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RESEARCH ARTICLE

A KNOWLEDGE-BASED MODEL OF RADICAL INNOVATION IN SMALL SOFTWARE FIRMS[1]

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Appendix A

Internet as Radical Innovation

Internet computing can be viewed as a radical IS innovation as follows:

(1) *Unique:* Internet computing added new elements into the existing computing architectures that significantly departed from existing alternatives. These included a universal thin browser and the idea of hyperlinking included in HTML (Lewin and Volberda 1999; Van Den Bosch et al. 1999). Firm-owned network-based systems with traditional user interfaces were insufficient substitutes for Web interface-based systems across the shared, world-wide infrastructure.

(2) *Novel*: The elements were organized using new architectural principles including open and universal access through URL resources (http) and an n-tier architecture, which separated data, business rules, access, and control flow. Knowledge of traditional systems patterns, languages, platforms, architecture, and designs provided little assistance in learning the prerequisite vast, volatile, and resource-intensive new skills for building Internet systems. This can be contrasted with a move from network to relational data base systems, which did not significantly change architectural principles, the types of applications being built, or how they were viewed or built; or the adoption of UML after SAD as a baseline for designing applications.

Appendix B

Response Accuracy and Sampling Bias

Response Accuracy

The *response accuracy* was checked (e.g., by answers to reverse items against their mirror counterpart items in the survey). For missing information, we sent a copy of the page(s) with missing items requesting respondents to complete the data set. To ensure consistency we sent not only the information about the missing items, but also their answers to other questions. We also made follow-up calls to verify some of their comments or suspicious answers.

Nonrespondent Bias

Nonrespondent bias was assessed by verifying that early and late respondents were not significantly different (Armstrong and Overton 1977). Following Pavlou and El Sawy (2006), a discriminant analysis compared the earliest 25 respondents and the latest 25 respondents in terms of the company demographics and responses on principal constructs. Wilk's Lambda was 0.96 ($p = 0.55$), indicating there was virtually no difference between the two groups. Random follow-up calls to 20 nonrespondents found three main reasons for their not participating in the study: they were too busy, not interested, or their company had a "no survey" policy. We concluded that there were no significant threats due to nonresponse bias.

Common Method Bias

We analyzed two sources for common method bias: (1) a single instrument of data collection and (2) the repeated use of identical wordings for "perceived radicalness" of each IT innovation type. Regarding the first source, we used Harman's single-factor test (Podsakoff et al. 2003) and found that the majority of data variance could not be accounted for by one general factor, suggesting no significant common method bias. Following Podsakoff et al. (2003), we also singled out a marker variable —base radicalness—as a surrogate for method variance by examining the structural parameters with and without this marker in our models. We found that all of the significant paths remained virtually unchanged. In addition, we used Lindell and Whitney's (2001) procedure to calculate the actual partial correlations (see Appendix G), and found that the statistical significance of the correlations among the predictors and between the predictors and outcome variables ($r_{Yi.M}$) remained unchanged after singling out the method variance, and the dis-attenuated partial correlations of all of the latent predictors with the outcome variables ($\check{r}_{Yi.M}$) are slightly higher than the corresponding first-order partial correlations ($r_{Yi.M}$). Thus, we conclude that the correlations among the predictors themselves and between the predictors and outcome variables cannot reasonably be accounted for by common method variance. We followed Podsakoff et al. to allow all the latent variables to load on their theoretical constructs and on an unmeasured latent method factor, and found that all of the items had higher loadings upon the traits than upon the method factor. These tests all suggest the lack of a common method bias.

To control for the second source, we asked the participants about their perceptions of each IT innovation type *immediately* after requesting them to identify specific innovations they had adopted in each type. In this way, we tried to proximally, temporally, and psychologically separate (Podsakoff et al. 2003) the measures by forcing the participants to mentally focus on the relevant innovation type. To test its effectiveness, we used the multitrait–multimethod (MTMM) model decomposing the data variance into *trait* (base, process, and service), *method* (improvement, revolutionary, breakthrough, replace, local), and *random error* components (Bagozzi and Yi 1990; Campbell and Fiske 1959). The loadings on the traits were higher than the loadings on the methods for items that were included in the final constructs, and all the trait loadings were greater than .30. The MTMM approach is "the strongest" of the tests depicted for common method variance (Podsakoff et al. 2003, p. 897); therefore, there was no significant indicator of common method bias due to the repeated measures for "perceived radicalness."

Appendix C

Construct Validation

We validated all of the constructs in terms of their face and content validity through 19 tape-recorded interviews of top experts in 7 SSFs in software and web development with a combined experience of over 100 years, as well as four Ph.D. students with extensive IT industry and consulting backgrounds (these responses from validation interviews were not included in the final analysis sample). Three additional faculty members with industry backgrounds were also consulted. As Petter et al. (2007) point out, expert panels are especially useful prior to data collection to establish the content validity of formative measures. Talk aloud protocols (Bolton 1993) were used during the validation. Participants talked aloud when filling out the questionnaire, and we observed their reactions to the questions and took notes. We also probed the participants for additional comments when they experienced difficulties identified by Bolton (1993), such as difficulty in understanding a question or retrieving answers. Items were continuously revised until participants made no additional requests for revisions and exhibited minimum processing difficulties.

In particular, we formulated the innovation items as neutral with regard to whether the innovations were either externally adopted (base innovation, process innovation, service innovation) or created internally (service innovation, process innovation). In the latter case, the wording of the items was purposefully selected so as not to reveal the source of innovation and thus bias the response toward externally adopted innovations.

To render the list of innovations complete, we added new items into the pool when interviewees mentioned new IT innovations that had not been included so far and tested them in subsequent talk-aloud interviews. We also deleted some items, when the interviewees indicated that they were not associated with the range of Internet technologies we studied. We continued until the inquiry about what items to include reached a saturation point. The cut-off point for inclusion was whether more than 50 percent of the interviewees said they had started to use the innovation after adopting Internet computing. By setting the cut-off point so high, we applied a conservative criterion, which guarantees that we examine widely adopted IT innovations.

Independent Variables and Mediators

Construct Measures	Loadings
Knowledge diversity: the degree of heterogeneity of knowledge and skills related to base and IT services.	
System platforms used: Mainframe; Client/server: Windows/XP; Midrange client/server: Unix (Solaris, Linux, HP-UX, etc). *Database technologies* used: hierarchical; object oriented; network; relational; Web-service (XML) *Application architectures* used: MIS/transaction processing; information retrieval/reporting/query; scientific/engineering/modeling/simulation; office automation/personal productivity/groupware; real-time/process control *Programming languages* used: COBOL; C++; Java; C-sharp (C#); other *Middleware* used: DCOM; .NET (e.g., Microsoft); Java J2EE (e.g., Websphere, Weblogic); other (php, pearl)	Formative
Knowledge depth: the depth and quality of expertise in base and IT services.	
Kdep Max (The level of internal technical expertise of your organization on this system platform/database system/application architecture/programming language/middleware, compared to peers to your industry)	Formative

Construct Measures	Loadings
Knowledge linkages: the scope and intensity of a SSF's channels to external actors with critical knowledge related to IT innovation.	
KL1 Our organization has strong relationships with leading technology vendors KL2 Our organization has strong relationships with the clients who are the leaders in applying cutting-edge technology in their industries KL3 Our organization has strong relationships with leading research universities	Formative
Experimentation: the degree of a SSF's engagement in trial and error learning leading to transformation and exploitation of new knowledge.	
EX1 We have several experimental technology projects.	0.81***
EX2 We often try out new technologies to build our systems/applications	0.85***
Ex3 We have several future oriented strategic alliances	—
EX4 Our organization is considered to be a leader in adopting new technologies	—
EX5 We often try out new processes to build our systems/applications	0.80***
Sensing: a SSF's ability to sense its environment and assimilate knowledge related to new technical opportunities.	
S1 We are often one of the first in our industry to detect technological developments that might potentially affect our business	0.8***
S2 We actively monitor technological changes in the environment that are likely to affect our business	0.77***
S3 We are often slow to detect changes in technologies that might affect our business [R]	0.78***
S4 We periodically review the likely effect of changes in technology on our business	0.64***
Customer Pressure: forces on a SSF from its customers in areas related to technologies adoption.	
CP1 Satisfying the needs of our major customers (internal or external) is an important factor in adopting new technologies	0.66***
CP2 Some of our major customers demand that we implement new technologies	0.82***
CP3 Our relationships with our major customers would have suffered if we had not implemented new technologies	0.9***

Dependent Variables

Number of Base Innovations

Has your organization adopted the following Internet-based technologies? Check *all* that apply.

☐ Uniform and ubiquitous clients (e.g., HTML browser) with multimedia capability that are platform independent
☐ Use of three-tier or higher level architecture
☐ Web services based on interoperability standards (e.g., XML, SOAP, UDDI, or WSDL)
☐ Peer-to-peer applications and protocols (e.g., groupware, or content ware)
☐ Application server middleware (e.g., Java Beans, CORBA, .Net, Java J2EE)
☐ Middleware protocols (e.g., CGI, ASP, JSP)
☐ Software patterns (e.g., broker and observer patterns)
☐ Ubiquitous services available at any terminal, anytime and anywhere across a multitude of often "unknown" client types (e.g., mobile or multi-channel web applications, WAP)
☐ Media-oriented services (e.g., video and graphics in web applications, or voice recognition and generation, VOIP)
☐ Open telecommunication services (e.g., wireless broadband services, 802.11.x, or TCP/IP v6)

Number of Process Innovations

Has your organization…. Check *all* that apply.

☐ Hired specialists in graphic design, or required existing staff to acquire such competencies
☐ Hired specialists in site branding, or required existing staff to acquire such competencies

☐ Hired specialists in telecommunications design, or required existing staff to acquire such competencies
☐ Used open source development
☐ Incorporated clients and other stakeholders into the development process (e.g., JAD sessions)
☐ Used external sources for developing solutions or carrying out development tasks (e.g., outsourcing/ offshoring)
☐ Used new specification models and techniques (e.g., agile development, extreme programming, UML variants for Web services, RUP)
☐ Bought software component libraries or frameworks in the market, instead of developing them in-house

Number of Service Innovations

Has your organization developed the following **e-business** applications for your clients (either internal or external clients)? Check *all* that apply.

☐ Intranet
☐ Web-based transaction-based data delivery
☐ Web-based periodic information delivery
☐ Web-based enterprise-wide document management and sharing
☐ Public web (e.g., external web presence)
☐ One-to-one marketing (e.g., rule-based and collaborative filtering, CRM)
☐ B2C order entry and customer management (e.g., ERP)
☐ Web-based R&D related knowledge management
☐ Business intelligence using Internet
☐ Extranet with business partners
☐ Electronic marketplace and exchange applications (e.g., Internet 2 or Manugistics)
☐ Electronic auctions
☐ Web-based Supply Chain Management (e.g., eCollaboration)
☐ Web-based logistic management systems

Manipulation Variable (* indicates dropped items)

Radicalness (adapted from Gatignon et al. 2002)

How radical the adopted innovations are:

Base

bRad1: These technologies were **major** improvements over previous technologies.
bRad2: These technologies were based on **revolutionary** changes in technology.
bRad3: These technologies were **breakthrough** innovations.
bRad4: These technologies have led to products that were difficult to replace or substitute using older technologies.*
bRad5: These technologies represented major technological advance (s) **within** the local contexts in which they were applied.*

Process

bRad1: These techniques/methods/approaches were **major** improvements over previous development practices.
pRad2: These techniques /methods/approaches were based on **revolutionary** changes.*
pRad3: These techniques /methods/approaches were **breakthrough** innovations.*
pRad4: These techniques/methods/ approaches have led to development outcomes that were difficult to replace or substitute using older methods/techniques/approaches.
pRad5: These techniques/methods/ approaches represented major methodological advance (s) **within** the local contexts in which they were applied.

Services

sRad1: These applications were **major** improvements over previous technologies.
sRad2: These applications were based on **revolutionary** changes in technology.
sRad3: These applications were **breakthrough** innovations.
sRad4: These applications have led to products that were difficult to replace or substitute using older technologies.
sRad5: These applications represented major technological advance (s) **within** the local contexts in which they were applied.*

Three factors constituting the knowledge base were conceptualized as formative constructs. Prior research has cautioned that misspecifications of formative measures as reflective lead to inflated Type I and II errors (Jarvis et al. 2003; Petter et al. 2007). Moreover, the indicators of the knowledge base factors are not interchangeable, as each focuses on a distinct aspect of the construct (Petter et al. 2007). For instance, a firm that scores high in knowledge diversity does not necessarily have deep expertise in all its areas. Therefore, instead of each item reflecting the construct, all indicators *together* determine the latent variable, suggesting a formative nature (Jarvis et al. 2003; Petter et al. 2007). We followed the established protocols (Diamantopoulos and Winklhofer 2001; Jarvis et al. 2003; Petter et al. 2007) to create the formative indices for knowledge diversity, knowledge depth, and knowledge linkages in PLS. The test for *construct reliability* revealed that knowledge depth in programming language has a VIF (variance inflation factor) of 3.43, larger than the desired level (3.0). This suggests a strong collinearity between the programming language item and other knowledge depth items (Diamantopoulos and Siguaw 2006; Petter et al. 2007). Because its influence on the latent construct could not be distinctly determined (Diamantopoulos and Siguaw 2006), knowledge depth in programming languages was dropped. To assess *construct validity*, we found that the weights of some items in knowledge diversity and knowledge depth were either negative or not significant. Following Fichman and Kemerer (1997), we eliminated one item with a negative sign (application architecture) in knowledge diversity. Since the content validity of the formative measures was previously established through expert panels (Diamantopoulos and Winklhofer 2001; Jarvis et al. 2003), and our theory suggested that additional removal of other items would omit essential parts of the construct, we followed Petter et al. (2007) by keeping the remaining nonsignificant items.

Construct	Indicator	Weight	Loading	T
Knowledge diversity	System Platforms	0.533***	0.815	3.964
	Database Technologies	0.435**	0.819	2.019
	Application Architectures	—	—	—
	Programming Languages	0.197	0.490	1.093
	Middleware	0.203	0.556	1.305
Knowledge depth	System Platforms	0.293	0.692	1.583
	Database Technologies	0.293	0.818	1.070
	Application Architectures	0.238	0.764	0.967
	Programming Languages	—	—	—
	Middleware	0.486***	0.774	2.606
Knowledge linkages	With Technology Vendors	0.443**	0.821	2.181
	With Clients	0.198	0.634	0.933
	With Research Universities	0.601***	0.849	3.624

***p ≤ 0.01; *p ≤ 0.05; *p ≤ 0.1

Indicator weights for formative measures

As shown in the table, knowledge diversity was reflected in a firm's expertise in systems platforms, database technologies, programming languages, and middleware. Knowledge depth was composed of a firm's expertise in system platforms, database technologies, application architectures, and middleware. Finally, knowledge linkages were measured by items referring to a firm's close relationships with technology vendors, lead clients, and research universities. Our items for knowledge diversity were consistent with those of Fichman and Kemerer. There were slight differences between our measure and the measure used by Fichman and Kemerer. We distinguished between knowledge diversity and depth while Fichman and Kemerer measured only knowledge diversity. We also included middleware as a new item. Therefore, the final items have sufficient breadth and face validity to capture the latent constructs.

Appendix D

Base Innovation Origins

Innovation Type	Source/Origin
Uniform and ubiquitous clients (e.g., HTML browser) with multimedia capability that are platform independent	Invented by Berner-Lee in CERN and Andreassen in University of Wisconsin (see http://en.wikipedia.org/wiki/Web_browser).
Use of three-tier or higher level architecture	Invented in the early 1990s in multiple places. See http://en.wikipedia.org/wiki/Multitier_architecture for details of sources.
Web services based on interoperability standards (e.g., XML, SOAP, UDDI, or WSDL)	Innovated and standardized by W3C in the late 1990s. See http://en.wikipedia.org/wiki/Web_services for details of sources.
Peer-to-peer applications and protocols (e.g., groupware, or content ware)	Early versions of distributed networks in late 1980s. Content based peer-to-peer in late 1990s. See http://en.wikipedia.org/wiki/Web_services for details of sources.
Application server middleware (e.g., Java Beans, CORBA, .Net, Java J2EE)	Invented in the middle 1990s by Sun, Microsoft, and OMG. See http://infolab.stanford.edu/~ullman/fcdb/jw-notes/middleware.html or http://en.wikipedia.org/wiki/Message-oriented_middleware for details of sources.
Middleware protocols (e.g., CGI, ASP, JSP)	Common gateway protocol (CGI) to integrate web pages and dynamic content in the data bases, developed in 1993 by W3C precursor. See http://en.wikipedia.org/wiki/Common_Gateway_Interface; Web application frameworks developed by Microsoft (ASP) or Java based developers (JSP) developed in the late 1990s. See http://en.wikipedia.org/wiki/ASP.NET and http://en.wikipedia.org/wiki/JavaServer_Pages for details of sources.
Software patterns (e.g., broker and observer patterns)	Developed in the 1995 by Gamma, Helm, Johnson, and Vlissides. See http://en.wikipedia.org/wiki/Design_pattern_%28computer_science%29 for details of sources.
Ubiquitous services available at any terminal, anytime and anywhere across a multitude of often “unknown” client types (e.g., mobile or multi-channel web applications, WAP)	Developed by WAP forum in 1997, extended by others. See http://en.wikipedia.org/wiki/Wireless_Application_Protocol for details of sources.
Media-oriented services (e.g., video and graphics in web applications, or voice recognition and generation, VOIP)	Multicasting. See http://en.wikipedia.org/wiki/MBone. Video/graphics in web made available in mid-1990s. See http://en.wikipedia.org/wiki/Internet#Services for details of sources.
Open telecommunication services (e.g., wireless broadband services, 802.11.x, or TCP/IP v6)	Open internet protocols since early 80’s, TCP/IP v6, around 1995. See http://en.wikipedia.org/wiki/Internet_Protocol_Suite for details of sources.

Appendix E

Mediation Testing Using the Shrout–Bolger Test and Fletcher Test

The Shrout and Bolger test does not assume that the chosen predictor alone significantly impacts the dependent variable. Therefore the test uses both bootstrap and bias corrected estimates to test for the significance of the mediation effect, has greater power, and yields more accurate Type I error rates for small and medium sample sizes (MacKinnon et al. 2002; Shrout and Bolger 2002). The procedure to test for mediation is (1) test the total effect of X → Y path (C); (2) test the direct effect of X → M path (a); (3) test the direct effect of M → Y path with X → Y held constant (b); (4) estimate the indirect effect of the X → M → Y path (a × b); (5) test the direct effect of X → Y path while including the mediator M in the model (c'); and (6) estimate the strength of mediation using the effect ratio a × b/C. Here, a × b/C is the mediated effect divided by the total effect. It reflects the percentage mediated (MacKinnon et al. 2002; Shrout and Bolger 2002). We only calculate the ratio for partial mediation, since the total effect C in partial mediation is not significant to begin with, and complete mediation implies a100 percent mediation.

This procedure allows us to distinguish among three types of mediated effects. Mediated effect and indirect effects are often used interchangeably but they are not conceptually the same (Mathieu and Taylor 2006; Preacher and Hayes 2004; Shrout and Bolger 2002). Mediated effects shed light on the nature of the relationships that exist between two variables x → y when the direct effect C is significant. By contrast, an indirect effect does not assume that there is a significant direct effect C. In this paper, we follow Shrout and Bolger (2002) and call indirect effects "distal mediation." Hence we distinguish three mediation types. First, *distal mediation* is where the predictor alone—absent a mediator—does not significantly impact the outcome variable (i.e., total effect C = not significant). In contrast, the indirect effect (a × b) is significant when the mediator is present. Second, *partial mediation* is where the predictor alone significantly impacts the dependent variable (C), and its impact remains significant after the mediator is introduced into the model (c'). Here, the indirect effect a × b is significant and the ratio (a × b/C) is less than 100 percent, which is reflected in the nonsignificant change from C to c', thus indicating that only part of the effect is mediated through the mediator. Third, *complete mediation* is where the predictor alone significantly and directly impacts the dependent variable (C), but its impact drops to nonsignificance after the mediator is introduced (c'), indicating that all of the impact is mediated through the mediator. In this case, the ratio (a × b/C) equals 100 percent, and is reflected in a significant change from C to c' (MacKinnon et al. 2002; Shrout and Bolger 2002).

Some of our hypotheses concerning the external path (HB1-3, HP1-3, and HS1-3) include two mediators in a chain (X → M1 → M2 → Y). Following Fletcher (2006) and Shrout and Bolger (2002), we use the following testing procedures: (1) test the total effect of X → Y path (C); (2) test each of the six direct effects, that of X → M path (a), M1 → M2 path (b), M2 → Y path (c), X → M1 path (e), and M1 → Y path (f); (3) estimate the indirect effect of X → M1 → M2→ Y path (abc + af + ec); (4) test the direct effect of X → Y path while including both mediators M1 and M2 in the model (c'); and (5) estimate the strength of mediation using the effect ratio (abc + af + ec)/C. Since our model is exploratory, for each direct path in step 2, we followed Fletcher's suggestions and held all other direct paths constant. This helps to reduce concerns of producing biased estimates of the indirect effect.

Following Shrout and Bolger, if the predictor alone— absent of any mediator—does not significantly impact the outcome variable (i.e., total effect C = not significant) but the total indirect effect (abc + af + ec) is significant, it is regarded a *distal mediation*. Note that Fletcher considers any indirect effect with multiple mediators as distal mediation. Here we adopted a more restricted definition following Shrout and Bolger and consider an indirect effect as distal only if there is no significant impact of the predictor X upon the outcome variable Y to begin with (total effect C is not significant). If both the total effect (C) and the total indirect effect (abc + af + ec) are themselves significant, the mediation could be either complete or partial: if e, f, and c' are each non-significant, it suggests a *complete mediation;* if these paths (e, f, c') are significant, then it suggests a *partial mediation*.

Appendix F

Correlation Matrix and Common Method Variance

		Knowledge diversity	Knowledge depth	Knowledge Linkage	Sensing	Experimentation	Customer Pressure	Size	Base Radicalness	Base	Process	Service
X1	Knowledge diversity	**NA**										
X2	Knowledge depth	0.61***	**NA**									
X3	Knowledge Linkage	0.37***	0.35***	**NA**								
X4	Sensing	0.39***	0.40***	0.36***	**0.83**							
X5	Experimentation	0.41***	0.28***	0.41***	0.40***	**0.87**						
X6	Customer Pressure	0.43***	0.14*	0.24***	0.16**	0.267***	**0.84**					
X7	size	0.18**	0.27***	0.25***	0.23***	0.07	0.14	**NA**				
M	Base Radicalness	0.09	0.12	0.12	0.19**	0.01	0.05	0.18*	**0.90**			
Y1	Base	0.35***	0.32***	0.17**	0.22***	0.26***	0.26***	0.09	0.20**	**NA**		
Y2	Process	0.45***	0.25***	0.31***	0.29***	0.41***	0.27***	0.20**	0.29***	0.61***	**NA**	
Y3	Service	0.47***	0.33***	0.16**	0.28***	0.24***	0.28***	0.20**	0.10	0.47***	0.55	**NA**
Common Method Variance Test Results (Lindell and Whitney 2001)												
$r_{Yi,M}$	Base	0.35***	0.31***	0.16*	0.21**	0.25***	0.25***	0.09				
$r_{Yi,M}$	Process	0.45***	0.24***	0.30***	0.28***	0.40***	0.26***	0.20**				
$r_{Yi,M}$	Service	0.47***	0.33***	0.16**	0.28***	0.24**	0.27***	0.19**				
$\check{r}_{Yi,M}$	Base	0.35	0.31	0.16	0.25	0.29	0.30	0.09				
$\check{r}_{Yi,M}$	Process	0.45	0.24	0.30	0.34	0.46	0.31	0.20				
$\check{r}_{Yi,M}$	Service	0.47	0.33	0.16	0.34	0.27	0.32	0.19				

*p < 0.10; **p < 0.05; ***p < 0.01.

Values on the diagonal are estimates of scale reliability; the correlation estimates reported are absolute values.

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