different types of value creation technologies on a continuum from weaker to stronger complementarities. We start with a loosely coupled ecosystem – an additive technology, where the total value created is the sum of the individual capabilities of the orchestrator and of the best complementor (as in messaging apps on a smartphone).¹ We then analyze a bottleneck technology, where the total value created is constrained by the capability of the least performing component – the orchestrator or the complementor (as in augmented reality apps, or components of a computer system), which is also a weak case of supermodular complementarity (Vives, 2007).² Finally, we examine a multiplicative technology where the total value created is the product of the individual capabilities of the orchestrator and of the best complementor (as in virtual reality games) – a classic case of supermodular complementarity (Milgrom and Roberts, 1990).

We model an archetypical ecosystem including an orchestrator, competing complementors, and a final customer. For a practical illustration consider, for instance, Airbus as an orchestrator, Pratt & Whitney and CFM as competing engine producers, and an airline company who chooses which engine to install on the Airbus aircraft. Competitive asymmetry between ecosystem components – a one-of-a-kind orchestrator vs. (partially) substitutable complementors – reflects the dynamic of many real-life ecosystems where there is a powerful platform or an orchestrator (e.g., smartphone OS, game console, aircraft producer) and multiple complementors (app developers, game developers, engine producers). This setup allows us to explore the effects of both between- and within-component competition. We use the value-based framework (Brandenburger and Stuart, 2007) to map value creation into value capture under competition, and rely on Cappelli and Chatain (2020) to ensure a mutually consistent distribution of value. We then compare each actor’s marginal returns to increasing its value creation capability to the benchmark given by a fully integrated ecosystem. We use a costless integration where the orchestrator and the complementor act as one actor as an idealized benchmark of a perfect alignment to show how competition for value capture between ecosystem participants shapes their incentives to invest under each value creation technology.³

¹This is what Jacobides et al. (2018) call “unique” complementarities: an orchestrator’s product doesn’t function without a complementor’s product, and vice versa (Hart and Moore, 1990).

²For a detailed explanation of the bottleneck value creation and supermodularity see Section 4.2.

³Cognizant of the “nirvana fallacy” (Demsetz, 1969), we do not consider the idealized integrated actor benchmark

We find that individual actor's marginal returns are typically less than the return to the ecosystem as a whole because the value they help create is only partially captured by them, creating an "ecosystem penalty" with respect to investing in value creation. This penalty differs sharply across the type of complementarities. Furthermore, within each value creation scenario it varies across the type of the actor (orchestrator vs. complementor) and the level of their capabilities.

In the most tightly coupled scenario – multiplicative value creation – the orchestrator faces a consistently large gap between private returns and ecosystem returns; the penalty is minimized only when both the orchestrator and the complementor are at their weakest. In a loosely coupled ecosystem – additive value creation – the best incentive alignment is achieved when the orchestrator has high capabilities while complementors are close substitutes. The bottleneck value creation features the most variance in ecosystem penalty leading to both the best and the worst alignment of incentives across all scenarios. The best alignment is achieved when the orchestrator is the least capable actor in an ecosystem, in a sharp contrast to the additive case. The worst alignment happens when the orchestrator is ranked between the best and the second best complementor. We show that while the orchestrator remains the ecosystem bottleneck and the source of improvement in the total value creation, the best complementor will have a claim on the returns to such improvement which will severely dampen the orchestrator's incentives. In configurations like these an ecosystem may get stuck in a situation where individual incentives to invest may be too low for the ecosystem's member who is constraining the overall value the most, creating a vicious circle of low returns and low investments. Table 1 provides a preview of the main findings.

By explicitly tracing how value creation by the ecosystem maps into private value capture, we are able to unpack what drives incentives to create more value in an ecosystem, which is crucial for its ability to maintain itself. In doing so we are able to address a gap in the ecosystem literature concerning the understanding of the key contingencies and mechanisms relating value creation and value capture. The insights from our model contribute to the literature on ecosystems and comple-

as feasible in practice. Rather, we use it as a common metric to compare the patterns and the degrees of incentive misalignment between the different value creation technologies. We acknowledge that there are other reasons why ecosystem components may not be integrated in the first place (e.g., differences in capabilities, diseconomies of scale and scope, etc.) but we leave them out of the scope of this study as our goal is not to compare governance modes (ecosystem vs. integration).

	Additive Value Creation	Bottleneck Value Creation	Multiplicative Value Creation
Ecosystem value creation	Loosely coupled	Tightly coupled, weaker form of supermodularity	Tightly coupled, stronger form of supermodularity
Function of participants' capabilities	Total value = Orchestrator + Complementor	Total value = $\min\{\text{Orchestrator}, \text{Complementor}\}$	Total value = Orchestrator x Complementor
Best ecosystem alignment	Strong orchestrator, high level of similarity among complementors	Very weak orchestrator (is a bottleneck), and ranked below more than one complementor	Weak orchestrator and weak complementor (orchestrator's penalty always significant, yet both penalties minimized when orchestrator's and complementor's capabilities are lowest)
Worst ecosystem alignment	Weak orchestrator, and high capability gaps among complementors	Value trap: Weak orchestrator (is a bottleneck) but ranked between best and second best complementor	Misalignment more acute as orchestrator's and complementors' capabilities increase

Table 1: Preview of the main findings

ments in several ways.

First, our analysis enables understanding the difference between total value creation – by the whole ecosystem (e.g., Adner and Kapoor, 2010) – and actual value capture by an individual actor. We find that higher total value creation does not necessarily translate into a proportionate increase in an individual value capture, which suggests that current ecosystem research, by not sufficiently elaborating on the determinants of the link between value creation and value capture, may be over-estimating the incentives of ecosystem participants to invest in value creation.

Second, we offer a structured analysis that helps establish new mechanisms underpinning ecosystem alignment (Adner, 2017) and ecosystem evolution (Hannah and Eisenhardt, 2018; Jacobides et al., 2018). Our results demonstrate how investment in ecosystem value creation is determined by the technology of value creation and affected by both between-component and within-component competition. In doing so we are able to infer ecosystem configurations that are more or less conducive to firms' investment. Moreover, our findings imply a number of empirically testable implications linking drivers of alignment to ecosystem (and members) performance.

Finally, we offer a workable model for the ecosystem literature that links the type of the underlying value creation technology to the value creation by the ecosystem, and to private value capture.

Our analysis demonstrates how the formalism of a mathematical model can be helpful in uncovering the mechanisms driving firms' strategies in a context featuring complex interdependencies (Gans and Ryall, 2017; Makadok, Burton, and Barney, 2018; Ross, 2018).

Our paper is organized as follows. We first provide the theoretical background for the study. We then describe and analyze a formal model of ecosystem value creation and value capture. Building on the model, we analyze the relationship between ideal types of value creation technology and participants' returns to value creation improvement. We finally discuss the results and conclude.

2 THEORETICAL BACKGROUND

A business ecosystem can be defined as “a set of actors that contribute to the focal offer's user value proposition” (Kapoor, 2018). A first stream of strategy research on ecosystems focuses on the value creation aspect of business ecosystems and investigates how firms can “align” the producers of complementary products/services – complementors – to ensure the availability of complements for their focal product (Adner, 2012, 2017). This stream examines how the availability of complements favors new product adoption (Adner and Kapoor, 2010; Hannah and Eisenhardt, 2018), innovator's performance (Adner and Kapoor, 2010), or the survival of an incumbent product (Adner and Kapoor, 2016a, 2016b). To achieve these ends, firms may attempt to affect the supply of complementary products by, for instance, selecting markets where the complements are already available (Kapoor and Furr, 2015), allying with producers of complementary products (Hannah and Eisenhardt, 2018; Kapoor, 2013; Kapoor and Lee, 2013), or developing complements in-house (Ethiraj, 2007).

In this stream, firms are understood to be motivated to invest to increase the total value creation in the ecosystem because they anticipate to capture some of that value in return. However, how much value a firm can capture depends on many factors, e.g., its role in the ecosystem (focal firm or complement), competition in each complementary segment, and the way the capabilities combine to create value for the final customer. As a result, it is often difficult to evaluate the determinants of a firm's incentives to invest in value creation in the ecosystem. This issue is explicitly taken up by Ethiraj (2007) in a key contribution that addresses the incentives to innovate in complements.

Ethiraj (2007) examines firms' investments into a component that constrains the performance of an ecosystem and theorizes about the relationship between ecosystem value creation and private returns to investment. Yet his theory does not focus on the impact of competition over value capture and does not investigate sources of variation in ability to capture value. Thus, while we understand that value creation for the overall ecosystem benefits its participants, we know less about each firms' returns to invest to further value creation, even though we can expect this to be one important driver of their investment behavior.

A second research stream, focusing on value capture, suggests that value may be unequally distributed among the ecosystem participants. Specifically, ecosystem participants who own a component in scarce supply – i.e., “bottlenecks” – may capture a disproportionate amount of value (Baldwin, 2018; Jacobides, Knudsen, and Augier, 2006). This advantageous position can arise due to technological scarcity – e.g., the technology is proprietary and only available to a limited set of firms (Baldwin, 2018) – or due to firms' actions, such as setting standards or quality control (Jacobides and Tae, 2015). This stream emphasizes firms' strategies to capture value *vis-à-vis* other ecosystem participants but addresses less the efforts to improve total value creation by the ecosystem. The focus is on improving one's value capture at the expense of other ecosystem participants while concerns about how to grow the total size of the pie are comparatively left in the background.

Finally, the closely related literature on platforms and platform-based ecosystem does acknowledge the trade-offs between value creation and value capture but focuses predominantly on value capture incentives. Value creation is usually analyzed through the lens of network effects: a platform chooses a strategy that may increase its value capture but in doing so may push away complementors who cannot capture enough value, in turn, lowering the platform's attractiveness for the final consumer (Cennamo and Santalo, 2013). Higher value creation is usually not due to technological innovation (as in the business ecosystems literature) but rather through network effects (Mantovani and Ruiz-Aliseda, 2016). Furthermore, the emphasis is usually only on one component of the ecosystem – either how platforms may use their position to extract more value (e.g., Gawer and Henderson, 2007; Wen and Zhu, 2019) or how complementors may try to protect their value capture

vis-à-vis platform (e.g., Wang and Miller, 2020; Zhu and Liu, 2018) – but not on both.

To summarize, on the one hand, the value creation-focused stream is concerned with strategies that enlarge the overall “pie” (the total value creation by the ecosystem) and acknowledges the role of changes in technology in the evolution of ecosystems (e.g., Adner and Kapoor, 2010; Hannah and Eisenhardt, 2018; Kapoor and Agarwal, 2017). However, it provides less in the way of understanding how improvement in value creation translates in additional value capture by participants. On the other hand, the value capture-focused stream, while leading the way in acknowledging the role of technology in the emergence of bottlenecks (Baldwin, 2018) could be extended to provide a more comprehensive account of how different technologies of value creation in the ecosystem affect firms’ incentives.

Against this backdrop, we seek to build on both approaches and forge a path that equally incorporates value creation and value capture. Using a formal model allows us to account at the same time for how total ecosystem value is furthered and how new value is split among participants. We can thus disentangle effects on value creation to the ecosystem versus those on individual value capture, and crucially analyze which contingencies, such as value creation technologies, matter to this question. We tackle this issue by modeling three different value creation technologies (from less to more tightly coupled ecosystems) to understand divergences in firms’ incentives.

Furthermore, we rely on a formal model that acknowledges how value capture by one type of actor feeds back on value capture by other types. We thus provide a logically consistent account of how incentives to invest in the ecosystem are shaped by interactions between participants to the ecosystem, giving equal billing to the viewpoint of all actors in an ecosystem (e.g., the orchestrator, the complementors, and the buyers).

3 A FORMAL MODEL OF ECOSYSTEM VALUE CREATION AND VALUE CAPTURE

We use the value-based framework (Brandenburger and Stuart, 2007; MacDonald and Ryall, 2004) to model an elemental ecosystem consisting of two complementary components. Components are the building blocks of the technology that forms the ecosystem (Baldwin, 2018). One component

comprises a single firm, the orchestrator (Furr and Shipilov, 2018; Gawer and Cusumano, 2008), while the other is competitive, with two complementors. A buyer, the final user, combines these components to create value. Taken together, this is most parsimonious configuration allowing for competition for value between and within components.

On this basis, we derive the bounds on value capture implied by the core, and the expected value capture given the shape of the core. Building on this, we examine three ways in which capabilities in each component combine to create value at the level of the ecosystem: the additive case, the bottleneck case, and the multiplicative case. In the additive case, ecosystem value creation is the sum of the best capabilities in each component. In the bottleneck case, ecosystem value creation is constrained by the component where capabilities available are least. In the multiplicative case, ecosystem value creation is the product of the best capabilities in each component.

3.1 Value creation

Our elemental ecosystem comprises two components. In the first component, the “base”, there is only one firm, the orchestrator (O) of the ecosystem. In the second component, the “complementor” component, firms compete with each other to offer a functionality on top of the base. We include two such complementors, C_1 and C_2 .

The structure of this ecosystem captures the situation whereby one leading entity, the orchestrator, creates and exclusively controls an infrastructure (e.g., an operating system) on top of which other firms can contribute a compatible component (e.g., an app) that serves to increase the value for the final user. The orchestrator, however, is in full control of its component and does not admit competition, while it provides the necessary elements (e.g., an API, a certification, standards) for firms in the second component to provide a complement. By having two disjoint components, we can study between-component competition for value capture. By including two competing firms in one of the components, we can assess the role of within-component competition.

Each firm can produce one unit of a product in its respective component. The final user, buyer B , consumes a bundle consisting of one unit from each component. A unit of any component has no value if it is not combined with a unit of the other component. That is, not only the complement has

no value without the base, but the base without the complement is not valuable either. Moreover, we normalize the alternatives available to the buyer outside of the game (e.g., participating to another, competing, ecosystem) to zero.

Formally, all players belong to the set $N = \{O, C_1, C_2, B\}$. Value creation possibilities are described by a characteristic function $v(S)$ that maps a set of players $S \subseteq N$ into the maximum value these players can create together. A set of players S can only create positive value if it comprises the orchestrator, at least one complementor, and the buyer. This means $v(O, C_1, B) \geq 0$, $v(O, C_2, B) \geq 0$, and $v(O, C_1, C_2, B) \geq 0$ while all other combinations of players have a worth equal to zero.

Furthermore, complementors are substitutes to one another and C_2 is, by convention, enabling higher value creation. I.e., $v(O, C_1, B) \leq v(O, C_2, B)$ and $v(O, C_2, B) = v(O, C_1, C_2, B) = v(N)$.

3.2 Value capture: The core

Following the logic of biform games (Brandenburger and Stuart, 2007), we calculate each actor's value capture under competition by first computing the core of the game. The core finds allocations of value such that no subset of players is better off turning down the allocation. The core of the game is given by the following constraints. Let π_i be the value captured by player i . The first constraint is that the sum of the value captured equals to the total value created: $\sum_{i \in N} \pi_i = v(N)$. The other constraints translate the notion that each subset of players captures at least as much as it can guarantee to itself unilaterally. That is: $\sum_{i \in S \subset N} \pi_i \geq v(S), \forall S \subset N$.

In the ecosystem described above, the core is characterized by the following constraints on the value captured by each member:

$$\begin{aligned} \pi_O + \pi_{C_1} + \pi_{C_2} + \pi_B &= v(N), \\ \pi_{C_1} &= 0, \\ 0 \leq \pi_{C_2} &\leq v(N) - v(O, C_1, B), \\ 0 \leq \pi_O &\leq v(N), \\ 0 \leq \pi_B &\leq v(N). \end{aligned}$$

The first constraint means that the value created ($v(N)$) is fully distributed among players. The second means that C_1 never captures value because it is not needed to create the maximum value in the ecosystem. As a result, the value created is split between the remaining players who are necessary to value creation: orchestrator O , complementor C_2 and buyer B . The third constraint says that C_2 cannot capture more than its added value to the ecosystem ($v(N) - v(O, C_1, B)$). The reason for this is the availability of C_1 to serve as an imperfect substitute. The last two constraints say that the orchestrator (O) and the buyer (B) ceiling on value creation is the total value created ($v(N)$). The key implication is that there is a floor on the value captured together by orchestrator O and buyer B . Indeed, since $\pi_{C_2} \leq v(N) - v(O, C_1, B)$ it follows that an amount equal to $v(O, C_1, B)$ (what would be left if C_2 captured its maximum value) must be split between the orchestrator (O) and the buyer (B).

We can further characterize the core based on its extreme points. Specifically, let $(\pi_O, \pi_B, \pi_{C_1}, \pi_{C_2})$ be an allocation of value. The extreme points of the core, the underlying interpretation and the coordinates are given in Table 2.

Coordinates in the core (i.e., players' value captured)	π_O	π_B	π_{C_1}	π_{C_2}
O and C_2 capture all ecosystem value, C_2 captures its maximum possible value	$v(O, C_1, B)$	0	0	$v(N) - v(O, C_1, B)$
B and C_2 capture all ecosystem value, C_2 captures its maximum possible value	0	$v(O, C_1, B)$	0	$v(N) - v(O, C_1, B)$
B captures full ecosystem value	0	$v(N)$	0	0
O captures full ecosystem value	$v(N)$	0	0	0

Table 2: Coordinates of the extreme points of the core in terms of value capture (π_i)

Since C_1 never captures any positive value, and the sum of the other value captures is $v(N)$ we can represent the core in the 3-dimension simplex. The simplex in Figure 1 shows all the ways in which value can be split between the three players O , B , and C_2 , holding the sum of their value capture constant and equal to the total value of the game ($v(N)$). A point in the simplex represents a way to split the full value of the game among the three players (coordinates thus sum to $v(N)$). The

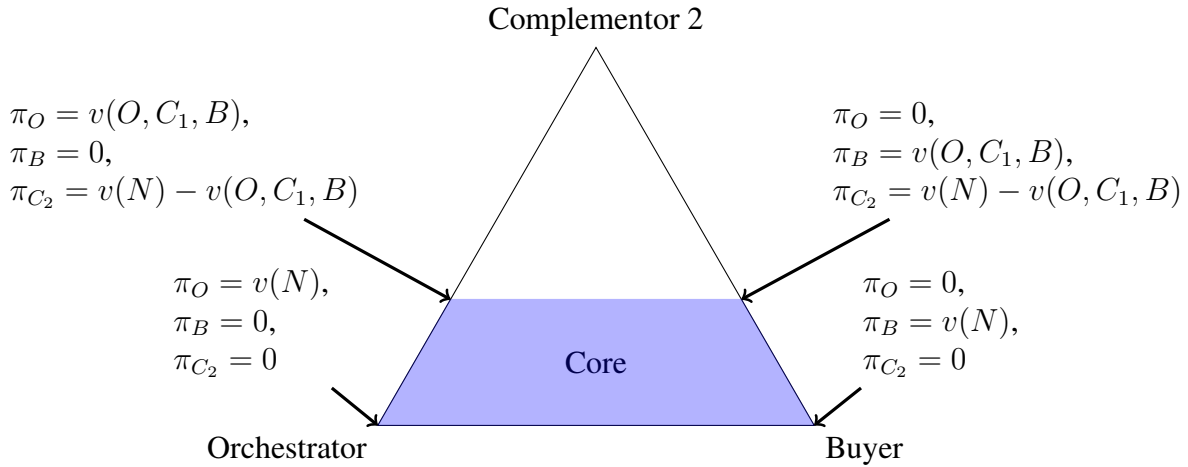


Figure 1: The core and its extreme points represented in the simplex

closer a point is to a summit of the triangle, the more value is allocated to the player whose summit it is. For instance, the summit labelled “Orchestrator” gives the coordinate $v(N)$ to the orchestrator, and 0 to the other players. The point of the core closest to “Complementor 2” summit, on the line between the orchestrator and complementor 2 corresponds to $v(O, C_1, B)$ for the orchestrator, $v(N) - v(O, C_1, B)$ for complementor 2 and 0 for the buyer. In this simplex, the core has the shape of a trapezoid whose extreme points represent situations where one of the players is getting the maximum permitted under the core.

3.3 Expected value capture

Given the bounds on value capture given by the core, we need to transform these constraints into a single value that represents the expected value captured by each player. The reader in a hurry can skip this section and move directly to section 3.4 as the development below can be at times technical.

To compute the value capture of each actor we draw on Cappelli and Chatain’s (2020) extension of Brandenburger and Stuart’s (2007) celebrated biform framework (referred to below as BS07). To motivate the use of this extension, rather than that of the original framework, we now show why relying exclusively on BS07 to calculate a point estimate of players’ value capture has substantial drawbacks in situations when more than two players are necessary for value capture, such as in business ecosystems. We then show how Cappelli and Chatain’s (2020) generalization offers a

solution to these issues.

In BS07's original framework, each player calculates its expected value capture as a linear combination of the lower and upper bound of the allocation in the core, using a parameter (the confidence index α_i) to weight the respective importance of each bound. Using that framework in our model, the buyer would expect to capture $\alpha_B \times 0 + \alpha_B \times v(N) = \alpha_B v(N)$. This formulation does not account for the totality of the constraints that define the core, even though they may matter to how much a player can capture. For instance, in our game, relying on BS07 makes the expected value capture of the buyer and of the orchestrator invariant (respectively equal to $\alpha_B v(N)$ and $\alpha_O v(N)$) to the degree of substitution between the two complementors even though this is material to how much they can collectively capture.

To see why this matters, consider the case where complementor 1 is so weak that it does not help create value (i.e., $v(O, C_1, B) = 0$). In that situation, the core is the full triangle in Figure 2, and the value $v(N)$ will be split three-ways between the buyer, the orchestrator, and complementor 2. Now, consider a change in the basic parameters whereby complementor 1 becomes gradually as good as complementor 2. This is illustrated in panels 2b and 2c. Their competing with each other means that the value is gradually pushed to the buyer and the orchestrator. The core is now reduced to the base of the triangle in panel 2c of Figure 2.

Clearly, the orchestrator and the buyer are better off collectively in 2c than in 2a. In the latter case, C_2 cannot capture any value, and consequently O and B must collectively capture more than in the other cases. However, in BS07's formalism, the orchestrator and the buyer would be considering the three situations as strictly equivalent because they would expect to capture the same amount of value, respectively $\alpha_O v(N)$ and $\alpha_B v(N)$, since the lower bound and the upper bound of the core are exactly the same for them (respectively, 0, and $v(N)$), and BS07 only consider these two parameters.

The key difference between 2a and 2c is that the shape of the core has changed from a triangle to a line. This geometric interpretation is directly translating a simple intuition about ecosystem strategy: when members of a component are less differentiated, the force of competition makes them unable to capture value versus the other components, which results in more value available

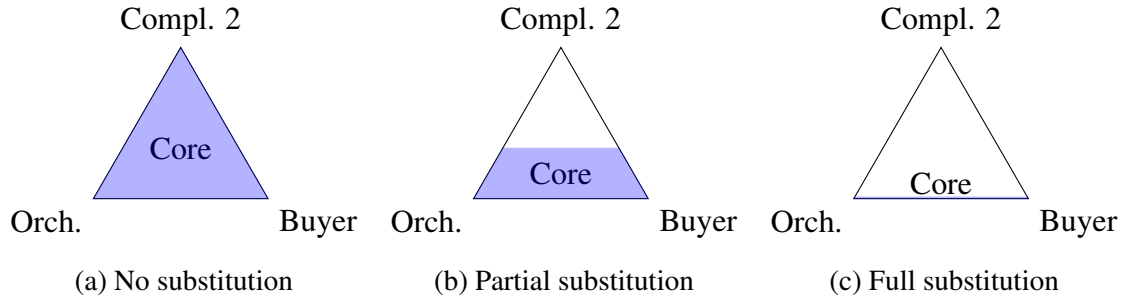


Figure 2: Shapes of the core in the simplex for different level of substitution of Complementor 2

to the other components. It stands to reason that players in the other components must be, *ceteris paribus*, better off in 2c than in 2a, yet this is not accounted for in BS07.

To capture this intuition, and retain the benefits of the value-based framework, we rely on Cappelli and Chatain’s (2020) generalization of BS07. In that generalized framework, each actor computes an expected value capture from the core under the assumption that a point in the core is randomly picked under a uniform distribution. This way, all constraints defining the core are accounted for. This information is then used to assess the actor’s value capture prospects, in addition to the values of the upper and lower bounds of the actor’s value capture interval. When positive weight is given to the expected value capture, the shape of the core matters. In this paper, we focus on the expected value capture under the uniform distribution of the possible payoffs in the core, and leave aside the behavioral aspects further explored in Cappelli and Chatain (2020).

Equating the expected value capture of each player to the average location of a point in the core has many attractive properties for modeling ecosystems. First, we obtain mutually consistent expectations of value capture regardless of the number and types of players without having to resort to *ad hoc* assumptions on confidence indices. This is advantageous in ecosystems as many players have a claim on the quasi-rent they create. Second, it enables capturing subtle shifts in the geometry of the core that may be consequential to how value will be distributed.

We prefer in this paper this method to alternatives such as the Shapley value, because the latter would allocate strictly positive value to actors who have zero added value, making them willing to invest in capabilities while competition would prevent them from capturing anything. For instance, the Shapley value would allocate strictly positive amount of value to the weaker complementor, even

though other actors would be better off working without it and not letting it capture anything.^{4,5} Moreover the core seems more appropriate as we envision free-form negotiations, as opposed to negotiations following a hierarchical structure as in Henkel and Hoffmann (2019).

The following lemma gives the closed form of the location of the centroid of a core of shape similar to what we study in this paper. The coordinates of the centroid give the expected value capture of each player under a uniform distribution of allocations in the core.

Lemma 1 *Consider a core allocation $(\pi_O, \pi_B, \pi_{C_1}, \pi_{C_2})$, with extreme points $(a, 0, 0, b-a)$, $(0, a, 0, b-a)$, $(0, b, 0, 0)$, and $(b, 0, 0, 0)$, with $b \geq a > 0$. The centroid of this allocation is given by:*

$$\left(\frac{a^2 + ab + b^2}{3(a+b)}, \frac{a^2 + ab + b^2}{3(a+b)}, 0, \frac{(b-a)(2a+b)}{3a+b} \right).$$

Moreover, the expected value captured by each player under a uniform probability distribution of core allocation is equal to its respective coordinate in the centroid.

The proof is in the Appendix.

3.4 Roadmap for the analysis

Thanks to our formal model of value creation in an ecosystem we have determined the relationship between value creation in the ecosystem, characterized at a general level by $v(N)$ and $v(O, C_1, B)$, and the expected value captured by each player $(\pi_O, \pi_B, \pi_{C_1}, \pi_{C_2})$, characterized in Lemma 1. We can now build on this basis to analyze specific value creation functions that reflect different value creation technologies. In the remainder of this paper, we leverage this general relationship by specifying closed forms for $v(N)$ and $v(O, C_1, B)$ and then substituting in Lemma 1 b for the closed form of $v(N)$, and a for that of $v(O, C_1, B)$.

⁴The Shapley value would provide the following value ϕ_i to the players: $\phi_O = \phi_B = \frac{1}{3}v(N) + \frac{1}{12}v(O, C_1, B)$, $\phi_{C_1} = \frac{1}{12}v(O, C_1, B)$, $\phi_{C_2} = \frac{1}{3}v(N) - \frac{1}{4}v(O, C_1, B)$.

⁵An astute reader may wonder why the weaker complementor would bother to show up in our game if it cannot hope to capture any value. This could easily be fixed by extending the model to include different segments of horizontally differentiated buyers so that the relative position of each complementor in each segment be reversed and each be able to capture value under the competitive assumptions of the core. For instance, complementor 1 could be the leading complementor in a second consumer segment while complementor 2 would not have added value within that segment. We leave such extension to future research as we are focusing this paper on exploring the interaction between between- and within-component competition and the technology of value creation in the most parsimonious model.

We will analyze the derivatives of the payoffs of the orchestrator and complementor 2 on parameters of value creation they control to gain insight in how much they profit from their investment in this setting. For simplicity and generality, we do not fully specify the investment game and do not seek to find a Nash equilibrium. Instead, we focus on analyzing differences in marginal returns to investment following the logic of the models in the property rights tradition (Grossman and Hart, 1986; Hart and Moore, 1990). We compare these marginal returns to a benchmark case when the orchestrator and the complementors act as a single unit I , combining O , C_1 , and C_2 as a unitary actor, who creates and splits value with buyer B .

We use the integrated actor as an efficient benchmark as in this case there are no distortions in alignment and incentives due to competition between the orchestrator and the complementors over value capture. In our analyses, we are normalizing integration costs, or benefits, to zero. Obviously, the very existence of ecosystems as a form of market organization implies that for those that we observe the costs of integration must be superior to its benefits. We thus merely use costless integration as an analytical benchmark allowing consistent comparison between different scenarios of value creation, and do not claim that integration is costless in general.

We consider three types of value creation technologies: additive value creation, where the total value created is the sum of the orchestrator's and complementor's individual value creation; bottleneck value creation, where the total value creation is equal to the value creation of the inferior offering in the bundle; and multiplicative value creation, where the total value creation is the product of the orchestrator's and complementor's individual value creation. In the parlance of experimental methods we use a three-by-two design: additive vs. bottleneck vs. multiplicative value creation, and ecosystem vs. integrated actor. All proofs and details of the analysis are in the Appendix.

4 VALUE CREATION TECHNOLOGY AND RETURNS TO INVESTMENT: MAIN ANALYSES AND RESULTS

We first describe the results of the additive value creation scenario, which we then contrast to the bottleneck value creation scenario and the multiplicative value creation scenario.

4.1 Loose technological coupling: Additive value creation technology

Under additive value creation technology, the value created by the bundle is the sum of the orchestrator’s and the complementor’s individual value creation. This is the case when the component on top of the orchestrator can be improved, but there is no interaction with the value provided by the orchestrator as they sum up together. Conversely, the orchestrator’s product can be improved, but there is no meaningful interaction with the value of the complementor’s offering. This type of interdependencies is sometimes referred to as “unique complementarities” (Jacobides et al., 2018). Examples of such technology include most simple apps on a smartphone (e.g., messaging) that do not depend on advanced hardware features, or content on a streaming platform that does not require special capabilities to be consumed.

Under this scenario, value creation by the orchestrator and the inferior complementor is normalized to $v(O, C_1, B) = V$, and value creation with the superior complementor is equal to $v(O, C_2, B) = V + r$. We calculate the marginal returns on payoffs of the orchestrator O and the superior complementor C_2 : respectively, π_O and π_{C_2} . Table 3 summarizes the characteristic function in the additive case (please note that from now on we use the terms “superior complementor” and “complementor” interchangeably as the inferior complementor captures zero in the core).

S	$v(S)$
$\{O, B, C_1, C_2\}$	$V + r$
$\{O, B, C_1\}$	V
$\{O, B, C_2\}$	$V + r$
Any other subset of N	0

Table 3: Characteristic function under additive value creation technology

Proposition 2 *Under additive value creation, the returns to investment for the orchestrator are positive and increase in the underlying quality of the orchestrator’s product. The returns to investment for the complementor are positive, but decrease in its advantage over the inferior complementor.*

Figure 3 illustrates the proposition: panel 3a shows the orchestrator’s marginal returns to investment in its product (V), and panel 3b shows the complementor’s return to investment in its advantage

over the inferior complementor (r). The solid line in panel 3a shows that the orchestrator's return to investment is lowest at $V = 0$ and increases toward $\frac{1}{2}$ as V increases (for the time being we focus on the solid lines and ignore the dashed lines). Conversely, the complementor's return to investment is maximum for $r = 0$ at $\frac{1}{2}$ and decreases toward $\frac{1}{3}$ as r increases. This means that the orchestrator has the highest incentives to invest in the quality of its base when the aforementioned quality is already high; while the complementor has the highest incentives to invest when its quality advantage over the inferior complementor is low. In other words, the complementor has the most incentives to invest when it is the least differentiated from the substitute complementor.

The differences in incentives between the two components are driven by competitive asymmetry between the orchestrator's and the complementor's components. The orchestrator faces no competition for its offering and can play the two complementors against each other to limit the value that goes to the superior complementor C_2 . As the quality of the orchestrator's base V increases, the role of the superior complementor in the overall value creation decreases, and the orchestrator captures more and more of the value creation from its product. By contrast, the superior complementor will have to share any improvement in its product vs. inferior complementor (r) with both the orchestrator (for whom no substitute exists) and the buyer in equal part. This explains the fact that as the difference vs. inferior complementor (r) is higher (keeping the quality of the orchestrator's product constant) the marginal return in r for the superior complementor decreases. This shows that even though the value creation from each actor are independent from each other as they simply add up, value capture is not, which, in turn, creates different incentives to invest.

We now compare these marginal returns to the benchmark of a single integrated actor I regrouping the orchestrator and the complementors. Value creation is equal to $v(I, B) = V + r$ and it is straightforward to show that it is equally split between the buyer and the integrated actor so that $\pi_I = \pi_B = \frac{V+r}{2}$. Comparing marginal returns to investment of the ecosystem participants from Proposition 2 to those of the integrated actor we have the following proposition:

Proposition 3 *Under additive value creation there is an “ecosystem penalty” as private returns to investment are equal or lower to those in the integrated benchmark. Furthermore, the penalty*

for the orchestrator decreases with its level of the product performance while the penalty for the complementor increases with its level of advantage over the inferior complementor.

Corollary 4 *The total ecosystem penalty is smallest when the orchestrator's underlying quality is at the highest and complementor's advantage is at the lowest, and largest when the orchestrator's quality is at the lowest and complementor's advantage is at the highest.*

Proposition 3 tells us that there is an ecosystem penalty – i.e., private returns to investment are below the integrated benchmark. This is illustrated in Figures 3a and 3b by the wedge between the integrated value creation incentive (thick dashed lines) and the individual value creation incentives (solid lines). The wedge is generally higher for the complementor than for the orchestrator, as shown by a steeper slope of the orchestrator's payoff in Figure 3a that gets closer to the integrated actor's benchmark faster. This is because the complementor faces both within-ecosystem competition (*vis-à-vis* the orchestrator and the buyer) and within-component competition (*vis-à-vis* the inferior complementor). The latter means that the superior complementor will have to give up a larger share of its improved value creation to the orchestrator and the buyer compared to the case of the orchestrator (as established in Proposition 2), implying that the difference versus an integrated player – who only has to share with the buyer – will be larger for the complementor.

Corollary 4 further qualifies when the ecosystem incentives are the most aligned and misaligned. Because competitive asymmetry between components allows the orchestrator to extract a higher share of value created with its product, and also a portion of value created with the superior complementor's product, the ecosystem penalty is highest when the *ex ante* performance of the orchestrator is low and when the *ex ante* performance of the complementor is much higher compared to the substitute complementor (i.e., high r). Conversely, the incentives of the actors are the closest to those of an integrated actor when the orchestrator is of high quality (high V) and the superior complementor is only marginally different from its rival (r converging to zero from above).

The implication is that the situation with the least distortion (the smallest ecosystem penalty) is that of very strong competition among complementors that are direct substitutes to each other (low r situation) while the orchestrator can, by its actions, increase value creation regardless of which

complementor is used. This resembles the situation found in many app stores in mature categories (e.g., email clients). Software complementors are plentiful, with relatively low differentiation and no new features, while the orchestrator is helping overall value creation by improving hardware and operating system but not really enabling new features.

Incidentally, if there were no competition in the complementor's component (i.e., if there were only three players – orchestrator, complementor and buyer), then, maybe counterintuitively, the ecosystem penalty would be highest. If there is no substitute complementor then the value created is split among the three players in equal part as $\pi_O = \pi_{C_2} = \pi_B = \frac{V+r}{3}$, and marginal returns to improvement in either orchestrator's product (V) or complementor's product (r) are equal to $\frac{1}{3}$. This is represented by the thin dashed line in Figures 3a and 3b, clearly below the returns in the competing complementors scenario. The implication is that while, on the one hand, within-ecosystem competition can blunt the incentives of the actors to invest in value creation, having competition within a component can help align incentives in the other component.

4.2 Tight technological coupling: Bottleneck value creation

We now turn our attention to consider the incentives to invest under bottleneck value creation. In this scenario, total value creation is constrained by the least performing part of the bundle (as in a Leontief production function).⁶ This represents a tighter interdependence between ecosystem components, and is also a weak case of a supermodular production function.⁷ We normalize the individual quality of the inferior complementor C_1 to 1, and that of the superior complementor C_2 is $1 + r$.⁸ Thereby value creation by the orchestrator and the inferior complementor is

⁶This is also how value creation is modeled in Ethiraj (2007).

⁷Formally, a function is supermodular when $f(x', y') - f(x, y') \geq f(x', y) - f(x, y)$ if $y' > y$ and $x' > x$. For the bottleneck value creation, where $f(x, y) = \min(x, y)$, we need to show that $\min(x', y') - \min(x, y') \geq \min(x', y) - \min(x, y)$ with $y' > y$ and $x' > x$. This holds true because: a) if $y > x$ then y is not binding, and an increase in x to x' is positive at both y and y' , and cannot have a smaller effect at y' as $y' > y$; b) if $y < x$ then y is binding and $\min(x', y) - \min(x, y) = 0$ while $\min(x', y') - \min(x, y')$ cannot be smaller than $\min(x', y) - \min(x, y)$ as $y' > y$ and $x' > x$. For further reference see Vives (2007).

⁸In the additive value creation scenario we normalized the value creation by the inferior complementor C_1 to 0, rather than to 1. This was done to simplify the exposition and avoid cumbersome calculations since, regardless of the value creation by complementor C_1 , the added value of the superior complementor C_2 remains r , while the value guaranteed to be split between the orchestrator and the buyer will increase to $V + 1$ instead of V . Changing value creation by C_1 to 1 will simply increase value capture by each actor while leading to results similar to Propositions 2, 3, and Corollary 4.

equal to $v(O, C_1, B) = \min(V, 1)$, and value creation with the superior complementor is equal to $v(O, C_2, B) = \min(V, 1 + r)$. Table 4 gives the characteristic function.

S	$v(S)$
$\{O, B, C_1, C_2\}$	$\min(V, 1 + r)$
$\{O, B, C_1\}$	$\min(V, 1)$
$\{O, B, C_2\}$	$\min(V, 1 + r)$
Any other subset of N	0

Table 4: Characteristic function under bottleneck value creation technology

This creates three different scenarios of value creation and added value of the superior complementor C_2 depending on the value of V with respect to 1 and $1 + r$ – i.e., depending on who is the bottleneck to the total value creation. The incentives to invest in value creation are as follows:

Proposition 5 *Under bottleneck value creation we have three scenarios:*

1. *When value creation is constrained by the orchestrator and neither complementor has positive added value, returns to investment of the orchestrator are positive and constant in the underlying quality of its product while there is no benefit to the complementor’s investment.*
2. *When value creation is constrained by the orchestrator, but the superior complementor has positive added value returns to investment of the orchestrator are the lowest, though positive and increasing in the underlying quality of its product. However, there is still no benefit to the complementor’s investment.*
3. *When value creation in the ecosystem is constrained by the superior complementor, then returns to investment of the complementor are positive, but decreasing in its advantage over the inferior complementor, while there is no benefit to the orchestrator’s investment.*

To understand the mechanisms in Proposition 5 let us first consider the players’ contribution to value creation in each scenario. Figure 4 shows value creation and complementor’s advantage depending on the relative standing of the players’ individual value creation. When the orchestrator’s

product quality is too low it constrains the value creation of both complementors, making the orchestrator the bottleneck for the value creation by the whole ecosystem (the left side of Figure 4). In this case even though the superior complementor has a better product it offers no advantage over the inferior complement because neither can perform to its full potential as they are constrained by the orchestrator's product. For example, a weak motion detection technology in the original iPad rendered moot the difference in quality among motion detection games.

Clearly, in the scenario when the orchestrator's performance is a constraint for all complementors, the only way to increase total value creation is to improve the orchestrator's performance, which is why complementors have no incentives to invest in their own product. The left-hand side of Figure 5a illustrates this case with the straight solid line showing the orchestrator's return to investment in its product (similarly to the previous section we ignore the dashed lines for the time being). Figure 5b shows the returns to the complementor's investment in its advantage and mirrors Figure 5a: because each scenario is defined by the relative relationship between the quality of the orchestrator's product and that of the complementors the range of $r > V - 1$ in Figure 5b mirrors the range of $V < 1 + r$ in Figure 5a). Thus the scenario with the orchestrator as the bottleneck corresponds to the right-hand side of Figure 5b showing complementor's returns equal to zero.

Once the orchestrator's quality is in the medium range, it no longer constrains the performance of the inferior complementor, but is still a bottleneck in the ecosystem since it constrains the performance of the superior complementor C_2 (the middle part of Figure 4). The only way to increase total value creation is still to improve the orchestrator's quality, but, in contrast to the previous scenario, the superior complementor has strictly positive added value, and could plausibly appropriate some value in the core, because without it, one would have to fall back on the inferior complementor and reduce value creation further. Continuing with the iPad example, this scenario can be reflected by the RealRacing video game that was the first to utilize iPad 2's full potential in terms of the updated motion detection technology and its improved potential for video output.

The key point is that the added value of the superior complementor lies not in its own product, but in de-constraining the complementary product (for instance, the way RealRacing de-constrained

iPad 2 and made it competitive with game consoles). This is why the superior complementor will, along with the orchestrator and the buyer, have a claim on any improvement in the orchestrator's value creation. The implication is that the marginal return on the orchestrator's investment drops significantly compared to the previous case due to the complementor being a third claimant on value capture. Figure 5a illustrates this case: there is a discontinuous drop of the orchestrator's returns once its product stops being a constraint for the inferior complementor (once V is above 1).

Finally, when the orchestrator's product quality is high, it is no longer a bottleneck for value creation (see the right-hand side of Figure 4). Now the only way to improve value creation is to invest in the complementor's quality while further investment in the orchestrator's product has no bite. This is the case of a well-developed platform but with the quality of complementary products wanting (e.g., iPad Pro for which apps that fully utilize its capacity are lacking). This scenario is illustrated by the right-hand side of Figure 5a, where the orchestrator's marginal return to investment goes to zero. By contrast, the superior complementor is now the bottleneck for value creation and it benefits from investing in its advantage over the inferior complementor (see the left-hand side of Figure 5b, which mirrors the right-hand side of Figure 5a). However, as the complementor's advantage gets larger we go back to the previous case when the orchestrator is the bottleneck, and the investment should be directed to the orchestrator's product.

Comparing these marginal returns to the integrated actor scenario, where the value is split in half between integrated actor I and buyer B we find:

Proposition 6 *Under bottleneck value creation we have three scenarios:*

- 1. When value creation is constrained by the orchestrator and neither complementor has positive added value, then the individual returns to investment of the orchestrator and of the complementor in their component of the value creation are equal to those of an integrated benchmark and there is no ecosystem penalty.*
- 2. When value creation is constrained by the orchestrator, but the superior complementor has positive added value then the orchestrator's return to investment is lower than that of the*

integrated benchmark, and there is a non-zero ecosystem penalty. Moreover, the more the orchestrator constrains value creation the higher the penalty. The complementor's return to investment is similar to that in the benchmark and equal to zero.

- 3. When value creation in the ecosystem is constrained by the superior complementor then the orchestrator's return to investment is similar to that in the benchmark and equal to zero. The complementor's return to investment in its advantage over the inferior complementor is below that of the integrated benchmark. The larger the complementor's advantage the higher the penalty.*

Corollary 7 *Under bottleneck value creation the total ecosystem penalty is smallest when the orchestrator's underlying quality is at the lowest and constrains the ecosystem while complementors are perfect substitutes. The ecosystem penalty is the largest when the orchestrator constrains the ecosystem but the superior complementor has positive added value.*

The thick dashed lines in Figures 5a and 5b show the marginal returns of an integrated actor. When the orchestrator is the bottleneck for the whole ecosystem and no complementor has any added value (scenario 1), the orchestrator is incentivized correctly as it is the only claimant on additional value within the ecosystem, and there is no ecosystem penalty (the left-hand side of Figure 5a where the orchestrator's marginal returns are equal to $\frac{1}{2}$). Using the example of video games this is the case where the console has, for instance, very poor motion detection technology while there is a number of good-quality motion capture video games which are not able to fully display their potential due to the console technology constraint. We can expect the console producer to be highly incentivized to improve the technology because it will be able to appropriate the returns from such improvement.

However, as the orchestrator's product quality increases to the level when the orchestrator remains a bottleneck but *at the same time* the superior complementor has added value (scenario 2), then we have a situation that deviates much more from the efficient benchmark. In this situation we have more claimants to the value in the ecosystem resulting in a steep reduction in the orchestrator's marginal return of increasing its product quality. The penalty ranges between $-\frac{1}{6}$ and $-\frac{1}{4}$, which

is of a higher magnitude than under any other scenario (see the middle part of Figure 5a). This is due to a somewhat unique configuration when the improvement in value creation has to come from the orchestrator (improvement in the quality of its product), yet a large portion of it can be claimed by the complementor who allows the orchestrator's product to perform to its full potential. For an example imagine that the aforementioned console producer improves its motion detection technology to the extent that some video games now appear outdated, while other games are still more technically advanced. Now the console producer would be reluctant to invest more in the console development to bring it to the level of the best video games – even though console quality is still wanting – because a large share of this improvement will only serve to augment value capture by the producers of those high-quality games.

This stands in contrast to the additive value scenario where the orchestrator mainly benefits from the improvement of its product and the complementor mainly benefits from the improvement of its advantage over the inferior complementor (Figures 3a and 3b). Note that so far the complementor has zero marginal returns to improving its advantage, which is similar to the incentives of the integrated actor.

When we switch to the case when the superior complementor is a bottleneck for the system (scenario 3, which is illustrated by the left-hand side of Figure 5b), then it is incentivized to increase value creation, but not as well as the orchestrator was when it was the sole bottleneck (scenario 1) because a portion of this value will be shared with the orchestrator, who is not substitutable. There is an ecosystem penalty similar to that in the additive value creation scenario, going from highest when complementor's advantage over the inferior one is large to lowest when complementors are fully substitutable. Continuing with the video games example this is the case when the console has a very high-quality motion detection technology, while even the best video games developers are lagging behind. In this case it will be those game developers who will invest to match the console's technical possibility. However they will be incentivized less if they are already much better than the next best game developer, as the console producer, due to its one-in-kind position, will be able to capture a large portion from that improvement.

Overall, comparing the bottleneck value creation technology with the additive one we can see that the former can feature both the highest and the lowest ecosystem penalty depending on the degree of substitutability between complementors. On the one hand, when complementors are full substitutes and the orchestrator is a bottleneck we have an “ideal” case where the orchestrator will be fully incentivized to improve its products. On the other hand, if the orchestrator is constraining the ecosystem value creation, but there is enough differentiation among complementors to make them not fully substitutable we get a potential “value trap”. This is the case when complementors are leading innovation for the ecosystem while the orchestrator is behind and constraining the system, yet the orchestrator is afraid of being held up by the complementor because there is not enough competition between the complementors (they are no longer fully substitutable). This could result in a lack of innovation for the whole system due to disputes and uncertainty about value capture.

For instance, Android smartwatch originally came to market with its Android Wear OS widely considered “half-baked”. Yet the subsequent software improvements didn’t live to the expectations, eventually leading Samsung and a number of other watchmakers to either switch to their own software, or abandon the product altogether. Android-based smartwatch ecosystem now appears to be lagging behind with serious doubts cast about its viability. One explanation could be that while originally only Samsung and LG were producing Android-powered watches, the ensuing wave of other watchmakers increased differentiation among complementors and shifted the ecosystem from scenario 1 to scenario 2. This made Google more reluctant to make significant improvement to its software as the benefits could be claimed by the better watchmakers (e.g., Samsung) locking the entire ecosystem into a “value trap”. By contrast, Apple, Samsung, and Fitbit – all of whom rely on their in-house software for their watches – continue to lead the market, which could be seen as using integration to avoid the ecosystem penalty.

To conclude, from the total value creation point of view it is best to reduce the gap between complementors (smaller advantage of the superior complementor) to pass this “value trap” as quickly as possible to the case when the complementor becomes the technological bottleneck – but this might dampen the incentives of the complementors to enter the market. In the context of platforms,

our insights suggest that improvement in a platform for which high-quality complements are available might backfire as it gets caught in a trap where it will have sub-optimal incentives for further improvement.

4.3 Tighter technological coupling: Multiplicative value creation

Finally, we consider the case of a tighter coupling – multiplicative value creation where the value created by the bundle is the product of the orchestrator’s and the complementor’s individual value creation – i.e., another case of a supermodular technology scenario (Milgrom and Roberts, 1990). This is the case when the value from the improvement in the complementor’s component is higher when the performance of the orchestrator’s component is higher, and *vice versa*. For an illustration consider virtual reality video games featuring a tight interaction between the quality of the game and the quality of the headset: game quality and effects become more valuable as the VR headset technology improves, while the creativity of the game experience make the investment in an improved VR headset more desirable.

Under this scenario value creation by the orchestrator and the inferior complementor, similarly to the additive scenario, is normalized to $v(O, C_1, B) = V$, while value creation with the superior complementor is equal to $v(O, C_2, B) = V(1 + r)$. Table 5 summarizes the characteristic function.

S	$v(S)$
$\{O, B, C_1, C_2\}$	$V(1 + r)$
$\{O, B, C_1\}$	V
$\{O, B, C_2\}$	$V(1 + r)$
Any other subset of N	0

Table 5: Characteristic function under multiplicative value creation technology

Comparing marginal returns of the orchestrator and the superior complementor to those of the integrated actor (value split in half between integrated actor I and buyer B) we have the following:

Proposition 8 *Under multiplicative value creation, the returns to investment for the orchestrator are positive and constant in the underlying quality of the orchestrator’s product. The returns to*

investment for the complementor are positive, but decrease in its advantage over the inferior complementor.

Proposition 9 *Under multiplicative value creation the ecosystem penalty for the orchestrator is constant in the underlying quality of the orchestrator's product. For the complementor the penalty increases with its level of advantage over the inferior complementor, and is minimized when complementor's advantage is at the lowest.*

In the multiplicative scenario the complementor exhibits a pattern similar to the previous two scenarios where its misalignment is minimized when complementors are close substitutes (see Figure 6b), while there is a significant difference when it comes to the orchestrator. Unlike in the additive and bottleneck scenarios, the orchestrator cannot minimize the penalty as it does not depend on the orchestrator's capabilities (see Figure 6a). This creates a situation where, despite being in a less competitive component, the orchestrator can nevertheless face high incentive misalignment.

Furthermore, because value creation is multiplicative incentive misalignment increases as the *other actor's* capabilities increase. Unlike the additive and bottleneck scenarios, where the ecosystem penalty is bounded both in one's own and in the other actor's capabilities, here the gap between the integrated benchmark and the ecosystem returns depends on the capabilities of the actor in the other component.⁹ Figure 6b shows that while both the integrated actor's returns and the orchestrator's returns under the ecosystem increase in the complementor's advantage r , the latter do so at a slower rate than the former resulting in an increasing gap between private returns and the benchmark. Figure 6a demonstrates a similar pattern regarding the complementor's penalty increase in the orchestrator's capabilities. The implication is that under multiplicative value creation it may be more challenging to minimize the ecosystem penalty as the misalignment grows more severe the stronger the actors are. For instance, if we think about virtual reality games example, the implication is that as the quality of the headset improves the best game developer's incentives to improve game quality will diverge further and further from the ideal case, because more of this improvement will have to

⁹We did not explicitly discuss how the ecosystem penalty varies depending on the other actor's capabilities to simplify the exposition, but in both additive and bottleneck scenarios the complementor's penalty keeps being bounded between 0 and $\frac{1}{6}$, and the orchestrator's penalty between 0 and $\frac{1}{4}$.

be shared with the headset producer. Conversely, as the top game developer improves the quality of the game the headset producers will be investing less and less compared to what the investment should be. This might explain the lackluster performance of the virtual reality games industry as opposed to augmented reality apps on mobile devices (e.g., Pokemon Go) which is more similar to the bottleneck technology (outside of the value trap).

If we compare the penalty size across different value creation scenarios, then multiplicative scenario generally features a higher penalty than the additive scenario, unless the *ex ante* quality of the orchestrator and the complementor is very low.¹⁰ Compared to the bottleneck scenario, the penalty for the complementor is similar as long as the latter is a bottleneck (otherwise in the bottleneck scenario the complementor is perfectly aligned in not exerting any effort). Similarly, when the orchestrator is perfectly aligned in the bottleneck scenario (case when either it is not a bottleneck any more, or when it is worse than both complementors) it faces higher penalty in the multiplicative scenario; however, the “value trap” in the bottleneck scenario entails the penalty higher than under the multiplicative value creation.

To conclude, we find that under the multiplicative value creation scenario it is more difficult to reduce the misalignment of incentives as both orchestrator’s and complementor’s capabilities augment the ecosystem penalty, which is minimized only when both are close to zero. Unless the orchestrator and the complementor have weak *ex ante* capabilities, the misalignment is higher compared to the additive value creation scenario; however, the “value trap” in the bottleneck scenario still remains the worst case of the orchestrator’s misalignment.

5 DISCUSSION AND CONCLUSION

The literature on ecosystems and complements posits that investment in value creation by its constituents is crucial for the ecosystem survival and evolution (Ethiraj, 2007; Hannah and Eisenhardt, 2018; Kapoor and Agarwal, 2017). Yet despite acknowledging the importance of incentive align-

¹⁰In order to have a consistent comparison across scenarios we look at the penalty size as a proportion of the integrated benchmark returns – i.e., the share of the returns under the perfect alignment that gets lost due to the within-ecosystem competition.

ment in an ecosystem (Adner, 2012) a structured account of the latter has been lacking. We use a formal model to examine firm's incentives to invest in value creation and how they are shaped by the type of value creation technology and the competition over value capture. Overall, we find an ecosystem penalty in the incentives to create value that is driven by within-ecosystem competition over value capture. While we acknowledge that there are good reasons why ecosystem parts may not be integrated in the first place (e.g., differences in capabilities, diseconomies of scale and scope, etc.), our analysis shows nevertheless that incentives are often misaligned due to disputes over value capture. We further show that the existence and the degree of incentive misalignment is shaped by the type of complementarities (i.e., the value creation technology) and by the *ex ante* quality of ecosystem participants' value creation capabilities, allowing us to identify conditions for the best and the worst incentive alignment in an ecosystem. Our results offer several contributions to the literature on ecosystems and complements.

Contributions to theory First, we provide a parsimonious and workable formal model that can be enriched to tackle new issues. The formalism of the value-based framework (Brandenburger and Stuart, 2007; Cappelli and Chatain, 2020; Gans and Ryall, 2017; Ross, 2018) allows us to rigorously map value creation by all ecosystem participants into their individual value capture, and to trace how the nature of interdependencies between ecosystem components affects both. The model can be easily adapted for further research questions pertaining to value creation and value capture in ecosystems. For instance, it could be used to explore other configurations of an ecosystem in terms of competition or value creation technology, such as competition between ecosystems, multi-homing, etc.

Second, our analysis offers additional mechanisms underpinning the determinants of ecosystem alignment, in addition to the behavioral explanations advanced by extant theory (e.g., Adner, 2012) and industry in depth case-studies (e.g., Hannah and Eisenhardt, 2018). Our model focuses on the interaction of the type of complementarities among ecosystem participants and the competitive asymmetry between ecosystem components. This allows us to straddle the ecosystems literature that focuses on value creation, the value capture literature that emphasizes the impact of compet-

itive scarcity (Jacobides et al., 2006; Jacobides and Tae, 2015), and the technology literature that examines the nature of interdependencies between ecosystem components (Ethiraj and Levinthal, 2004). Incorporating concepts from the value capture and the technology literature enables us to come up with novel predictions on one of the key questions in the ecosystems literature: how to ensure ecosystem alignment and foster value creation.

Specifically, our findings reveal that ignoring competition over value capture in ecosystems may lead to severely overestimating firms' incentives to invest in value creation. We cannot assume that increases in value creation by the ecosystem as a whole will necessarily translate into a proportionate increase in the private value capture as other ecosystem participants may be in a position to claim a share of these returns.

While it is generally the actor facing the short end of the competitive asymmetry who has a higher misalignment (complementor in our model) we show that, paradoxically, it may be the actor who is seemingly in a better position to capture the returns on its investment who actually faces the highest misalignment. This allows us to provide a more nuanced view on the incentives to invest into the resolution of ecosystem bottlenecks (Hannah and Eisenhardt, 2018; Kapoor, 2018). Sometimes, the actor who is best poised to resolve a bottleneck may still be poorly incentivized as demonstrated by the discontinuous drop in the orchestrator's returns to investment leading to a "value trap" in the bottleneck value creation scenario. It also suggests that being in a position of competitive scarcity (Jacobides et al., 2006; Jacobides and Tae, 2015) does not always guarantee high returns on the investment in value creation: in the aforementioned scenario the "value trap" happens not because complementors are squeezed by the orchestrator, but because the orchestrator is afraid of being held up by a superior complementor – which also stands in contrast to the conventional wisdom of the platform literature.

More generally, our analysis shows that value creation technology in the ecosystem (i.e., the type of complementarity) shapes competition over value capture, above and beyond competitive asymmetry between components. The existence of non-generic complementarities is a necessary characteristic of an ecosystem that distinguishes it from markets (Jacobides et al., 2018). To our

knowledge this paper is the first to unpack how different types of such non-generic complementarities affect value capture of ecosystem participants, and therefore their incentives to improve the ecosystem's value creation. Our analysis shows that ignoring the type of value creation technology may lead to erroneous estimates not only of firm's incentives, but also of the dynamic of these incentives. For instance, in a loosely coupled ecosystem the best alignment is achieved when the orchestrator is strong, while in a bottleneck scenario it is with a weak orchestrator that alignment is the best.

Managerial implications Our analyses suggest that managers need to consider competition over value capture – and, in particular, competitive asymmetry between the component of their firm and complementary components – to understand whether producers of complements will invest in improving the quality of their products. For instance, a firm in an orchestrator position may find it advantageous to pick a value creation technology that promotes higher level of competition, or seek to diminish the differentiation among complementors to induce investment by the latter.

Moreover, understanding the link between the type of value creation technology and ecosystem alignment is made even more important as the latter may change over time. For instance, the current trend of streaming for video games is arguably transforming the technology from “bottleneck” to “additive” as the tight combination of components on console is made irrelevant if the game is run on a server. Conversely, the whole point of adding novel hardware features on a cell phone is to create new applications that require these hardware features, but they are often bottleneck types of value creation technologies. In the same vein, improvements in engine efficiency and in fuselage used to be largely independent and additive for single-aisle commercial aircraft, until, in the case of the Boeing 737 Max the fuselage became a bottleneck to take advantage of newer engines. Our model suggests that when technologies of value creation transition from one type to another, managers may need to reassess their assumptions about incentive alignment in their ecosystem.

Testable implications Finally, the insights from our model offer a number of empirically testable implications for the dynamic of ecosystem value creation and firms' investment. If we could mea-

sure the investment in value creation (e.g., through patents), the level of capabilities of ecosystem participants (e.g., rankings) and the total value creation (e.g., quality reviews, adoption) we could observe how the former change as a function of the latter. For instance, in contexts featuring *additive* value creation by components (e.g., streaming video games) we should be able to observe an increase (decrease) in complementors' investment as the closeness in terms of capabilities between complementors increases (decreases), as well as the overall increase in the ecosystem value creation. Conversely, we should observe that the increase in the orchestrator's capabilities increases orchestrator's investment. In contexts exhibiting *bottleneck* type of technology (e.g., personal computers) we should be able to observe a drop in the orchestrator's investment and in the total value creation as the orchestrator's capabilities improve and overshoot those of a worse complementor.

Our insights also suggest that we should observe a change in firms' investment behavior if the underlying value creation technology changes: switching from bottleneck to additive – for instance, going from console games to streaming – could increase (decrease) complementors' investment if *ex ante* complementors had capabilities superior (inferior) to those of the orchestrator. Conversely, an increase in the tightness of the component coupling – for instance, going from additive to super-modular value creation – might lead to observed integration among ecosystem components, or the entry into complementary component by the orchestrator.

Limitations and future research We acknowledge several limitations of our model. First, we assume that there is no competing ecosystem, or that there is a sufficiently high horizontal differentiation that allows us to consider a single ecosystem in isolation. This allows us to focus on within-ecosystem competition to elucidate the mechanisms of the value creation technology and competitive asymmetry, yet future research could explore a more complicated setup with competing orchestrators.

Second, we assume away the cost of integration in order to use it as an ideal benchmark. This allows us to explore within-ecosystem alignment, while remaining cautious as to the recommendation of the governance mode. Future research could examine the full spectrum of the ecosystem – hierarchy tradeoffs by incorporating the cost of integration and the potential benefits of ecosystem in

terms of innovation (Baldwin and Clark, 2000). Future work could also further develop the current model to fully endogenize investment and technology choice to understand when the orchestrator is incentivized to increase or dampen the competition among complementors.

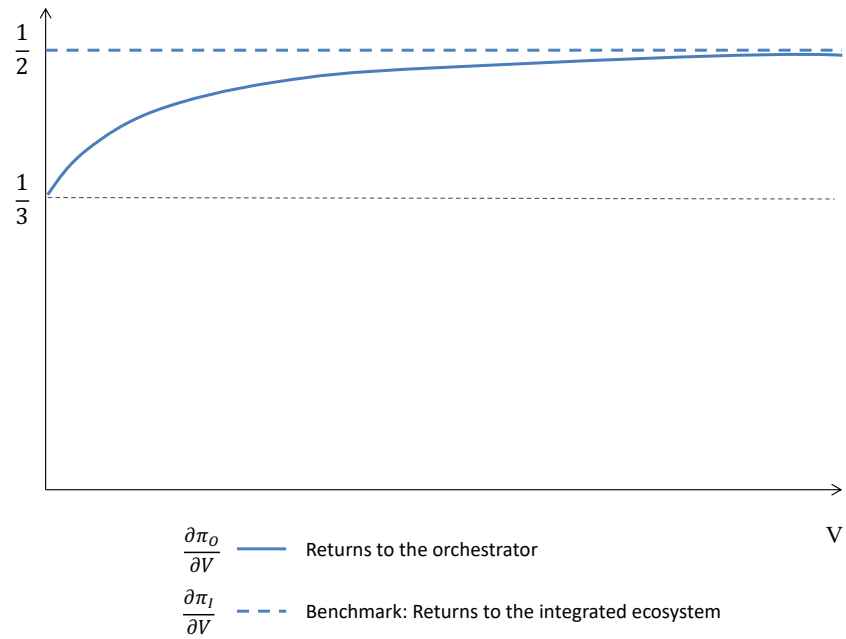
In conclusion, we develop a formal model of an ecosystem that examines firms' incentives to improve value creation taking into account competition over value capture and the type of complementarities between ecosystem components. Our model provides a rigorous account of how competition to capture value can distort firms' incentives to invest. It offers novel insights on value creation in an ecosystem by suggesting the mechanisms underpinning incentive alignment that result in a high variance in firms' investment. We hope that this research will pave the way for further analyses of the mechanisms underpinning value creation and value capture in ecosystems and the implications for firms' strategies.

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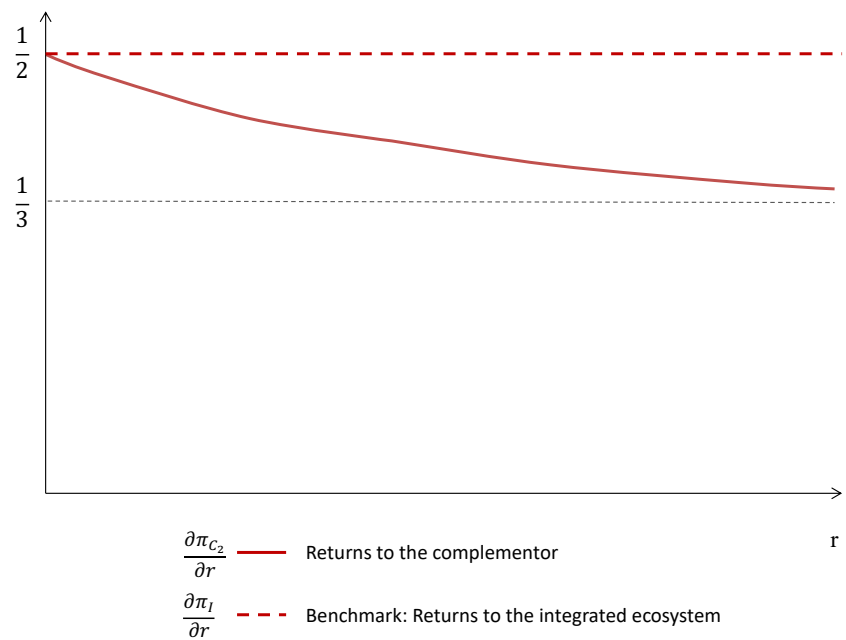
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(a) Returns with respect to V



(b) Returns with respect to r

Figure 3: Additive value creation: marginal returns of orchestrator O , complementor C_2 , and integrated actor I

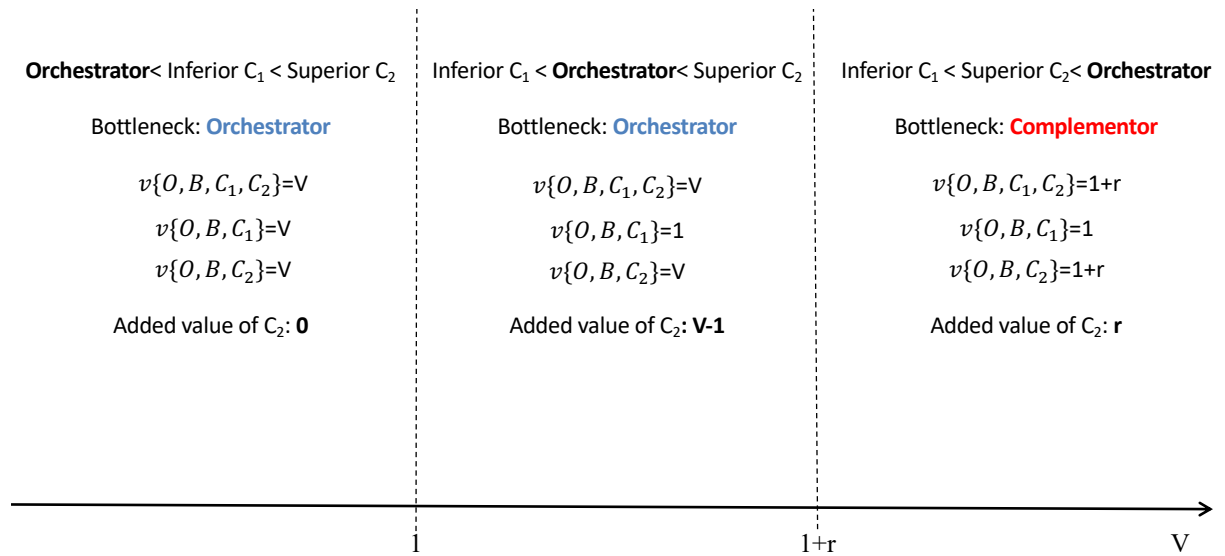
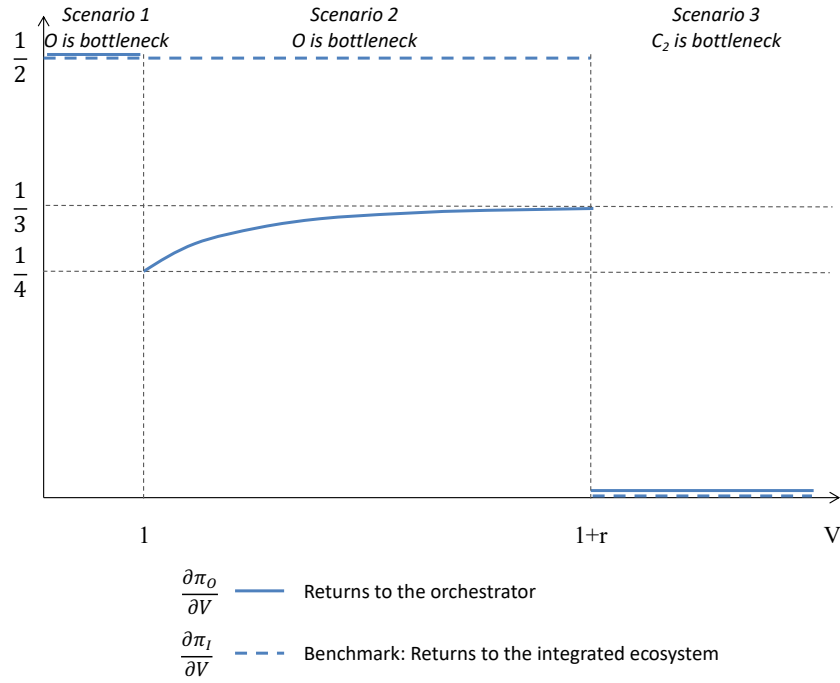
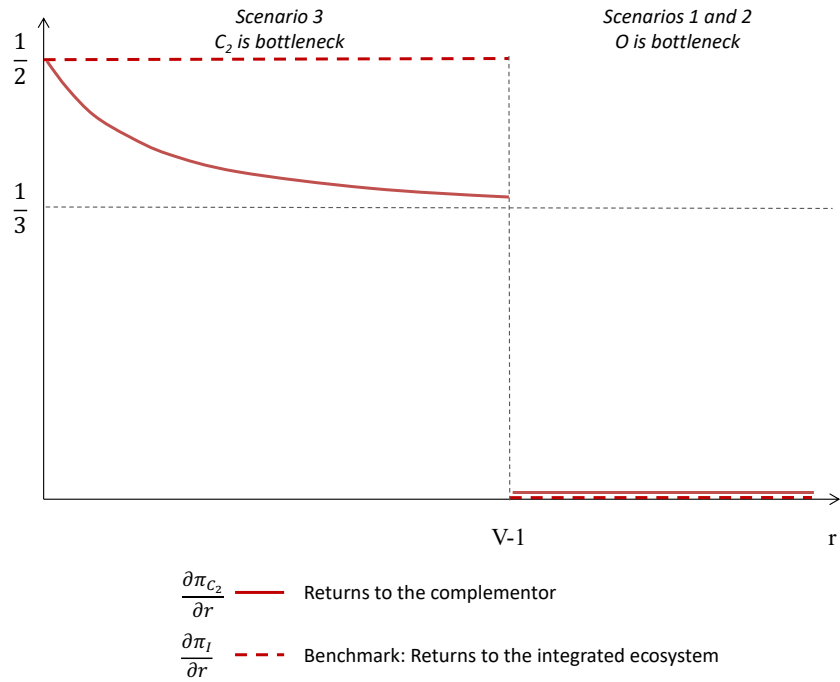


Figure 4: Bottleneck value creation: three scenarios of value creation and complementor's advantage

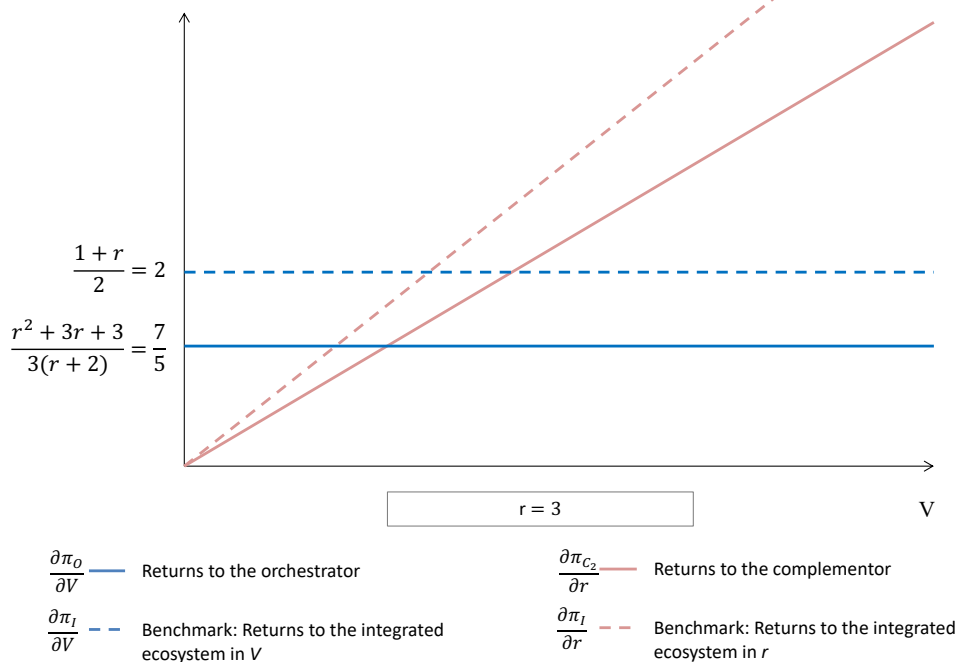


(a) Returns with respect to V

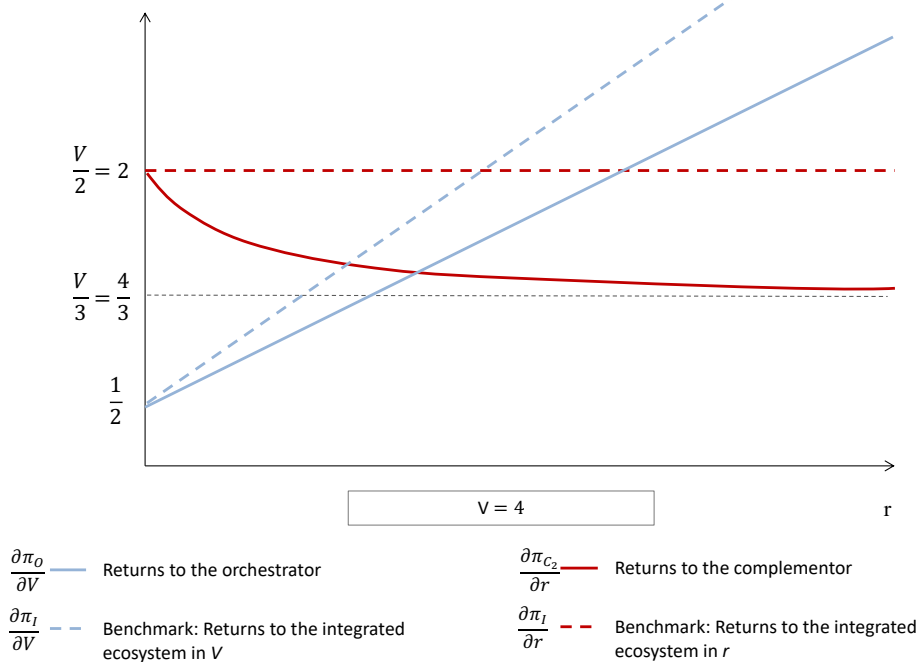


(b) Returns with respect to r

Figure 5: Bottleneck value creation: marginal returns of orchestrator O , complementor C_2 , and integrated actor I



(a) Returns to V and r as a function of V



(b) Returns to V and r as a function of r

Figure 6: Multiplicative value creation: marginal returns of orchestrator O , complementor C_2 , and integrated actor I

APPENDIX

Proof of Lemma 1.

We have four players: orchestrator (O), buyer (B), superior complementor (C_2), and inferior complementor (C_1). The characteristic function is given by:

S	$v(S)$
$\{O, B, C_1, C_2\}$	b
$\{O, B, C_1\}$	a
$\{O, B, C_2\}$	b

All other coalitions produce zero. The constraints from the core are, assuming $b \geq a > 0$:

$$\begin{aligned} \pi_O + \pi_B + \pi_{C_1} + \pi_{C_2} &= b, \\ 0 &\leq \pi_O \leq b, \\ 0 &\leq \pi_B \leq b, \\ \pi_{C_1} &= 0, \\ 0 &\leq \pi_{C_2} \leq b - a. \end{aligned}$$

From the core, we determine the extreme points of the convex set defined by the core:

Extreme point	π_O	π_B	π_{C_1}	π_{C_2}
A	a	0	0	$b - a$
B	0	a	0	$b - a$
C	0	b	0	0
D	b	0	0	0

Because C_1 appropriates 0 in the following we keep the analysis on the plane and only consider the simplex consisting of the value appropriated by O , B , and C_2 .

To find the centroid of core, we split the trapezoid $ABCD$ into two triangles ADC , and CBA (Figure 7). We are going to use the property that the centroid of a triangle in barycentric coordinates is found by averaging the coordinates of the summits. The coordinates of the centroid of the trapezoid are then given by the average of the coordinates of the centroids of the triangles, weighted by

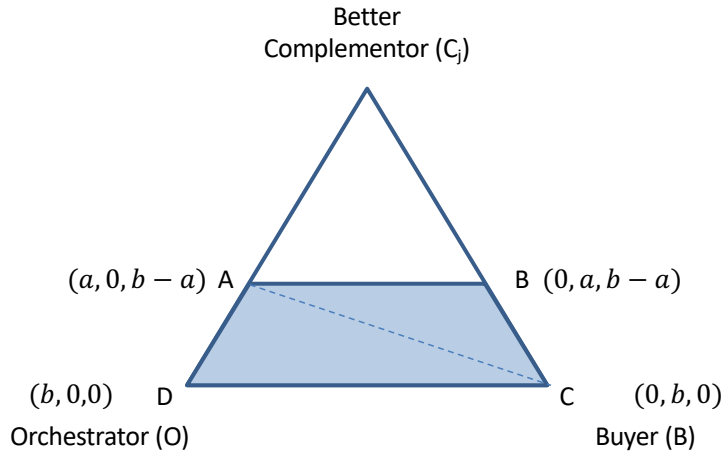


Figure 7: Splitting the core in triangles to calculate centroid coordinates

the areas of the triangles. More generally, note that the core is always a convex set and that in higher dimensional spaces, any convex set can be split into a set of tetrahedrons with known centroids and volumes, which guarantees that such centroid coordinate calculation can always be done.

The centroid of ADC is directly given by the average of the coordinates of the summits:

$$\left(\frac{a+b}{3}, \frac{b}{3}, \frac{b-a}{3} \right).$$

For a triangle whose barycentric coordinates are $P_i(x_i, y_i, z_i)$, $i = 1, 2, 3$, the signed area $[P_1, P_2, P_3]$, as a fraction of the area of the simplex, is given by:

$$[P_1P_2P_3] = \begin{vmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_1 & z_3 \end{vmatrix}.$$

The points have to be listed counterclockwise for the area to be positive.

The signed area of ADC , as a fraction of the area of the simplex, is thus:

$$[ADC] = \begin{vmatrix} a & 0 & b-a \\ b & 0 & 0 \\ 0 & b & 0 \end{vmatrix} = b^3 - ab^2$$

The centroid of CBA is:

$$\left(\frac{a}{3}, \frac{b+a}{3}, \frac{2(b-a)}{3} \right).$$

The signed area of CBA , as a fraction of the area of the simplex, is:

$$[CBA] = \begin{vmatrix} 0 & b & 0 \\ 0 & a & b-a \\ a & 0 & b-a \end{vmatrix} = ab^2 - a^2b$$

The centroid of trapezoid $ADCB$ is given by:

$$\begin{aligned} & \frac{[ADC]}{[ADC] + [CBA]} \left(\frac{a+b}{3}, \frac{b}{3}, \frac{b-a}{3} \right) + \frac{[CBA]}{[ADC] + [CBA]} \left(\frac{a}{3}, \frac{b+a}{3}, \frac{2(b-a)}{3} \right) \\ &= \frac{b}{b+a} \left(\frac{a+b}{3}, \frac{b}{3}, \frac{b-a}{3} \right) + \frac{a}{b+a} \left(\frac{a}{3}, \frac{b+a}{3}, \frac{2(b-a)}{3} \right) \\ &= \left(\frac{a^2 + ab + b^2}{3(a+b)}, \frac{a^2 + ab + b^2}{3(a+b)}, \frac{(b-a)(2a+b)}{3(a+b)} \right) \end{aligned}$$

Since the inferior complementor C_1 captures zero, the expected value capture in the core $(\pi_O, \pi_B, \pi_{C_1}, \pi_{C_2})$ is given by

$$\left(\frac{a^2 + ab + b^2}{3(a+b)}, \frac{a^2 + ab + b^2}{3(a+b)}, 0, \frac{(b-a)(2a+b)}{3(a+b)} \right).$$

■

Proof of Proposition 2.

Given the characteristic function under additive value creation in Table 3 and the allocation of

value from Lemma 1 (where a is substituted for $v\{O, B, C_1, C_2\}$ and b is substituted for $v\{O, B, C_1\}$) we have the following value capture:

$$\begin{aligned}\pi_O &= \frac{r^2 + 3Vr + 3V^2}{3(r + 2V)}, \\ \pi_B &= \frac{r^2 + 3Vr + 3V^2}{3(r + 2V)}, \\ \pi_{C_1} &= 0, \\ \pi_{C_2} &= \frac{r^2 + 3Vr}{3(r + 2V)}.\end{aligned}$$

To calculate the marginal returns to investment we calculate the derivatives of the orchestrator's and the superior complementor's expected value capture with respect to V and r , respectively:

$$\begin{aligned}\frac{d\pi_O}{dV} &= \frac{r^2 + 6Vr + 6V^2}{3(r + 2V)^2} > 0, \\ \frac{d\pi_{C_2}}{dr} &= \frac{r^2 + 4Vr + 6V^2}{3(r + 2V)^2} > 0.\end{aligned}$$

Taking second-order derivatives we get:

$$\begin{aligned}\frac{d^2\pi_O}{dV^2} &= \frac{2r^2}{3(r + 2V)^3} > 0, \\ \frac{d^2\pi_{C_2}}{dr^2} &= -\frac{4V^2}{3(r + 2V)^3} < 0.\end{aligned}$$

■

Proof of Proposition 3.

Under the integrated benchmark the only two players are the buyer B and the integrated actor I with the total value creation of $V + r$. It is straightforward that under the uniform distribution the expected value capture of the integrated actor will be a half of the value creation $\pi_I = \pi_B = \frac{V+r}{2}$, and the derivatives with respect to both V and r are equal to $\frac{1}{2}$.

From the proof of Proposition 2 we can re-write the derivative of π_O w.r.t. V as

$$\frac{d\pi_O}{dV} = \frac{r^2 + 6Vr + 6V^2}{3(r + 2V)^2} = \frac{1}{3} + \frac{2Vr + 2V^2}{3(r + 2V)^2}.$$

As $V \rightarrow 0$ we have $\frac{2Vr+2V^2}{3(r+2V)^2} \rightarrow 0$, thus $\frac{d\pi_O}{dV} \rightarrow \frac{1}{3}$, creating a difference of $\frac{1}{6}$ vs. $\frac{d\pi_I}{dV}$.

As $V \rightarrow \infty$ we have $\frac{2Vr+2V^2}{3(r+2V)^2} \rightarrow \frac{1}{6}$, thus $\frac{d\pi_O}{dV} \rightarrow \frac{1}{2}$, making it equal to $\frac{d\pi_I}{dV}$. Since $\frac{d\pi_O}{dV}$ increases monotonically in V the ecosystem penalty decreases in V .

Similarly, we can re-write the derivative of π_{C_2} w.r.t. r as

$$\frac{d\pi_{C_2}}{dr} = \frac{r^2 + 4Vr + 6V^2}{3(r + 2V)^2} = \frac{1}{3} + \frac{2V^2}{3(r + 2V)^2}.$$

As $r \rightarrow 0$ we have $\frac{2V^2}{3(r+2V)^2} \rightarrow \frac{1}{6}$, thus $\frac{d\pi_{C_2}}{dr} \rightarrow \frac{1}{2}$, making it equal to $\frac{d\pi_I}{dV}$.

As $r \rightarrow \infty$ we have $\frac{2V^2}{3(r+2V)^2} \rightarrow 0$, thus $\frac{d\pi_{C_2}}{dr} \rightarrow \frac{1}{3}$, creating a difference of $\frac{1}{6}$ vs. $\frac{d\pi_I}{dV}$. Since $\frac{d\pi_{C_2}}{dr}$ decreases monotonically in r the ecosystem penalty increases in r . ■

Proof of Corollary 4.

Omitted. Corollary 4 follows directly from the results of Proposition 3. ■

Proof of Proposition 5.

Under the bottleneck value creation technology there are three different scenarios of value creation and value capture depending on the relative positioning of V with respect to 1 and $1+r$ (Figure 4). Table 6 specifies the characteristic function under each of those scenarios:

	Scenario 1	Scenario 2	Scenario 3
S	$V < 1 < 1+r$	$1 < V < 1+r$	$1+r < V$
$\{O, B, C_1, C_2\}$	V	V	$1+r$
$\{O, B, C_1\}$	V	1	1
$\{O, B, C_2\}$	V	V	$1+r$
Any other subset of N	0	0	0

Table 6: Three scenarios of value creation under the bottleneck value creation technology

Given the characteristic function in Table 6 and the allocation of value from Lemma 1 (where a is substituted for $v\{O, B, C_1, C_2\}$ and b is substituted for $v\{O, B, C_1\}$) we have the following value

capture in each scenario:

	Scenario 1	Scenario 2	Scenario 3
π	$V < 1 < 1 + r$	$1 < V < 1 + r$	$1 + r < V$
π_O	$\frac{V}{2}$	$\frac{V^2+V+1}{3(V+1)}$	$\frac{r^2+3r+3}{3(r+2)}$
π_B	$\frac{V}{2}$	$\frac{V^2+V+1}{3(V+1)}$	$\frac{r^2+3r+3}{3(r+2)}$
π_{C_2}	0	$\frac{V^2+V-2}{3(V+1)}$	$\frac{r^2+3r}{3(r+2)}$
π_{C_1}	0	0	0

Table 7: Three scenarios of value allocation under the bottleneck value creation technology

To calculate the return on investment we calculate the derivatives of the orchestrator's and the superior complementor's expected value capture with respect to V and r , for each scenario:

Scenario 1: It is straightforward that $\frac{d\pi_O}{dV} = \frac{1}{2}$, and $\frac{d\pi_{C_2}}{dr} = 0$.

Scenario 2:

$$\frac{d\pi_O}{dV} = \frac{V^2 + 2V}{3(V + 1)^2} > 0,$$

$$\frac{d\pi_{C_2}}{dr} = 0,$$

and the second-order derivative for the orchestrator is

$$\frac{d^2\pi_O}{dV^2} = \frac{2}{3(V + 1)^3} > 0.$$

Scenario 3:

$$\frac{d\pi_O}{dV} = 0,$$

$$\frac{d\pi_{C_2}}{dr} = \frac{r^2 + 4r + 6}{3(r + 2)^2} > 0,$$

and the second-order derivative for the complementor C_2 is

$$\frac{d^2\pi_O}{dV^2} = -\frac{4}{3(2+r)^3} < 0.$$

■

Proof of Proposition 6.

Table 8 summarizes value creation, value capture, and the derivatives of an integrated actor I with respect to V and r under each scenario, given that under the uniform distribution the expected value capture is a half of the total value creation.

	Scenario 1	Scenario 2	Scenario 3
π	$V < 1 < 1+r$	$1 < V < 1+r$	$1+r < V$
$v\{I, B\}$	V	V	$1+r$
π_I	$\frac{V}{2}$	$\frac{V}{2}$	$\frac{1+r}{2}$
$\frac{d\pi_I}{dV}$	$\frac{1}{2}$	$\frac{1}{2}$	0
$\frac{d\pi_I}{dr}$	0	0	$\frac{1}{2}$

Table 8: Integrated actor benchmark under the bottleneck value creation technology

Given the proof of Proposition 5 we have the following:

Scenario 1: It is straightforward that $\frac{d\pi_I}{dV} = \frac{d\pi_O}{dV} = \frac{1}{2}$ and $\frac{d\pi_I}{dr} = \frac{d\pi_{C_2}}{dr} = 0$, and there is no ecosystem penalty.

Scenario 2: We have $\frac{d\pi_I}{dr} = \frac{d\pi_{C_2}}{dr} = 0$. We can re-write the derivative of π_O w.r.t V as

$$\frac{d\pi_O}{dV} = \frac{1}{3} - \frac{1}{3(V+1)^2}.$$

As $V \rightarrow 1$ we have $\frac{1}{3(V+1)^2} \rightarrow \frac{1}{12}$, thus $\frac{d\pi_O}{dV} \rightarrow \frac{1}{4}$, creating a difference of $\frac{1}{4}$ vs. $\frac{d\pi_I}{dV}$.

As $V \rightarrow \infty$ we have $\frac{1}{3(V+1)^2} \rightarrow 0$, thus $\frac{d\pi_O}{dV} \rightarrow \frac{1}{3}$, creating a difference of $\frac{1}{6}$ vs. $\frac{d\pi_I}{dV}$. Since $\frac{d\pi_O}{dV}$ increases monotonically in V , the ecosystem penalty decreases in V .

Scenario 3: We have $\frac{d\pi_I}{dV} = \frac{d\pi_O}{dV} = 0$. We can re-write the derivative of π_{C_2} w.r.t r as

$$\frac{d\pi_{C_2}}{dr} = \frac{1}{3} + \frac{2}{3(r+2)^2}.$$

As $r \rightarrow 0$ we have $\frac{2}{3(r+2)^2} \rightarrow \frac{1}{6}$, thus $\frac{d\pi_{C_2}}{dr} \rightarrow \frac{1}{2}$, making it equal to $\frac{d\pi_I}{dr}$.

As $r \rightarrow \infty$ we have $\frac{2}{3(r+2)^2} \rightarrow 0$, thus $\frac{d\pi_{C_2}}{dr} \rightarrow \frac{1}{3}$, creating a difference of $\frac{1}{6}$ vs. $\frac{d\pi_I}{dr}$. Since $\frac{d\pi_{C_2}}{dr}$ decreases monotonically in r , the ecosystem penalty increases in r . ■

Proof of Corollary 7.

From the proof of Proposition 6 it follows that the ecosystem penalty is equal to 0 in scenario 1, is bound between $\frac{1}{6}$ and $\frac{1}{4}$ in scenario 2, and is bound between 0 and $\frac{1}{6}$ in scenario 3. It is straightforward that the penalty is at the lowest in scenario 1 and at the largest in scenario 2. ■

Proof of Proposition 8.

Given the characteristic function in Table 5 and the allocation of value from Lemma 1 (where a is substituted for $v\{O, B, C_1, C_2\}$ and b is substituted for $v\{O, B, C_1\}$) we have the following expected value capture allocation:

$$\pi_O = \frac{V(r^2 + 3r + 3)}{3(r + 2)},$$

$$\pi_B = \frac{V(r^2 + 3r + 3)}{3(r + 2)},$$

$$\pi_{C_2} = \frac{V(r^2 + 3r)}{3(r + 2)},$$

$$\pi_{C_1} = 0.$$

To calculate the return on investment we calculate the derivatives of the orchestrator' and the superior complementor's expected value capture with respect to V and r , respectively:

$$\frac{d\pi_O}{dV} = \frac{r^2 + 3r + 3}{3(r + 2)} > 0,$$

$$\frac{d\pi_{C_2}}{dr} = \frac{V(r^2 + 4r + 6)}{3(r + 2)^2} > 0.$$

Taking second-order derivatives we get

$$\begin{aligned}\frac{d^2\pi_O}{dV^2} &= 0, \\ \frac{d^2\pi_{C_2}}{dr^2} &= -\frac{4V}{3(r+2)^3} < 0.\end{aligned}$$

■

Proof of Proposition 9.

Under the integrated benchmark the only two players are the buyer B and the integrated actor I with the total value creation of $V(1+r)$. It is straightforward that under the uniform distribution the expected value capture of the integrated actor will be a half of the value creation $\pi_I = \pi_B = \frac{V(1+r)}{2}$. Returns to increasing V are thus equal to $\frac{d\pi_I}{dV} = \frac{1+r}{2}$, and returns to increasing r are equal to $\frac{d\pi_I}{dr} = \frac{V}{2}$.

We have the following ecosystem penalty for the orchestrator:

$$\frac{d\pi_I}{dV} - \frac{d\pi_O}{dV} = \frac{r(r+3)}{6(r+2)}.$$

It is straightforward that the ecosystem penalty for the orchestrator is constant in V and is minimal when $r \rightarrow 0$. Taking derivative of the penalty w.r.t r we get $\frac{6+4r+r^2}{6(2+r)^2} > 0$, meaning that the orchestrator's penalty increases in r .

For the complementor we can re-write the derivative of π_{C_2} w.r.t. r as

$$\frac{d\pi_{C_2}}{dr} = \frac{V(r^2 + 4r + 6)}{3(r+2)^2} = \frac{V}{3} + \frac{2V}{3(r+2)^2}.$$

As $r \rightarrow 0$ we have $\frac{2V}{3(r+2)^2} \rightarrow \frac{V}{6}$, thus $\frac{d\pi_{C_2}}{dr} \rightarrow \frac{V}{2}$, making it equal to $\frac{d\pi_I}{dr}$.

As $r \rightarrow \infty$ we have $\frac{2V}{3(r+2)^2} \rightarrow 0$, thus $\frac{d\pi_{C_2}}{dr} \rightarrow \frac{V}{3}$, creating a difference of $\frac{V}{6}$ vs. $\frac{d\pi_I}{dr}$. Since $\frac{d\pi_{C_2}}{dr}$ decreases monotonically in r , the ecosystem penalty increases in r . It is straightforward that the complementor's penalty $\frac{d\pi_I}{dr} - \frac{d\pi_{C_2}}{dr} = \frac{V}{6} + \frac{2V}{3(r+2)^2}$ increases in V .

To have a consistent comparison of the ecosystem penalty across value creation scenarios we look at it as a proportion of the integrated benchmark returns, i.e. under a value creation scenario i

the penalty for the orchestrator is $p_O^i = \frac{\frac{d\pi_I}{dV} - \frac{d\pi_O}{dV}}{\frac{d\pi_I}{dV}}$, and for the complementor is $p_{C_2}^i = \frac{\frac{d\pi_I}{dr} - \frac{d\pi_{C_2}}{dr}}{\frac{d\pi_I}{dr}}$. We have the following penalty as a proportion of the integrated benchmark for the orchestrator:

$$p_O^{Add} = \frac{r^2}{3(r + 2V)^2},$$

$$p_O^{Bottle} = 0 \text{ if } V < 1 \text{ or } V > 1 + r,$$

$$p_O^{Bottle} = \frac{V^2 + 2V + 3}{3(V + 1)^2} \text{ if } 1 < V < 1 + r,$$

$$p_O^{Multi} = \frac{r(r + 3)}{3(r + 1)(r + 2)}.$$

From the above, it is straightforward that if $V < 1$, or $V > 1 + r$ then $p_O^{Bottle} < p_O^{Multi}$ and $p_O^{Bottle} < p_O^{Add}$. From the proof of Proposition 6 we know that if $1 < V < 1 + r$, then $p_O^{Bottle} > p_O^{Add}$. Comparing bottleneck and multiplicative scenarios when $1 < V < 1 + r$ we have p_O^{Bottle} constant in r and decreasing in V , and $p_O^{Bottle} \rightarrow \frac{1}{3}$ as $V \rightarrow \infty$. p_O^{Multi} is constant in V and is increasing in r and $p_O^{Multi} \rightarrow \frac{1}{3}$ as $r \rightarrow \infty$. Therefore, we will have $p_O^{Multi} \leq p_O^{Bottle}$ when $1 < V < 1 + r$. Comparing additive and multiplicative scenarios, we have $p_O^{Add} < p_O^{Multi}$ if $V > V^*$, where $V^* = \frac{\sqrt{r(r^3 + 6r^2 + 11r + 6)} - r^2 - 3r}{2(r + 3)}$, $V^* < 1$. Therefore we have for the orchestrator:

If $V < V^* < 1$	then $p_O^{Bottle} = 0 < p_O^{Multi} < p_O^{Add}$,
If $V^* < V < 1$	then $p_O^{Bottle} = 0 < p_O^{Add} < p_O^{Multi}$,
If $1 < V < 1 + r$	then $0 < p_O^{Add} < p_O^{Multi} < p_O^{Bottle}$,
If $1 + r < V$	then $p_O^{Bottle} = 0 < p_O^{Add} < p_O^{Multi}$.

We have the following penalty as a proportion of the integrated benchmark for the complementor:

$$p_{C_2}^{Add} = \frac{r(r + 4V)}{3(r + 2V)^2},$$

$$p_{C_2}^{Bottle} = 0 \text{ if } V < 1 + r,$$

$$p_{C_2}^{Bottle} = \frac{r(r + 4)}{3(r + 2)^2} \text{ if } V > 1 + r,$$

$$p_{C_2}^{Multi} = \frac{r(r + 4)}{3(r + 2)^2}.$$

From the above we can see that when $V > 1 + r$ (complementor is the bottleneck) $p_{C_2}^{Bottle} = p_{C_2}^{Multi}$. It is straightforward that when $V < 1 + r$ (complementor is no longer the bottleneck) $p_O^{Bottle} < p_O^{Multi}$ and $p_O^{Bottle} < p_O^{Add}$. Comparing additive and multiplicative scenarios, we have $p_O^{Add} < p_O^{Multi}$ when $V < 1$. Therefore we have for the complementor:

If $V < 1$	then $p_O^{Bottle} = 0 < p_O^{Multi} < p_O^{Add}$,
If $1 < V < 1 + r$	then $p_O^{Bottle} = 0 < p_O^{Add} < p_O^{Multi}$,
If $1 + r < V$	then $p_O^{Add} < p_O^{Multi} = p_O^{Bottle}$.

■