Complementor Participation in Platforms: Evidence from the 7th and 8th Generations of Video Game Consoles

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Abstract

This paper analyses how the factors breadth of content offerings, boundary resources, and exclusive content explain complementor participation in platform-based ecosystems, in the context of video game consoles. Fixed effects regressions on a panel comprising two generations of consoles across six platforms show that the breadth of content offerings positively affects complementor participation. We find that breadth of content offerings, but not boundary resources and exclusive content, are positively related to complementor participation. When studied in one model, breadth of content offerings dominates the relationship. Our results show how complementor ecosystems can be orchestrated to proliferate a variety of complementary product offerings.

1. Introduction

Platform-based ecosystems have received increasing attention in recent years to describe competitive environments [1]. Here, we define platforms as meta-organizations that federate and coordinate innovating and competing actors, facilitate economies of scale and scope, and entail a modular architecture [2]. Ecosystem refers to the platform leader and the providers of complementary goods that increase the value of the platform to its users [3, 4]. For example, video game consoles such as Microsoft Xbox and Sony PlayStation are platforms for which third-party game developers produce games consumed by end users. When users decide whether to buy into either of the two, they often consider the number and quality of the available complements next to the characteristics of the platform itself. This effect is known as indirect network effects [5] and highlights the importance of the developers of complementary products, called complementors, for the platform's overall success.

The participation of complementors on platforms, and the availability of complementary products, though, cannot be taken for granted [6]. Previous research has singled out factors that are expected to influence complementor participation and lie within the platform's sphere of influence. Such factors include the breadth of content offerings [7], the availability of boundary resources, which are the tools and regulations that serve as an interface between platform owners and complementors [8, 9, 10], and exclusive content, content that is only published on the focal platform [11, 12, 13]. Although availability of boundary resources is known to positively relate to complementor participation, it is not yet clear how it relates to complementor participation when studied in concert with the other two factors. This paper addresses the following question: *How do these three factors together affect complementor participation?* This matters as our understanding of coexisting complementor strategies and their influence on ecosystem outcomes are still limited [14].

These three factors capture different aspects of platform competition. Breadth of content offerings and exclusive content relate to indirect network effects. Boundary resources relates to modularity and expandability of the platform. All three factors also relate to technology strategy. Breadth of content offerings reflects choices regarding technological performance, such as Wii's move towards simple and intuitive gaming instead of high-end performance [15]. Boundary resources relates to the sharing to technological capabilities, and exclusive content relates to technological compatibility across platforms,

We empirically study boundary resources jointly with breadth of content offerings, and exclusive content and examine how they affect complementor participation. The use of longitudinal data highlights the process aspect in our research. We study these issues in the context of the 7th and 8th generation of video game consoles in the video game industry. This ecosystem consists of the game console (e.g., Sony PlayStation) with its platform leader (Sony in this example), video games (complements) that are compatible with this specific game console, and the users of video game consoles. We show how three factors that are inherent and unique to plat-

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form-based ecosystems affect the participation of complementors, which is essential for the ecosystem innovation process. Our results show that breadth of content offerings, but not boundary resources and exclusive content, are positively related to complementor participation. When studied in one model, breadth of content offerings dominates the relationship. This study sheds light on the dynamics of platform management by putting *federation* [2] central, which in this case is the attraction of complementors. This is relevant as "…neither the existence nor the process of federation of complementors into a collective can be taken for granted …" [2:1245]. This study contributes to the literature on orchestrating an ecosystem of complementors [2, 16], platform openness in general [7], and boundary resources in particular [8, 9] by studying three factors that affect complementors' intention to stay with a platform and by suggesting measures to address these.

2. Theoretical background: complementor participation in platforms

In many industries, platform-based business models are a way to reduce complexity by sharing modules, components, and other assets [17, 18] and by co-creating value outside the firm's boundaries [19]. In some cases, the existence of a platform leads to the emergence of a platform ecosystem. By joining the platform ecosystem, complementors can access the platform's end users [1]. Complementary goods and services are primarily developed for the platform and increase the core platform's value [6]. In the literature, platforms have been approached from an economic and an engineering perspective [2]. The economic perspective sees platforms as two (or multi-sided) markets and has a strong interest in the dynamics and mechanisms related to platform competition [20, 21]. The growth of the installed base and the availability of complements are seen as the main mechanisms behind a platform's value and market share [22, 23]. The value of a platform to its users is dependent on indirect network effects, which refer to the incremental increase in value to users that originates from the number and quality of products and services on another side of the market. Theoretically, three different patterns are possible: A monotonic pattern would imply that each additional complement increases the platform's value to uses. More likely, though, are decreasing returns where the additional value stemming from addition complements decreases. Lastly, a critical value of complements may exist above which users experience no additional benefits [24].

Both direct and indirect network effects lead to some sort of 'chicken and egg' problem as users would hesitate to join the platform without the presence of actors on each of the sides [6, 25]. In this view, the relationship between both sides of the market is seen as a buyer-seller relationship, irrespective of whether it refers to end users or innovating complementors [2]

In contexts where the platform is not just a market place, its objective is different [26]. If a platform offers the technological infrastructure for the development of complementary innovations, it is important to align complementor incentives with the platform ecosystem's objective [1, 27, 28]. This perspective on platforms, called engineering perspective, focuses on how to drive innovation across industries [2]. Central to this perspective is that platforms contribute to achieving economies of scope, defined as reducing costs by developing two products jointly instead of separately [2], which can be achieved by following a modular approach to platform design [29]. The architecture of a platform includes more stable components at its core and more variable components in its periphery [30]. In the case of video games, for example, the game console is at the platform's core while the complements (video games) are the periphery. For the most part, this stream views platforms as stable components at the core upon which innovation occurs on modules by using stable interfaces [2] – an assumption that is questioned by digitalism which has made interfaces more fluid [8, 31].

This modular architecture makes platforms suitable for facilitating innovation [2], which is in line with modularity theory [32, 33]. Modularity reduces complexity by splitting systems into components arranged according to a standardized architecture and connected via standardized interfaces. In this respect, modularity also facilitates innovation by reducing the scope of information designers have to work with, enabling more specialization and the division of innovative tasks [34]. Interfaces are crucial for modularity and innovation as they divide innovative activities and connect them simultaneously [32].

To draw on the knowledge and capabilities of external innovations and to enable independent experimentation, platforms can publish boundary resources, which are the tools and regulations that mediate access to the platform's core [9]. Platform providers influence the degree of openness through boundary resources. In other words, boundary resources enable platform owners to shift design capabilities to complementors [35]. This makes it easier to develop diverse complements for end users, thus combining economies of scale with product differentiation and creating incentives for complementors [9]. Boundary resources are hence a facet of platform openness [36]. Openness covers both the technological dimension (e.g., accessibility of interfaces) and the organizational dimension (e.g., conditions to use the interfaces) [37]. Open standards are one of the

means to achieve technical openness [38, 39]. Organizational openness can be controlled via rules and contracts that determine whether, and to what extent, complementors can participate in the platform [37]. In the context of video games, exclusive content is a facet of organizational openness. It refers to releasing a complementary product only on one platform, based on a contractual agreement between the platform owner and the complementor [12]. At its core, exclusive content restricts multihoming.

An open strategy can help platform firms to decrease the cost of developing future products while also increasing development by reducing the amount of redesign necessary for future product generations [40]. Giving complementors access to the platform increases their adoption rates and leads to more diverse and innovative complementary product offerings [41]. However, these benefits are dependent on the right open platform strategy. To shed light on potential complementor strategies, we first discuss three factors for complementor participation.

2.1. Breadth of content offerings

When deliberating whether to develop a complement for a specific platform, a complementor may consider the value users derive from the marginal complement [24], together with the number of available complements. The complementor may be less willing to develop for a platform in the cases of decreasing returns to scale or a critical value of complements, especially if current complement supply is high, or current complement supply is close or above the critical value.

Consumer demands are often heterogeneous, and platforms can address these demands by expanding to different markets. It is likely that the above-mentioned patterns of return for additional complements are at work in parallel across various markets. For example, early smartphone apps were mostly productivity-related tools such as calculators, address books, and note pads. Today, smartphone apps cover all conceivable areas, including health (e.g., nutrition trackers), automotive (e.g., CarPlay), and many more. Hence, expanding the opportunities for complementors to reach into different markets allows the platform to increase the strength of indirect network effects as individual users may rely on particular likes and dislikes, resulting in a unique combination of frequented game title markets. Variety-seeking teenagers, for instance, often use specific video games very extensively for several weeks to then trade them for a new game without ever returning to it [42]. Giving complementors horizontal access to different markets allows them to differentiate their products and specialize, thereby decreasing competition compared to a platform focused on a narrower set of markets and avoiding situations of crowding. We define breadth of content offerings as the variety of markets that a platform is represented in via complementary products. Breadth, here, refers to the number of categories (as opposed to depth, which is the number of items per category) [7].

Similarly, if a console is already represented in a specific game title market, complementors who intend to enter that market might be more inclined to do so on this console, as the platform will already be known for serving this market. That might give the focal console an advantage over competing consoles that are not present in that market. Boudreau [43] supports this argument with evidence from the context of mobile handheld devices. He found an increase in hardware complements when many complementors from heterogeneous industries were given access to the platform. This leads to the following hypothesis:

Hypothesis (H1). Breadth of content offerings has a positive effect on complementor participation in a platform.

2.2. Boundary resources

Relying on complementors poses the challenge of designing the technology so that complementors have access to the core technology but without exposing too much of it. In the case of video games, the right tools and resources allow game developers to develop high-quality games that take advantage of the console's unique architecture, enabling a rich experience for end users. Developing a game involves large investments of effort and time – here is where game engines come to the rescue for game developers.

The literature on boundary resources focuses on the perspective of platform owners [8, 9, 44]. Boundary resources have mostly been studied in terms of APIs and Software Development Kits as a means to involve complementors [8, 9, 45]. They are an important tool for managing the tension between securing control of the platform infrastructure and maintaining its generativity [8, 46]. Platform owners can exert control via boundary resources by introducing new ones or modifying existing ones [47]. Ghazawneh and Henfridsson [9] introduced the concept of self-resourcing, referring to the development of additional boundary resources by complementors themselves in response to perceived limitations of existing boundary resources. In this respect, boundary resources feature "feedback mechanisms and mutual shaping" [9:178]. New boundary resources can be initiated by both the platform owner and complementors so that the platform owner's role could be both reactive and proactive. The use of some boundary resources may also be mandatory. Still, most boundary resources are op-

tional, and their use depends on the preference and design choices of complementors in their pursuit to serve their clients [9]. A better assortment of boundary resources may allow complementors to focus more on game design and creative tasks instead of developing core technologies and making a platform more interesting for complementors. Boundary resources can also be seen as modules that facilitate economies of scope. In the case of third-party applications for Apple's iOS platform, Ghazawneh and Henfridsson (2013) found that the number of applications on the platform increased with every new boundary resource introduced. This suggests that boundary resources may be important to attract complementors to the platform, as captured in our second hypothesis.

Hypothesis (H2). The availability of boundary resources has a positive effect on complementor participation in a platform.

2.3. Exclusive content

Platform owners have used exclusive contracts with complementors to differentiate their product offerings from rivals through the exclusive offering of high-quality or premium content [48, 49]. Exclusive content refers to content that is only available on the focal platform [12] so that a specific game title would only be available on one platform. Whether to pursue exclusive contracts with complementors is a strategic trade-off for both platform and complementors.

From the perspective of *platform owners*, exclusive contracts with complementors are a way to secure unique content for end users and to enjoy the benefits of indirect network effects. As exclusivity usually comes in exchange for a lump-sum payment or an attractive licensing fee, the platform owner must compare the possible benefits gained from exclusive content against the cost of reducing licensing fees or lump-sum payments [12]. From the perspective of *complementors*, whether to join a platform depends on both the installed base of the focal platform *and* the installed base of competing platforms. The complementors' incentive to license their product to a platform is dependent on the market's potential that they can reach through the platform's installed base [50]. In markets with several incompatible platforms, complements developed for one platform do not function with other platforms. In this situation, with similar market shares, complementors tend to multi-home to spread the fixed costs of development over several platforms [12]. However, multi-homing is not for free as variable costs (called porting costs) are necessary to make a complement compatible with another platform. Additionally, the availability of a complement on other platforms may reduce the indirect network effects stemming from this complement and possibly lead to higher royalty payments to other platform owners [51].

Some scholars have studied exclusivity empirically. Lee [52] finds that the absence of exclusive contracts may actually reinforce an incumbent's leading position as high quality software would primarily be released on the incumbent platform based on its higher installed base. In this respect, exclusive contracts might help complementors release high-quality content at very favourable conditions on the smaller platform. We argue that exclusivity might signal the platform's aspiration to potential future complementors and attract new complementors. Furthermore, complementors compete strongly on the quality of content. Cennamo, Ozalp, and Kretschmer [53] show that the quality of complements drops if complementors decide to produce simultaneously for different platforms, which could be a quality signal for future complementors. A higher share of exclusive content on a platform may hence signal superior quality to aspiring complementors. Hence:

Hypothesis (H3). Exclusive content has a positive influence on complementor participation in a platform.

3. Data and methods

3.1. Data and sample

The video game industry is an ideal setting to understand complementor-platform dynamics. Several studies [e.g., 28, 50] have used this setting to show the typical characteristics of platform ecosystems. The industry is characterized by technological changes that have led to the emergence of eight generations of incompatible video game consoles to date, with new generations being introduced roughly every five years [13]. Although competition has been fierce in each generation, this has not led to one dominant console. Consequently, consumers carefully consider each console in their purchasing decision for game quality and diversity. Moreover, the success of a platform in this industry heavily depends on the platform owner's ability to attract complementors (video game developers) who produce high-quality content (video games) for the respective platform (game console).

We created a panel from multiple sources. We obtained quarterly global sales data from VGChartz. This industry research firm compiled a game database covering over 40,000 titles and 1.5 million data points, spanning two generations of consoles and game titles (seventh and eighth generation, 2005-2015). It also documents every game title's release year, publisher, developer, genre, and the platform on which it was released. We validated the data by cross-checking with Mobigames.com, which has been consulted for information on

game titles by other studies [12]. The Internet Game Database (IGDB) provides information on game engines available for each console (including release dates), validated by cross-checking with online news and press releases. In summary, our dataset comprises six game platforms and two generations, during which 2199 game titles were released.

3.2. Measures

Regarding the dependent variable, we conceptualize indirect network effects as complementor participation, which we define as the count of unique game developers on platform i in quarter t. Boudreau [43] found a causal effect of the number of complementors on the number of complements. From this follows that a platform owner would be concerned to increase the participation of complementors relative to the competing platforms. We refer to unique game developers to imply that a game developer with more than one game for a platform is counted only once, irrespective of the number of games by that game developer on the specific platform.

Regarding independent variables, we measure *breadth of content offerings* as the proportion of game genres produced for platform i over the total existing game genres in quarter t. A specific genre represents a user group that is characterized by distinct demands. Here, genres serve as a proxy for markets, and the availability of a game title by platform i in a specific genre is seen as catering to this market. The more genres a platform covers, the more accessible it is to different markets from the complementor perspective. We operationalize *availability of boundary resources* as a count of game engines available for platform i in quarter t. Game engines are software tools to equip game developers with a set of features to support core game development areas such as audio, video, physics, or animation. We measure *exclusive content* as the proportion of exclusive game titles produced on platform i in quarter t to total exclusive game titles for all platforms in quarter t. A game title is exclusive if it is available only for the focal platform and never on the rival platforms during the period of observation. Hence, exclusive content is the platform's ability to negotiate exclusive contracts with game developers, as also used by others [50] to study the effect of exclusivity on hardware demand.

Exclusive content and breadth of content offerings are defined as proportions as we expect complementors to weigh exclusive content on a particular platform in comparison to other platforms. Similarly, we expect them to compare portfolios of served game genres across platforms, rather than the absolute number. With boundary resources, we deem it more likely that complementors are on the look for specific game engines rather than taking a portfolio-perspective.

We control for *installed base* as the cumulative unit sales of console i in quarter $t-1$, as it has an influence on indirect network effects and the intention of complementors to develop games for a platform. We use the natural logarithm of installed base. The video game industry shows a strong seasonal pattern as many new games and consoles are released in the last quarter of the year. We, therefore, use a seasonality dummy (*seasonality*) to control for the last quarter of the year.

Whenever a new generation of a platform is released, consumers are drawn to the new and technologically superior platform. This decreases complementors' support for the older version of that platform as the direct network effects tend to decrease with the introduction of newer generations. As in Srinivasan and Venkatraman [13], we use a dummy variable (*generation dummy*) for the period in which both a newer and an older generation of a platform coexist.

3.3. Estimation method

As discussed above, we seek to estimate whether, and to what extent, breadth of content offerings, boundary resources, and exclusive content are related to the number of complementors that offer complements for a specific platform. To study this, we estimate conditional fixed-effects Poisson panel data models of how the count of complementors depends on each of these dimensions, and on all of them simultaneously.

The Poisson distribution requires that variance and mean be equal [54], which does not hold based on our dependent variable complementor participation (the variance is more than 10 times the mean). In this case, a negative binomial distribution may be a better fit. However, Allison and Waterman [55] show that the conditional negative binomial model for panel data is not a true fixed-effects method as it allows for the introduction of individual specific regressors. It does not necessarily remove the individual fixed effect, it only does so if the individual overdispersion parameter is related to the individual fixed effects in a very specific way [56]. Based on these properties, Wooldridge advises against the use of the negative binomial distribution in combination with fixed effects (See post #4: https://www.statalist.org/forums/forum/general-stata-discussion/general/1580248-issue-about-xtpoisson-xtnbreg-panel-data-regression-with-not-concave-iteration). As the Poisson distribution is more suitable for mean estimations, we rely on this distribution for the estimations in this paper.

$$Y_{it} = \mathrm{f}(breadth\ of\ content\ offerings_{it-1},\ availability\ of\ boundary\ resources_{it-1},\ platform\ exclusivity_{it-1},\ Ln\ installed\ base_{it-1},\ seasonality_{it},\ generation\ dummy_{it})$$

Y_{it}, complementor participation, is our dependent variable. Installed base was scaled by dividing by 100. We chose the fixed effects estimator as the preferred method for several reasons. It is suitable for analysing variables that vary over time [57]. It removes all time-invariant characteristics of the platform, mitigating omitted-variable bias due to time-invariant characteristics. Testing for fixed effects versus random effects with the Hausman test also recommends the fixed-effects estimator over random-effects.

We calculated McFadden's [58] pseudo r-squared based on the log-likelihood for the full model and the model with only the intercept. As Stata's *xtpoisson, fe* does not work without independent variables, we used the command *poisson* with dummies for the individual platforms to compute the model with intercept only.

Theoretically, the causation could also be opposite to what we hypothesize (from boundary resources to complementors) as game engines (these underlie the variable boundary resources) could belong to the very game developers who are the complementors. This would mean that boundary resources are driven by the number of complementors. The other independent variables (breadth of content offerings and exclusive content) could also be driven by the dependent variable. If we were studying a situation with only two platforms, all the variation would be explained by exclusive games, since non-exclusive games are available on both platforms. This is less the case in a three-way competition, but an exclusive game as we define it increases complementor participation if this is the only game offered by this complementor. Similar concerns may apply to breadth of content offerings. The serving of a genre manifests as the platform having a game on offer in that genre. In the case of high breadth (many categories) and low depth (few games per category), our dependent variable could also affect the breadth of content offerings. We use a lag of each of the independent variables as we are interested in their effect on future complementors

3.4. Descriptive statistics

The panel contains 139 observations across six platforms (PS3, Xbox 360, Wii, Wii U, PS4, and Xbox One) with an average of 23.2 time periods per platform (the data is recorded quarterly). We computed pairwise correlations for all variables in the model. At first, we also included platform age in the model but dropped based on very high correlations with installed base (0.941). All correlations are below 0.5 (magnitudes), with the highest correlations between breadth of content offerings and complementor participation (0.570), and exclusive content and breadth of content offerings (0.529), and the generation dummy and installed base (0.531). Table 1 contains summary statistics.

4. Results

4.1. Main Results

We present the results in Table 2. We rely on conditional fixed-effects Poisson panel data models. In all models, complementor participation is the dependent variable. Model 1 contains the control variables only, explaining 42% of the variance in the sample. We hypothesized that the presence of a platform in various markets makes it easier to attract complementors, as captured in the variable *breadth of content offerings*, and we found evidence for this hypothesis in model 2. Breadth of content offerings positively influences complementor participation, as indicated by the coefficient of 1.655 ($p<0.001$). In model 3, *boundary resources*, together with the controls, are regressed on complementor participation. The coefficient of 0.047 ($p=0.028$) supports the hypothesis that the availability of boundary resources is positively related to complementor participation. However, the coefficient's magnitude is rather small, and additional regressions (not reported) show that boundary resources alone is not a strong predictor of complementor participation (in a model with independent variables only, without controls). Taken together, we do not consider this evidence robust and are careful to draw conclusions with respect to boundary resources. In model 4, *exclusive content* is regressed on the dependent variable together with the controls. Exclusive content has a positive and insignificant coefficient of 0.742 ($p=0.255$), refuting the hypothesis.

In model 5, we combine all variables into one model. Comparing r-squared across all models suggests that most of the explanatory power lies with *breadth of content offerings*, with a coefficient of 1,564 ($p=0.000$). In terms of r-squared, model 5 offers no substantive advantage over model 3, where only *breadth of content offerings* and the controls are regressed on complementor participation. Although distinctly positive together with the controls, the coefficient of *boundary resources* is now small and insignificant, with a coefficient of 0.026 ($p=0.149$), as it seems that this information is conveyed by breadth of content offerings.

Taken together, we can accept H1 (related to breadth of content offerings) but cannot confirm H2 (related to boundary resources) and H3 (related to exclusive content). Conceivably, boundary resources are more important in the nascent stages than in mature stages. After introducing a new platform, developers have not yet had the time to accumulate experience with the platform, so that better support might make the difference in opting for or against a specific platform. However, during later stages, developers may already have gained experience, and developer knowledge regarding a particular platform might already have spread

and led to commodification, reducing the importance of boundary resources.

4.2. Robustness and comparison with other studies

To address multicollinearity concerns, we compute the variance inflation factors (VIFs). The highest VIF (2.80) regards breadth of content offerings in model 5. All other VIFs are below 2.1, concluding that multicollinearity is not a problem.

As Ghazawneh and Henfridsson [9] attribute a prominent role to boundary resources, one would expect a more pronounced result. In the 7th generation of video game consoles, Wii is an outlier as it targets more casual gamers with a larger variety of less high-end games. With this strategy, Wii is distinguished from the other platforms as its strategy requires less sophisticated game engines – yet it manages to attract complementors. Additional data analysis supports this point. We created an additional dataset with game engines, release dates, and the platforms the game engines were available for. Correlating the availability of game engines per platform shows very high correlations for PS3, PS4, XOne, and X360, and low to low negative correlations between the former platforms and Wii / WiiU The effect of boundary resources seems contingent on the whether the platform pursues a high-end or variety strategy (calculations not shown).

Table 1. Descriptive statistics

Variables	Mean	Std. Dev.	Min	Max
Complementor participation	21.683	17.476	0.000	107
Breadth of content offerings	0.646	0.250	0.000	1.000
Boundary resources	19.050	7.901	7.000	30.000
Exclusive content	0.281	0.237	0.000	1.000
Installed base	17.162	1.161	14.040	18.430
Generation dummy	0.223	0.418	0.000	1.000
Seasonality	0.252	0.436	0.000	1.000

Table 2. Regression results

	(1)	(2)	(3)	(4)	(5)
Variables	Dependent variable: complementors				
Installed base	0.142***	0.158***	-0.00397	0.174***	0.0793***
	(0.0296)	(0.0450)	(0.0477)	(0.0456)	(0.0146)
Generation dummy	-1.394***	-0.860***	-1.411***	-1.275***	-0.902***
	(0.483)	(0.184)	(0.468)	(0.292)	(0.259)
Seasonality	0.744***	0.675***	0.746***	0.725***	0.681***
	(0.119)	(0.119)	(0.121)	(0.0923)	(0.126)
Breadth of content offerings		1.655***			1.564***
		(0.452)			(0.217)
Boundary resources			0.0474**		0.0259
			(0.0216)		(0.0180)
Exclusive content				0.742	0.0689
				(0.651)	(0.517)
Log-pseudolikelihood	-639.240	-529.78595	-626.22564	-604.33453	-526.27842
Pseudo R-squared	0.421	0.520	0.432	0.452	0.523
Observations / platforms	139 / 6	139 / 6	139 / 6	139 / 6	139 / 6

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Data covering six platforms in the 7th and 8th generation of video game consoles. Conditional fixed-effects Poisson regression.

This difference with respect to other studies might occur because the effect of boundary resources is driven by specific, high-quality boundary resources rather than their count. While we do not see a clear association with respect to complementor participation, it is imaginable that boundary resources help attract the right complementors, i.e., those producing high quality and novel

complements. It may, however, be difficult to consider boundary resource quality at scale.

5. Discussion and conclusion

We examined how breadth of content offerings, boundary resources, and exclusive content affect complementor participation. We hypothesized that each would have a positive influence on complementor participation and tested this in the context of the 7th and 8th generation of video game consoles. The results show that breadth of content offerings, but not exclusive content and boundary resources, are positively related to complementor participation. When studied in one model, breadth of content offerings dominates the relationship. This highlights the importance of studying facets simultaneously instead of focusing on single aspects.

The three factors for complementor participation are related to several streams in platform literature. Boundary resources, as tools and regulations that serve as an interface between platform owners and complementors [8, 9, 10], relate to the literature on access openness, i.e., decreasing the cost of complementary product development [59]. We contribute to the measurement and dimensionality of platform openness by suggesting measures for the breadth of content offerings and for boundary resources, something scholars have not yet agreed on [7]. Previous approaches to studying boundary resources were mostly qualitative [9, 47]. Exclusive content, content that is only published on the focal platform [11, 12, 13], relates to platform openness in the classical sense, as a restriction to multihome [60]. But it also relates to platform differentiation as a form of content curation. Breadth of content offerings and exclusive content relate to different kinds of network effects. Our study contributes by testing these factors' effect on complementor participation, which has rarely been studied to date [7]. All three factors also relate to technology strategy. Breadth of content offerings reflects choices regarding technological performance.

This study also contributes to the growing literature on how the hub of a platform federates and orchestrates an ecosystem of complementors [16]. Gawer [2] calls for research on the drivers and consequences of changes in platform openness. Further, several studies propose relationships between platform openness and various organizational outcomes, such as market growth [61], coordination [62], or value capture and value creation [19, 38]. The choice of our dependent variable adds to the literature by focusing on what Gawer [2] describes as a *federation*, which may be loosely defined as the gathering or joining together of actors into a larger organization. In the absence of managerial hierarchy or authority, as it is the case in platform-based ecosystems, a federation of innovative agents is one of the initial steps in nurturing an ecosystem. In other words, complements can only become available once complementors have decided to commit to the platform.

From a practical perspective, the results can guide managers on how to increase complementor participation in their platform. By studying how to influence the number of complementors instead of the number of complements, our study helps practitioners create and maintain a diverse ecosystem of complementors. Our results suggest that breadth of content offerings is most relevant in attracting future complementors. When negotiating exclusive content agreements, platform leaders should consider the differentiation and positioning of the platform towards customers and its attractiveness to future complementors. Our results do not show that the number of boundary resources is strongly associated with complementor participation. However, this does not preclude that qualitative attributes of boundary resources are relevant.

Our findings are subjected to several limitations. The factors for complementor participation we have studied are not exhaustive. While focusing on complementor dynamics, our data reflect video gaming platforms and interconnected ecosystems. We study whether different factors for complementor participation are related to new complementors (game developers) joining the platform. From our model's perspective, a complementor can join one or several of the covered platforms or none of these. But the model does not reflect the multitude of other options beyond video gaming that complementors face in practice, which poses limitations to our findings. Future research could incorporate these aspects by covering several types of platforms (consoles, handheld devices, PCs). Further, the results may benefit from the inclusion of more control variables. It would be desirable to improve the identification of causal effects, for example using an instrumental variable approach [11].

We see promising research directions in studying the attraction of especially productive, successful, or innovative complementors in addition to our measure of general complementor participation. It seems that the literature on complements evolves in two camps, one studying complementors [e.g., 63, 64], the other studying complements [e.g., 8, 14]. Future research could explore the relation between the two measures of ecosystem activity. Future studies could consider differences in quality, affordance, or usefulness of boundary resources. For example, Petrik and Herzwurm [10] study boundary resource quality with respect to complementor satisfaction which might help in considering quality differences. Ghazawneh and Henfridsson [9] conceptualize boundary resources as serving two distinct purposes. It may be worthwhile to differentiate between boundary resources for sourcing (control-related) and resourcing

(scope, diversity) [9]. Similarly, our measure of boundary resources counts all published boundary resources but remains inconclusive about their actual use by complementors. Due to the industry's nature, it is difficult to obtain information about game engines that were used by complementors to develop game titles.

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6. References

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