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# **The Thrill and the Agony of Digital Ecosystems: A Complementor's Perspective on Co-Innovation Risk**

*Complementors are the cornerstone of innovation and a vital part for every platform ecosystem. Nevertheless, their perspective is commonly neglected in academic research. By drawing on external resources, they develop complementary products, use distribution channels and benefit from the development of the platform and the surrounding ecosystem. Their accelerating dependence on platform owners, however, has not only created new business opportunities but also introduced essential new risks. These co-innovation risks are especially accelerated by the dominant position of the platform owner and the related uncertainty of the transaction environment. Hence, we apply a quantitative survey among 42 complementors of five leading cloud platforms to explore the drivers of such risk and the role of platform specificity, governance as well as app architecture in such settings. We thus provide valuable insights for both practice as well as theory on platform ecosystems.*

## **Introduction**

In today's interconnected digital economy, the emergence of technological platforms like Salesforce's Force.com, SAP's HANA or Apple's iPhone operating system (iOS) substantially changed the logic of value creation. A platform, i.e. an extensible codebase, allows the development of complementary subsystems (i.e. extensions) that extend a platform's native functionality and become the locus of innovation (Yoo et al. 2010). Companies offering such complementary extensions are called complementors or third-party developers (Ghazawneh & Henfridsson 2013). Modular platform architecture enables complementors to develop their own extensions independently, yet platform interfaces ensure their interoperability. This tendency towards a disintegrated architecture is mirrored by an increasing degree of interorganizational modularity, distributing the partitioning of innovation among many firms (Baldwin & Clark 2006). The platform and its corresponding modules form an ecosystem in which numerous participants, including the platform owner (e.g. Salesforce.com, SAP), suppliers, end users, and complementors, transact with one another in complex ways to develop novel value propositions (Boudreau 2012). Hence, platform owners are increasingly engaging vibrant ecosystems around their platform to foster third-party innovation. Such are becoming the dominant form of organizing innovation in various domains, for instance Enterprise Application Software (EAS), mobile or video games (e.g. Gawer 2009).

Despite all the potential benefits for complementors, however, platform ecosystems have also been known for its fluctuation and high rates of desertion (Tiwana 2015b). The accelerating dependencies with the platform (owner) on a technical, contractual or resource-based level, however, has not only created new business opportunities but also introduced essential new risks as the new organizing logic of digital innovation requires interfirm exchange to develop complementary products. These risks go beyond traditional risks of software engineering (e.g. Barki et al. 1993; Wallace et al. 2004) because innovation on platforms has blurred conventional firm boundaries and includes multiple and heterogeneous actors. Exogenous and relation specific factors like for instance opportunistic behavior of the platform owner constitute crucial threats for complementors. These risks of co-innovation, especially accelerated by the dominant position of the platform owner, are at the center of our paper.

The purpose of our research is to shed light on complementors' co-innovation risk on the interorganizational level of exchange in single "hub and spoke" relations rather than the whole ecosystem. Therefore, we identified two relation specific categories of drivers that are affecting the risk of co-innovation on platforms: the complementor's dependence on the platform (owner) during innovation that arise from the IT artifact itself (e.g. Tiwana 2015b) as well as economic reasons (e.g. Adner 2006; Pfeffer & Salancik 1978). In addition, exogenous uncertainties regarding the environment as well as the behavior of the platform owner, which are theoretically anchored in Transaction Cost Theory (TCT) (Aubert et al., 2004; Williamson 1991), are relation specific drivers for risk. These are vice versa influenced in two ways, (1) through the micro architecture of the third-party innovation (i.e. modularization of extensions), which reflects an endogenous choice of complementors that is to some extent constrained by but not necessarily equal with the platform's architecture (Tiwana 2015a), and (2) the platform governance mode (i.e. input & clan control; decision rights delegation) (Tiwana et al. 2010), which is accomplished by the platform owner and therefore an exogenous factor for third-party developers.

Therefore, our work addresses several critical gaps in academic research on platform ecosystems. First, previous research on the complementor's relation with the platform owner, like most research on interorganizational alliances, focuses on collaborative advantage (e.g. Ceccagnoli et al. 2012; Kude et al. 2012). However, we know little about the dark sides of the new organizing logic in platform ecosystems. Particularly the risks of co-innovation in power asymmetric and dependent relationships of ecosystems and its drivers remain underexplored. Second, research on innovation in IS is traditionally focusing on the risk of software engineering from an internal project perspective (e.g. Barki et al. 1993; Wallace et al. 2004). However, the focus of IT innovation is shifting to platforms and their ecosystems that allow the development of complementary extensions by third-parties. Hence, we know little about the risks of this new approach of software engineering especially from the perspective of complementors. Third, research on intra-platform dynamics, and particularly the interplay of governance and extension architecture remains generally underinvestigated. Our research complements existing studies (e.g. Tiwana 2015 a & b) by examining effects of extension architecture and platform control on the drivers of risk.

Using data from a quantitative survey among complementors of five leading cloud platforms (i.e. Microsoft Azure, Oracle Cloud Platform, Amazon Web Services, SAP HANA, and Salesforce Force.com) hypothesized relationships are tested guided by our research questions:

- (1) How do relation specific drivers enhance complementor's co-innovation risk in platform ecosystems?*
- (2) How do different control mechanisms of the platform owner as well extension architecture influence the drivers of co-innovation risk?*

## **Theoretical Background**

### **Co-Innovation Risk**

In IS research, the concept of risk is defined as the variation in the distribution of possible outcomes, their likelihoods of occurrence, and their subjective values. Thus, an alternative is conceived risky if the variance of outcome is large and negative (March & Shapira 1987). Following Kaplan & Garrick (1981) we define risk as a function of both uncertainty and some kind of loss or damage, which is experienced by a complementor. For analyzing the risk of co-innovation we combine two streams: literature on risk in alliances (e.g. Das & Teng 2001) as well as research on risk in software engineering (e.g. Barki et al. 1993; Wallace et al. 2004).

In emphasizing relational risks, past research essentially built on the transaction cost economics (TCE) (Williamson 1991). In particular, Das & Teng (2001) divide the risks of alliances into two broad categories – relational and performance risk. The latter one is related to market and capability factors that may disturb the cooperation. On the contrary, relational risk is an inherent part of any cooperation. This category of risk is concerned with “the probability and consequence of not having satisfactory cooperation” (Das & Teng 2001: 253). As one idiosyncrasy of interorganizational arrangements is related to the cooperation with a partner, opposing goals and self-interest of each individual party create uncertainty in the behavior of the counterpart (Ouchi, 1980). This uncertainty can destabilize an alliance due to the possible opportunistic behavior of the partner and creates multiple the rates of failure (Parkhe, 1993). Transaction cost economists argue that some partners are likely to pursue their individual interests at the expense of other parties (Nooteboom et al. 1997).

Research on risks in alliances, however, did not consider a number of crucial facets particularly related to third-party innovation. Applied to the platform context for instance, the architecture of products can create risks regarding the loss of intellectual property (Baldwin & Henkel 2015). Particularly, opportunism of the platform owner may cause a replication of the third-party developer’s technology if it intends to enter into the application market itself to offer a competing product (Ceccagnoli et al. 2012). Furthermore, the platform owner’s control over boundary resources (i.e. software development kit (SDK) application programming interfaces (APIs)) makes complementors increasingly dependent on the platform owner (Ghazawneh & Henfridsson 2013). Therefore, Adner (2006) introduced the concept of co-innovation risk, emphasizing the role of interfirm dependence during innovation of interdependent technological solutions in ecosystems. We therefore argue that the three most important sources that drive risk are the behavior of the platform owner, which enables opportunism, the role of digital technology as well as the dependence of the complementor on the platform owner.

### **Platform Governance and App Architecture**

Following modular system theory, modularity refers to the concept of any complex system with intentionally minimized interdependences between the single subsystems it consists of (Sanchez & Mahoney 1996). The modularity of the platform and its modules attempts to minimize interdependence between both by decoupling and the use of standardized interfaces. Decoupling allows that changes within a module do not require parallel changes in the platform and vice versa. Standardization refers to the use of APIs that are applied to meet conformance between the platform and the extensions (Tiwana 2015a). In particular, extension modularization minimizes the extension–platform dependencies on the degree to which an extension is required to be conform to the specifications interface that is vice versa determined by the platform owner. Hence, extensions within the same ecosystem can significantly vary in their level of modularization (Mikkola & Gassmann 2003).

Although such modular architecture is commonly believed to reduce the need for control (Sanchez & Mahoney 1996), platform owners utilize different mechanism to ensure that the interaction between the extensions and the platform meet its interests and to balance between retaining control and fostering third-party innovation (Tiwana et al. 2010). Ecosystem represent rather characteristics of a market than a dyadic alliance, and innovation outcome is not predefined a priori by a focal firm like for instance within conventional authority relationships. Hence, traditional control mechanisms are less viable in platform ecosystems (Tiwana 2015a). However, control is a major component when trying to understand the interaction between complementors and a platform owner during third-party innovation. In this context, control refers to the mechanisms that govern actions of the partners established by a central platform owner (Choudhury & Sabherwal 2003). Although, the interests of the platform owner and third-party developers are not necessarily misaligned, the applied mechanisms are an exogenous variable for complementors. As typically platform owners choose the form and amount of control, complementors are rather influenced by the consequences of these decisions. Control theory (Kirsch 1997; Ouchi 1979), typically segments into formal and informal control modes, which are both applied in platform ecosystems.

Two suitable control mechanisms in this context are input control, i.e., screening which extensions are allowed into an ecosystem, as well as clan control, i.e. shared values and common norms (Kirsch 1997). Particularly for ecosystems, input control, i.e. the degree to which platform owners control the extensions of the complementor and assures interoperability (Tiwana 2015a). Hence, not all complementary extensions are admitted to the ecosystem. Although, both control mechanisms are widespread in practice, little is known about their consequences, especially from the perspective of complementors.

Apart from different modes of control, another central element of platform governance is the delegation of decision rights (Tiwana 2015b), which reflects the interorganizational modularity of an ecosystem (Karim, 2006). This form of governance encompasses different classes of decision rights (Fama & Jensen 1983). Taken to the platform context, platform owners distribute the locus of authority of what an extension should do (e.g., features and functionality), how it should do it (e.g., design, user interface), and the control of boundary resources (e.g. the platform's interfaces) among itself and the complementor (Tiwana et al. 2010).

## **Theoretical Development**

Within this section, we develop our research model. Therefore, we propose that three drivers (H1a, H1b, and H1c) enhance the complementor's co-innovation risk. We then propose that the interplay of different control mechanisms introduced by the platform owner as well as extension architecture influence the drivers of co-innovation risk (H2, H3a, H3b, H4, H5, H6 and H7). Our research model is shown in Figure 1.

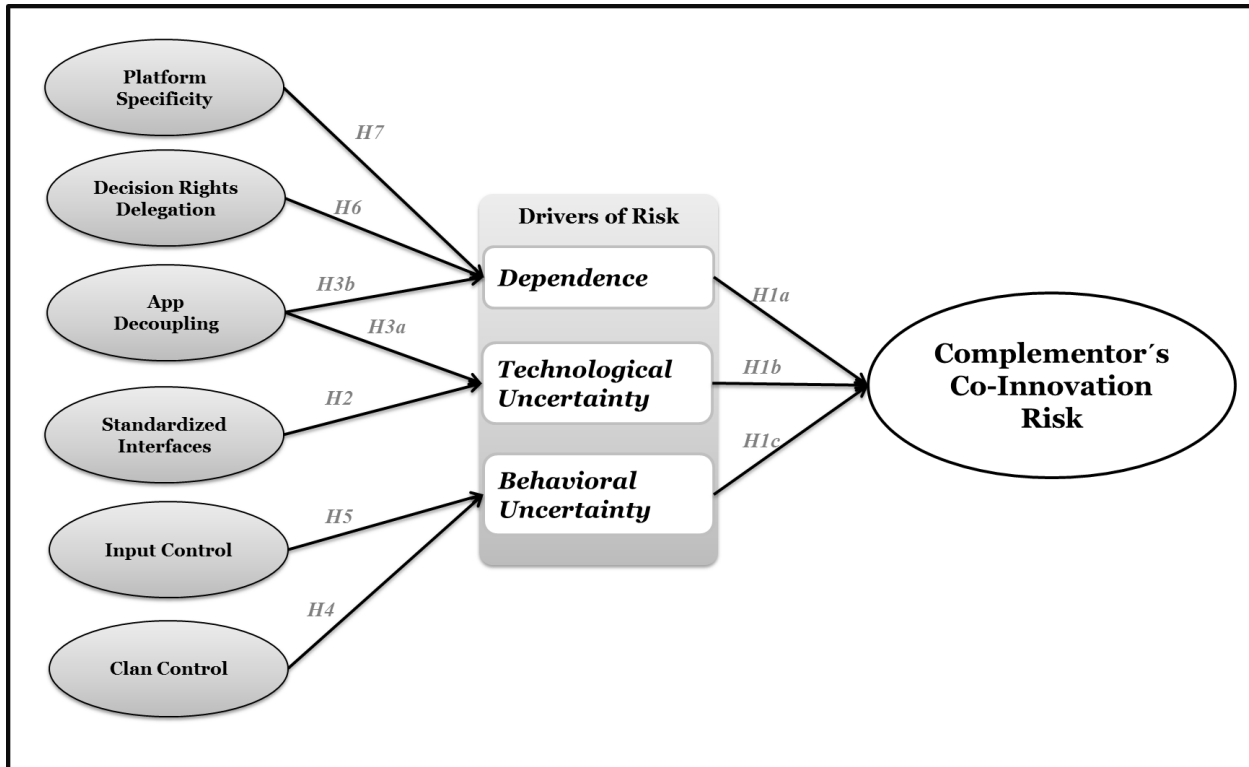


Figure 1: Research Model

## Relation Specific Drivers of Co-Innovation Risk

### *Dependence on the Platform Owner*

When complementors join ecosystems, they become increasingly dependent upon a platform owner to provide interface specifications, guidelines, requirements, or the access to other resources (Tiwana 2015b). These dependencies go beyond the technological dependencies with the platform itself. Scholars have used concepts like resource dependence theory to consider firms as entities that rely on an exchange with external organizations (Pfeffer & Salancik 1978). The amount of dependence of the complementor on the platform owner inversely reflects the power of the platform owner on the complementor during innovation. Hence, platforms typically create asymmetric relationship between platform owners and complementors (Casciaro & Piskorski 2005). For instance, the platform owner may exert power over the complementor by defining constraints, such as technological specifications, branding guidelines, access to APIs and design rules. In other words, complementary extensions depend on products and technologies of platforms to fully exploit their value making dependencies a crucial driver of co-innovation risk (Adner 2006) and the magnitude of a potential loss.

*Hypothesis 1a: Greater dependence on the platform owner facilitate the complementor's co-innovation risk*

## ***Technological Uncertainty in Platform Ecosystems***

Technological uncertainty as one key dimensions of environmental turbulence refers to the unpredictability of the firm's surrounding environment and therefore the fact that not just the direct exchange partners but also the environment of the ecosystem influences the transaction costs of complementor. While technological evolution is unpredictable in principle (Tiwana et al. 2010), complementors furthermore face technological uncertainties especially because it is the platform owner who sets crucial technological framing conditions like for instance APIs, SDKs, system governance (component boundaries and real-time support) and shared assets (e.g., maps, fields for data input-output) (Bresnahan & Greenstein 2014). These may heavily influence the value and functionality of new and existing apps. Hence, third-party developers face an adaptation problem and might be forced to adjust internal resources, external agreements and especially the relationship towards the platform owner in order to fit the new circumstances surrounding the platform ecosystem (Rindfleisch & Heide 1997). On the one hand, the less predictable the technological surroundings are the more likely are up-front investments to make agreements adaptive. On the other hand, uncertainty may induce opportunistic behavior by the platform owner, e.g. through extracting concessions at the partner's expense (Wathne & Heide 2000).

*Hypothesis 1b: Greater technological uncertainty facilitates the complementor's co-innovation risk*

## ***Behavioral Uncertainty in Platform Ecosystems***

Behavioural uncertainty arises from the instance that partnership evaluation is often complex and the partner's actions and performance are hard to capture and interpret. Behavioral uncertainty covers the complexity of monitoring the contractual performance of exchange partners, which makes it difficult to monitor if the partner is acting opportunistically by for instance cheating, distorting information or appropriating resources (e.g. Aubert et al. 2004; Williamson 1991). Such behavior is especially relevant in ecosystem relations because each firm has its own individual interests that are not necessarily congruent with those of their partners. This can be further strengthened by the partners if they refuse to disclose information, disguise or distort it (Kude & Dibbern 2009). The participants in an ecosystem therefore face the threat of opportunistic behavior within exchange after they have already committed resources to the platform (Aubert et al. 2004). Behavioral uncertainty is especially high in small numbers bargaining situations, i.e. distribution of power to a small number of dominant firms (Doz & Hamel 1998). For instance, the platform owner might utilize the complementor's lock-in situation and take advantage at its cost. Platform owners may use a dominant position to refuse to share resources that are crucial for mutual value creation. Furthermore, the platform owner may absorb the complementor's knowledge and imitate the solution itself to provide a substitute product (Kude & Dibbern 2009). Particularly within the context of platform-based third-party development there are quite asymmetric relationships between platform owners and complementors (Casciaro & Piskorski 2005) so that a large part of the risk emerging from behavioral uncertainty is on the complementors' side.

*Hypothesis 1c: Greater behavioural uncertainty facilitates the complementor's co-innovation risk*

## ***The Role of App Modularization***

On the micro-level of single applications, the standardization of interfaces describes the degree to which the linkages between the single app and the platform are stable, formalized and well-documented (Tiwana 2015a). Thereby, stability is ensured by the application of boundary resources like application programming interfaces (APIs) (Ghazawneh & Henfridsson 2013). Such standards codify the relationships between the app and the platform as well as clearly articulated rules and specifications for apps and platform infrastructure. Such clarity and transparency describes technological stability a complementor can expect the platform owner to obey. Hence, it reduces technological uncertainty.

*Hypothesis 2: Greater standardization of interfaces reduces technological uncertainty*

The second dimension of app modularization is app decoupling. Usually the complementor makes such a design choice within the exogenous constraints of the platform and minimizes the app-platform dependencies on the degree to which an app is required to be conforming to the specifications interface (Tiwana 2015a). This is achieved by carefully selecting and placing “thin connections” between app and platform while removing the remaining so that changes to the app or the platform do not cause ripple effects to the respective counterpart (Baldwin 2008). In particular, decoupling reduces the need for adaptations in the complementor’s extension after changes in the platform (Nambisan 2002). Modification of the platform therefore does not affect the single extension of third-party developers. The technological requirements of the relationship are hence less complex and volatile accelerated by the use of stable interfaces (Schilling 2000). Therefore, extension modularization decreases the volatility of technological requirements.

*Hypothesis 3a: Greater app decoupling reduces technological uncertainty within the ecosystem*

On the other hand, extension modularization in general and app decoupling in particular decreases platform dependencies and aims at reducing complexity (Simon 1962). The more decoupled an app is, the more independently it can be developed by a complementor while still ensuring fluent interoperation with the platform. Therefore, it reduces the requirement for parallel adaption in the platform when internal changes are made in an app (Nambisan 2002), which enables a more independent development of complementary applications.

*Hypothesis 3b: Greater app decoupling reduces the complementor’s dependence on the platform owner*

## ***Clan Control and Behavioral Uncertainty***

The most common informal mechanism to govern partners and the interaction with them is clan control. This form of governance is accomplished by mutual values and shared goals within the ecosystem, which are introduced by a controller but also, emerge among members of an effective ecosystem. Such control is a crucial soft power instrument for platform owners to bring actors around their platform on a common path (Kirsch et al. 2002; Tiwana et al. 2013). For instance, platform owners may release norms, mutual values and goals that are beneficial for the strategic aims of the platform like app features that consumer needs or behaviors covering app updates and bug fixing. For instance, platform owners may release norms, mutual values and goals that are beneficial for the strategic aims of the platform like app features, which consumer need or



behaviors covering app updates and bug fixing (Goldbach & Benlian 2015). As a result, levels of uncertainty may be bilaterally reduced if clan control is prevalent within the platform ecosystem.

*Hypothesis 4: Greater use of clan control reduces behavioural uncertainty in ecosystem relationships*

### ***Input Control and Behavioral Uncertainty***

A suitable formal control mechanism for the platform owner to govern the ecosystem is input control. It describes the degree to which platform owners control complementary apps by utilizing application and selection processes (Tiwana 2015a). Hence, not all complementary apps are admitted to the ecosystem. Input control keeps tabs on the admission to the ecosystem and allows the platform owner to guarantee interoperability, quality or the fit with the platform's interests, values, and positioning (Tiwana 2015b). However, from the perspective of a complementor it requires the monitoring of the platform owner's behavior as this control mechanism provides space for opportunistic behavior. Hence, the higher the level of input control the higher the level of uncertainty a complementor faces regarding the actions of the platform owner.

*Hypothesis 5: Greater use of input control increases behavioural uncertainty in ecosystem relationships*

### ***Decision Rights Delegation and Dependence***

Prior research in IS focused to a lesser degree on decision rights portioning as a control mechanism in platform governance, especially on the decentralization of such among actors in an ecosystem. However, the amount of coordination for interoperability relies on the extension architecture as well as the delegation of rights concerning the design and specifications of the third-party innovation (Langlois 2002). This partitioning of autonomy for the development of complementary extensions shifts a certain amount of power to the complementors in the ecosystem and therefore decreases the effect of modularization in reducing the complementor's dependencies with the platform owner during the development of complementary applications (Tiwana & Konsynski 2010).

*Hypothesis 6: Greater use of decision rights delegation reduces the dependence on the platform owner*

### ***Platform Specificity and Dependence***

Specificity refers to the transferability of a certain asset that is needed for transactions in a relationship (Rindfleisch & Heide 1997). Specific' assets are significantly more valuable in a particular exchange than within alternative partner relations and lead to a 'lock-in' effect to a certain platform. Specific assets for the ecosystem participation can be for instance, human assets, technological assets or knowledge about platform architecture, interface specifications and market characteristics. High levels of asset specificity and the related investment requirements create dependence between partners and leads to lock-in effects and increases switching costs making it difficult for the complementors to leave the actual ecosystem and move to another (Kude & Dibbern 2009). A high specificity of assets required for building complementary products therefore results for instance in high multi-homing costs (Armstrong & Wright 2007), i.e. the sum of costs for adopting, operating, and opportunity costs to maintaining

affiliation with a certain platform. Greater specificity of a platform therefore increases the complementor’s dependence on the platform owner.

*Hypothesis 7: Greater specificity of a platform increases the dependence on the platform owner*

## Research Methodology

### Data collection and Sample Description

In order to test our hypotheses we conducted an online survey hosted on [www.unipark.de](http://www.unipark.de). The sampling frame of our research consists of 750 firms equally distributed among the complementors of five leading cloud platforms (i.e. Microsoft Azure, Oracle Cloud Platform, Amazon Web Services, SAP HANA, and Salesforce Force.com). The platforms were chosen for two reasons. First, they are all well-established and have a solid traction among complementors. Second, due to their size and high level of power imbalance they perfectly meet our requirements for analyzing asymmetric co-innovation relationships and the corresponding risk.

Congruent with previous surveys of third-party innovators (Benlian et al. 2015), we utilized a web-crawling approach which randomly collected contact data from the platforms’ app stores. A link to the online questionnaire was sent via mail and recipients were asked to forward the questionnaire to high-level executives (C-level; IT executives) as key informants (Kumar et al. 1993). The invitation mail and the start page of our survey included the purpose of the study and ensured confidentiality and anonymity to the participants. Our sampling approach resulted in a total of N=42 valid cases (response rate: 5.6 percent), which is a common response rate in such settings. Although our sample size is relatively small it is sufficient for PLS. The most complex construct in our research model has four reflective indicators. Following the “10 times” thumb rule, which requires a minimum sample size of 10 times the most complex relationships within the research model (Chin 1998), our sample size is sufficient to get reliable PLS results. We assessed non-response bias by comparing response of early and late respondents did not significantly differ (Armstrong & Overton 1977). T-tests between the means of the early and late respondents did not reveal any significant differences ( $p > 0.05$ ), hence rejecting the presence of non-response bias in our study.

**Table 1: Sample Description**

Sample Descriptives					
Platform		Hierarchy		Working Experience	
AWS	4.8%	Project Manager	2.4%	< 3 years	2.4%
SAP	21.4%	Department Director	7.2%	3-5 years	-
Salesforce	42.9%	Business Unit Director	19%	5-10 years	14.3%
Oracle	9.5%	C-Level	71.4%	> 10 years	83.3%
Microsoft	21.4%				

Complementors in our study were distributed among all five platforms (Microsoft Azure: 9; Oracle Cloud Platform: 4; Amazon Web Services: 2; SAP HANA: 9; and Salesforce Force.com: 14). Most of our respondents were high-level executives (C-level: 71.4 percent; BU executives: 19 percent). Furthermore, participants in our sample indicated that they are highly experience in this topic (>10 years: 83.3 percent) and were experts in the context of our survey (95.2 percent) (see Table 1).

## Construct Operationalization and Scale Development

To ensure rigorous scale development and validation procedures, we used existing scales and adapted them for the purpose of our research where possible (Babbie 1990). All survey questionnaire measures except of “dependence” are multi-item measures with reliable scales and are measured on a 7-point Likert-scale. Furthermore, all latent constructs in the survey instrument were measured reflectively. The measures and their sources are shown in Table 2.

To assure the precise measurement of our constructs we discussed and defined the domain and dimensionality of the constructs. To asses content validity we furthermore used a qualitative pre-test with managers in the software industry to ensure that our items were interpreted unambiguously, which leads us to the minor adaption of some wording (Moore & Benbasat, 1991). Refined items were again evaluated in a pre-test to ascertain that our survey items were interpreted unambiguously.

For developing our construct of co-innovation risk we relied on the methodology of Lewis et al. (2005). To develop this organization-level instrument we build on an extensive literature review in this field and several interviews with managers in the software industry. We followed previous approaches to measure the risk of alliance (Das & Teng 2001) and adapted these items for the context of our study. Finally, the single items of our construct are justified by observations from practice, reviews of the literature as well as logic (Webster & Watson 2002).

**Table 2: Construct Measures**

Construct	Items	Anchor
<i>Co-Innovation Risk</i> (following Das & Teng 2001)	The platform provider may not always do things that it promises to do	1:Strongly disagree 7:Strongly agree
	The platform provider may not be fair in its dealings	1:Strongly disagree 7:Strongly agree
	The platform provider’s policies and programs may not benefit the ecosystem	1:Strongly disagree 7:Strongly agree
	The interests of the platform provider and the complementor may conflict in the ecosystem	1:Strongly disagree 7:Strongly agree
<i>Dependence</i> (Anderson & Dekker 2005)	How large do you estimate the dependence of your firm on the platform owner?	1: very low 7: very high

<p><i>Technological Uncertainty</i> (Walker &amp; Weber 1984; Stump &amp; Heide 1996)</p>	<p>The frequency of expected changes in specifications of the platform is high</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>The frequency of expected changes in specification of interfaces is high</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>The unpredictability of changes in technological requirements is high</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>The unpredictability of need for adaptations in the end product is high</p>	<p>1:Strongly disagree 7:Strongly agree</p>
<p><i>Behavioral Uncertainty</i> (Stump &amp; Heide 1996)</p>	<p>Evaluating the platform provider's performance is a highly subjective process</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>It is difficult to determine whether agreed upon quality standards and specifications are adhered to</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>It is difficult to determine whether the platform provider shares unlimited information about the platform</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>It is difficult to determine whether the platform provider is absorbing the complementors' critical knowledge</p>	<p>1:Strongly disagree 7:Strongly agree</p>
<p><i>Platform Specificity</i> (Heide &amp; John 1990)</p>	<p>Our engineering system has been tailored to using the particular architecture of this platform</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>Much specific technological know-how is required to effectively develop on this platform</p>	<p>1:Strongly disagree 7:Strongly agree</p>
	<p>The strategic importance of this business segment is high for our firm</p>	<p>1:Strongly disagree 7:Strongly agree</p>
<p><i>App Decoupling</i> (Tiwana 2015a)</p>	<p>Please assess the degree to which the relationship between your product and the platform is loosely coupled</p>	<p>1: no extent 7: high exten</p>
	<p>Please assess the degree to which the relationship between your product and the platform had a small number of interdependencies</p>	<p>1: no extent 7: high exten</p>
	<p>Please assess the degree to which the relationship between your product and the platform had minimal unnecessary interdependencies</p>	<p>1: no extent 7: high exten</p>
<p><i>Standardized Interfaces</i> (Tiwana 2015a)</p>	<p>Please indicate the degree to which the interface standards and protocols through which the extension interacts with the platform are clearly specified</p>	<p>1: no extent 7: high exten</p>
	<p>Please indicate the degree to which the interface standards and protocols through which the extension interacts with the platform are unambiguous</p>	<p>1: no extent 7: high exten</p>

	Please indicate the degree to which the interface standards and protocols through which the extension interacts with the platform are stable	1: no extent 7: high exten
	Please indicate the degree to which the interface standards and protocols through which the extension interacts with the platform are standardized	1: no extent 7: high exten
<i>Clan Control</i> (Kirsch et al. 2002)	Please indicate the degree to which your company clearly understood the platform provider's goals	1: no extent 7: high exten
	Please indicate the degree to which your company clearly understood the platform provider's norms	1: no extent 7: high exten
	Please indicate the degree to which your company clearly understood the platform provider's values	1: no extent 7: high exten
<i>Input Control</i> (Tiwana 2015a)	Please indicate the degree to which the platform provider sets criteria for approving new extensions	1: no extent 7: high extent
	Please indicate the degree to which the platform provider approves new extensions	1: no extent 7: high extent
	Please indicate the degree to which the platform provider verifies extension functionality	1: no extent 7: high extent
<i>Decision Rights Delegation</i> (Tiwana 2015b)	Please indicate the extent to which the platform provider is primarily responsible for decisions regarding app design*	1: no extent 7: high extent
	Please indicate the extent to which the platform provider is primarily responsible for decisions regarding user interfaces*	1: no extent 7: high extent
	Please indicate the extent to which the platform provider is primarily responsible for decisions regarding app implementation*	1: no extent 7: high extent
	Please indicate the extent to which the platform provider is primarily responsible for decisions regarding app functionality*	1: no extent 7: high extent
*reverse coded		

## Data Analysis and Results

To test our hypotheses we utilized structural equation modeling (SEM) (Gefen et al. 2000) with partial least squares (PLS). We choose the PLS approach for analyzing our data as it allows testing the measurement model (i.e., the psychometric properties of measurement scales) and the estimation of the structural model (i.e., the strength and direction of relationships between the variables) simultaneously. PLS provides an advantage over covariance-based methods (e.g., LISREL) by maximizing the explained variance of endogenous variables in the structural model that enables to understand the level of variance explained in the constructs and by not making any a priori distributional assumptions for the data (Chin 1998). Furthermore, this technique is well suited to explore relationships between latent variables in this new theoretical context

(Gefen et al. 2011). PLS results are robust also for a small sample size (Hair et al. 2012). For our analysis, we applied the open source software SmartPLS 3.2.3 (Ringle et al. 2015). This software allows for using a non-parametric bootstrapping method to examine the variables 't-statistic in order to calculate significance levels of predicted correlations. We therefore used the statistical software. For assessing the significance levels of the paths in our model, we applied a bootstrapping procedure with no sign changes and 5,000 resamples (Hair et al. 2012). We first assessed the measurement model and then tested the research hypotheses in a two-step approach.

### **Measurement Model Assessment**

To assess our measurement model, we analyzed the reliability, convergent validity and discriminant validity of all latent reflective constructs. To assess internal consistency reliability we examined Cronbach's alpha, which was above .869 for all constructs. We then evaluated convergent validity with the three criteria proposed by Fornell & Larcker (1981): (1) Factor must load significantly and exceed a threshold value of .70, (2) composite reliabilities should be above .80, and (3) the average variance extracted (AVE) exceeds the value of .50 (i.e. above the variance due to measurement error). Our results show that all item loadings were significant ( $p < .001$ ) and loaded above .784 (See Table 3). Furthermore, the composite reliabilities of all constructs exceeded .920 and all values for AVEs were above .725 (see Table 3). We can therefore conclude that all constructs in our study fulfill the norms for convergent validity.

**Table 3: Descriptive Statistics, Reliability, and Validity of Constructs**

		MEAN	Standard Deviation	Loadings Range	Cronbach's Alpha	Composite Reliability	Average Variance Extracted
1	App Decoupling	5.10	1.62	0.818-0.947	0.891	0.928	0.812
2	Behavioral Uncertainty	3.77	1.64	0.784-0.959	0.892	0.926	0.760
3	Clan Control	4.34	1.83	0.982-0.986	0.984	0.989	0.969
4	Decision Rights Delegation	5.10	1.62	0.830-0.877	0.874	0.913	0.725
5	Dependence	4.93	1.65	Single-item			
6	Platform Specificity	4.99	1.41	0.847-0.925	0.869	0.917	0.787
7	Input Control	4.27	1.82	0.922-0.970	0.946	0.965	0.903
8	Co-Innovation Risk	4.18	1.69	0.913-0.948	0.961	0.970	0.865
9	Standardized Interfaces	6.03	1.04	0.791-0.931	0.892	0.920	0.743
10	Technological Uncertainty	3.83	1.68	0.808-0.951	0.925	0.945	0.813

To assess discriminant validity, we followed the Fornell-Larcker criterion, which requires that the AVE's square root (bold cells) exceed the shared variance between a single construct and all other constructs within model (Fornell & Larcker 1981). The factor correlation matrix shows that all inter-correlations between latent variables are below the square root of the AVE (see Table 4).

Therefore, we can conclude that the constructs of our study represent theoretically as well as empirically distinguishable concepts. Finally, we performed Harman’s single-factor test to test for the threat of common method bias (Podsakoff et al. 2003). Our results revealed 8 factors that explain 85.59% of the variance. The first factor explained 35.58% of the variance and is therefore significantly below the critical threshold of 50%. Hence, one single factor could not account for the majority of the variance among variables in our model and our results consequently did not show any signs of common method bias.

**Table 4: Correlations and Average Variance Extracted**

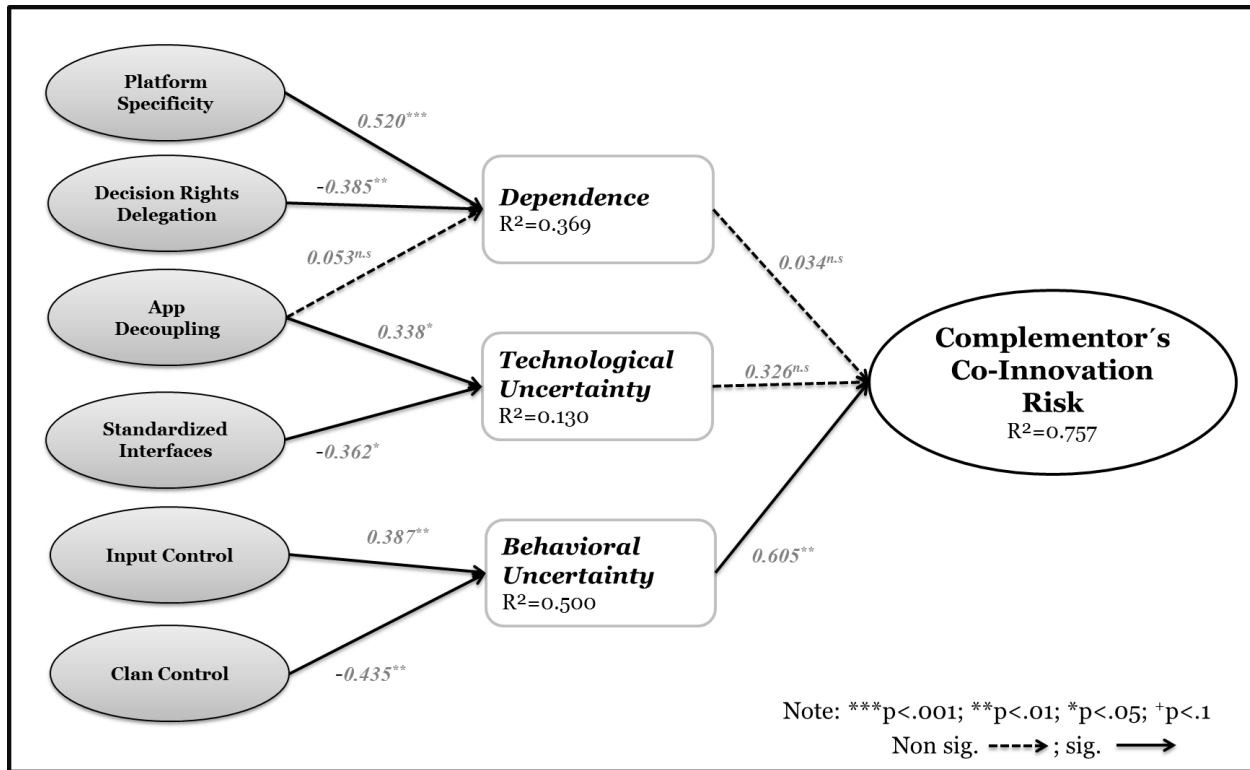
	1	2	3	4	5	6	7	8	9	10
1 App Decoupling	<b>0.901</b>									
2 Behavioral Uncertainty	0.090	<b>0.872</b>								
3 Clan Control	-0.021	-0.620	<b>0.984</b>							
4 Decision Rights Delegation	0.308	-0.140	0.043	<b>0.851</b>						
5 Dependence	-0.002	0.334	-0.549	-0.305	<b>1.000</b>					
6 Platform Specificity	0.108	0.388	-0.262	0.071	0.500	<b>0.887</b>				
7 Input Control	0.131	0.596	-0.479	-0.415	0.603	0.224	<b>0.950</b>			
8 Co-Innovation Risk	0.196	0.834	-0.712	-0.128	0.344	0.295	0.625	<b>0.930</b>		
9 Standardized Interfaces	0.471	-0.261	0.162	0.213	0.257	0.314	-0.012	-0.231	<b>0.862</b>	
10 Technological Uncertainty	0.167	0.668	-0.620	-0.157	0.331	0.308	0.612	0.741	-0.203	<b>0.902</b>

**Bolded cells: Square root of AVE**

### ***Hypotheses Testing***

Overall, our structural model was successful in explaining a considerable amount of variance in dependence ( $R^2 = .369$ ), behavioral uncertainty ( $R^2 = .500$ ) as well as co-innovation risk ( $R^2 = .757$ ) and a smaller portion of variance in technological uncertainty ( $R^2 = .130$ ). To test our hypotheses we analyzed the path coefficients in our structural model. We found a positive and significant effect of platform specificity on dependence ( $\beta = .520$ ;  $p < .001$ ) and of input control on behavioral uncertainty ( $\beta = .26$ ;  $p < .01$ ). Furthermore, we were able to identify a negative and significant effect of standardized interfaces on technological uncertainty ( $\beta = .362$ ;  $p < .05$ ), clan control on behavioral uncertainty ( $\beta = .435$ ;  $p < .01$ ) and decision rights delegation on dependence ( $\beta = .385$ ;  $p < .01$ ), while the effect of app decoupling on dependence was not significant ( $\beta = .053$ ;  $p > .10$ ). Consequently, we found support for our hypotheses H2, H4, H5, H6 and H7, while H3b was rejected. Contrary to our theoretical expectations, we found a significant and positive influence of app decoupling on technological uncertainty ( $\beta = .338$ ;  $p < .05$ ). Hence, H3a had to be rejected but a theoretically unexpected effect emerged.

Regarding the effects of the drivers of co-innovation risk on the actual perception of risk we were only able to identify a positive and significant effect of behavioral uncertainty on co-innovation risk ( $\beta = .605$ ;  $p < .01$ ), which supports H1c. However, the effect of technological uncertainty ( $\beta = .326$ ;  $p > .10$ ) and dependence ( $\beta = .034$ ;  $p > .10$ ) on co-innovation risk was not significant. Therefore H1a and H1b had to be rejected. The results of our model are displayed in Figure 2.



**Figure 2: Research Results**

Finally, we analyzed a full model including several control variables in order to control for alternative explanations as previous studies on risk mentioned the role of personal traits in influencing the perception of risk (e.g. Das & Teng 2001). However, neither complementor's experience in the software industry nor the level of hierarchy significantly influenced the perception of risk (all  $p > .001$ ). Therefore, the main results of our study remained robust.

## Discussion and Conclusion

Our primary objective in this paper is to analyze the drivers of co-innovation risk in platform ecosystems and its antecedents. In particular, we attempt to shed light on how the architecture of an application, different governance mechanisms introduced by platform owners as well as the specificity of a single platform facilitate or diminish our proposed drivers, which are likely to raise complementors' co-innovation risk. This paper therefore addresses a gap in recent literature by focusing on intra-platform dynamics (Tiwana 2015a) and the role of architecture, control mechanisms and decision rights portioning (Tiwana et al. 2013) in creating strategic outcomes. Table 5 displays that 6 of our 10 research hypothesis were supported by the empirical findings in our study.



**Table 5: Outcome of Hypothesis Testing**

<b>Hypothesis</b>	<b>Values</b>	<b>Sig.</b>	<b>Outcome</b>
<i>Hypothesis 1a: Greater dependence on the platform owner facilitate the complementor's co-innovation risk</i>	0.034	n.s.	not supported
<i>Hypothesis 1b: Greater technological uncertainty facilitates the complementor's co-innovation risk</i>	0.326	n.s.	not supported
<i>Hypothesis 1c: Greater behavioural uncertainty facilitates the complementor's co-innovation risk</i>	0.605	p<.01	supported
<i>Hypothesis 2: Greater standardization of interfaces reduces technological uncertainty</i>	-0.362	p<.05	supported
<i>Hypothesis 3a: Greater app decoupling reduces technological uncertainty</i>	0.338	p<.05	not supported
<i>Hypothesis 3b: Greater app decoupling reduces the dependencies with the platform owner</i>	0.053	n.s.	not supported
<i>Hypothesis 4: Greater use of clan control reduces behavioural uncertainty in ecosystem relationships</i>	-0.435	p<.01	supported
<i>Hypothesis 5: Greater use of input control increases behavioural uncertainty in ecosystem relationships</i>	0.387	p<.01	supported
<i>Hypothesis 6: Greater use of decision rights delegation reduces the dependence on the platform owner</i>	-0.385	p<.01	supported
<i>Hypothesis 7: Greater specificity of a platform increases the dependence on the platform owner</i>	0.520	p<.001	supported

The results of our analysis provide several interesting insights for both theory and practice. First, our results reveal the crucial role of behavioral uncertainty in driving co-innovation risk, while we were not able to identify empirical evidence for dependence and technological uncertainty in increasing such risk. Second, we were able to uncover that the platform owner (by balancing governance mechanisms) as well as the complementor (by applying different app architectures) are able to influence the amount of dependence, technological and behavioral uncertainty in platform ecosystems and hence also antecedents for co-innovation risk. Third, our data provides empirical evidence for app decoupling to increase the level of technological uncertainty. This finding seems counterintuitive and calls for further investigations.

All in all, we extend theory on platform ecosystems by contributing to previous work on factors that influence ecosystem dynamics (e.g. Tiwana 2015a&b). To extend current perspectives on risk, we analyzed different facets of platform specificity, control mechanisms and app architecture to provide a deeper understanding of how both a platform owner and a complementor can leverage mechanisms to reduce risk.

In the next steps we attempt to address several limitations of our work. First, we will enrich sample size to gather more valuable empirical insights. Second, we intend to provide a more comprehensive picture of risk related to co-innovation by examining different additional dimensions of risk (e.g. market-related, performance-related etc.). Third, further studies should put a focus on the interplay of app architecture and platform governance rather than examining them in separation.

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