Fichman, R. and C.F. Kemerer, "Toward a Theory of the Adoption and Diffusion of Software Process Innovations", IFIP Working Conference on Diffusion, Transfer and Implementation of Information Technology, Pittsburgh, PA, October 11-13, 1993.

Toward a theory of the adoption and diffusion of software process innovations

R. G. Fichman and C. F. Kemerer[a]

[a]MIT Sloan School of Management, Bldg. E53-313, Cambridge, Massachusetts 02142-1347

Keyword Codes: D.2.2; D.2.9; K.6.1
Keywords: Software Engineering, Tools and Techniques; Software Engineering, Management; Management of Computing and Information Systems, Project and People Management

1. INTRODUCTION

It has become increasingly clear that no single, strongly predictive theory of innovation adoption and diffusion is likely to emerge. The variations in innovations (e.g., product versus process; administrative versus technical; incremental versus radical) and the adoption contexts in which they may be applied (e.g., individual versus organizational adoption; autonomous versus non-autonomous adoption decisions; competitive versus non-competitive adoption environments) are simply too great.

One response to this problem is to work at a higher level of abstraction and to identify general classes of explanatory factors or characteristic patterns related to adoption and diffusion of broadly defined innovations in broadly defined contexts. This can be useful for some purposes—particularly in assisting researchers who wish to avoid unintentional "reinvention" of diffusion concepts—and the literature contains several notable examples of this type of work [11, 13, 17, 21]. Another response is to narrow the focus to more specific innovations and contexts, and to develop a more strongly predictive theory centered around the *distinctive characteristics* of those innovations and contexts [2, 3, 14, 20]. This position paper, takes the latter approach, and, in particular, will argue that *software process innovations* (SPIs) (defined as a change to an organization's process for producing software applications, e.g., changes in tools, techniques, procedures, or methodologies) are distinguished by two characteristics—strongly *increasing returns* to adoption [1] and substantial *knowledge barriers* impeding adoption [2]. The combination of these two factors suggests that the study of the adoption and diffusion of SPIs across the internal IS units of large organizations will require new explanatory variables and knowledge of new patterns of diffusion. Some of the ideas in this position statement were originally presented in [8-10].

2. INCREASING RETURNS

Although it has been known for many years that increasing producer experience and economies of scale in production result in improved price/performance for most technologies over time, only recently have researchers explored situations where the more general phenomenon of *increasing returns* to adoption may be a primary driver of technology diffusion dynamics [1, 5, 7, 12, 14].

Arthur [1] provides a classification of five sources of increasing returns: 1) learning by using, 2) scale economies in production/learning by doing, 3) technological interrelatedness, 4) informational increasing returns, and 5) network externalities. We suggest that many SPIs are strongly subject to all five sources of increasing returns (see Table 1 below).

Increasing returns matter for the adoption and diffusion of SPIs because when increasing returns are strongly present, "critical mass" dynamics and associated factors which inhibit, promote or sustain bandwagons can become dominating considerations in understanding the overall rate, level, and pattern of innovation diffusion. For example, "excess inertia" can develop around an existing technology because of reluctance to leave a mature technological network and join an immature one [7], particularly when investments in the new technology are irreversible [6]; in extreme cases, an industry may become "locked-in" to an inferior technology, such as the QWERTY keyboard [6]. In addition, the degree of sponsorship and standardization, and the use of subsidies for early adopters can become critical in tipping the balance between competing technologies or in establishing a new one [7, 12]. For example, France's PTT established "critical mass" for the Minitel videotext service by literally giving away equipment to hundreds of thousands of heavy telephone users during introduction of the technology [18]. "Small events" such as widely publicized successes or failures, might also tip the balance between competing technologies [1].

Even in the absence of an obvious directly "competing" technology, it has been argued that managerial expectations about the future course of technological change of an innovation, its complements, and its substitutes can dominate the timing and outcome of the adoption decision [19]. In addition, a high degree of heterogeneity of interests and/or resources across adopters may be necessary for some technologies to "bootstrap" to "critical mass" [14]. Christensen argues that this is what happened in the hard disk drive market, where the demand for smaller, less expensive drives for use in smaller computers provided the production volumes required for the 5.25 inch, and later the 3.5 inch diameter formats to sufficiently improve recording density so as to displace 8 and 14 inch formats even in larger computers [4].

3. KNOWLEDGE BARRIERS

All organizational innovations require some measure of organizational learning if they are to be adopted. However, some innovations—what Attewell [2] has termed "complex organizational technologies" (e.g., material requirements plan-

Table 1
Sources of Increasing Returns (Adapted from Arthur [1])

Source	Explanation	SPI Example
1. Learning by Using	By employing new technologies in a variety of production settings, users engage in a process of learning about how the technology can be best applied and improved, and this learning gets funneled back to producers and mediating institutions as an important source of product improvement ideas.	Early adopters of "upper" CASE tools have learned that it is not feasible to develop a detailed, global enterprise model as a discrete project, and that more selective and/or incremental approaches are more likely to be successful.
2. Economies of Scale/ Learning by Doing	Wider adoption provides vendors with benefits of scale and experience that get translated into better price/ performance (thus promoting further adoption by users) and/or higher unit margins (thus promoting further adoption by producers).	Later vintages of leading fourth generation languages have had superior machine performance compared with early vintages.
3. Technological Interrelatedness	Widespread adoption of a "core" technology (e.g., autos) frequently triggers the emergence of "infrastructure" technologies that substantially improve the utility of the core technology (e.g., service stations, refineries, highways).	Widespread adoption of relational databases led to the availability of compatible database design methods and tools, a variety of language interfaces, and even dedicated database machines for high performance applications.
4. Informational Increasing Returns	As a technology becomes more widely adopted, it becomes better known and understood (e.g., uncertainty is lowered).	The burgeoning popularity of object-oriented programming has lead to an explosion of materials (articles, books, conferences, etc.) explaining the technology and extolling its benefits.
5. Network Externalities	Simply belonging to a larger network of users can offer advantages, independent of the other sources of increasing returns.	Adopters of popular CASE tools benefit from a wider variety of application templates, greater availability of trained staff, larger user groups etc.

ning)—fall on the extreme end of the spectrum in terms of the burdens they place on would-be adopters in obtaining the knowledge needed to understand, implement and assimilate the innovation.

Attewell argues this is true of technologies that, when first introduced, 1) have an abstract and demanding scientific base, 2) are "fragile" in the sense that they don't always operate as expected, 3) are difficult to trial in a meaningful way, and 4) are "unpackaged" in the sense that adopters can not treat the technology as a "black box," but must acquire broad tacit knowledge and procedural know-how to use it effectively [21]. All of this describes most SPIs; in fact, we suggest that SPIs are exemplars of the kinds of "complex organizational technologies" Attewell had in mind, although his study focused on "business computing" in general (see Table 2 below).

Attewell argues that when innovations initially impose a heavy knowledge burden, diffusion is better conceptualized as a process driven by lowering knowledge barriers over time than as a process of communication and social influence (as per classical diffusion). Relationships between suppliers and users will go beyond selling, and will become structured around the task of reducing knowledge hurdles. Mediating institutions that specialize in creating and accumulating technical know-how, such as consulting and service firms, will come into existence and will effectively capture economies of scale in learning. Many organizations, rather than adopting the innovation directly, will obtain the benefits of the technology indirectly as a service, with a transition to self-service occurring more gradually over time.

4. PROPOSED RESEARCH DIRECTIONS

As discussed above, increasing returns and knowledge barriers, each viewed separately, may have important implications for the study of SPI adoption and diffusion. Accordingly, a fruitful line of research could be built around confirming the expected roles of increasing returns and knowledge barriers. We are most intrigued, however, about how these two characteristics might interact, and the possibility of generating additional theory related specifically to innovations like SPIs where both characteristics are strongly present. We present an outline of four components of such a theory below.

First, when a technology is strongly subject to increasing returns, then it necessarily follows that a wide discrepancy will exist between its *initial performance* (defined as the performance an average adopter is likely to achieve with a technology during its first few years of commercial availability, including not only productivity improvements or decrements, but also amortized conversion, adaptation, learning, and disruption costs) and its *network potential* (defined as the hypothetical future performance a technology would provide if it were to become universally adopted by the network of users, suppliers, and mediating institutions). In fact, we believe that because of knowledge barriers, most organizations will find the initial performance of most SPIs to be lower than pre-existing best practices. In other words, increasing returns are not simply

Table 2
Technology attributes associated with high knowledge barriers

Technology Attribute	Explanation	SPI Example
1. Scientific base	Technologies with an abstract or demanding scientific base, or that are not physically observable, are more difficult to explain and require a more active and prolonged learning period on the part of users in order to grasp and deploy them.	Early adopters of structured design were confronted with a daunting array of new design principles and techniques, the use and benefits of which could not be physically observed.
2. Fragility	Technologies with core features that must be replicated exactly to get expected results, or where performance in the laboratory is a poor predictor of performance in the field, create uncertainty for users and require more resources and "hand holding" during deployment.	Getting adequate performance from early relational databases required subtle tradeoffs between normalization and denormalization during logical design, and sophisticated selection and tuning of indexes during physical design.
3. Trialability	Technologies that can not be easily installed in stages and still obtain benefits effectively require that organizations compress all learning about the technology into a pre-implementation phase. Also, large scale implementations require inherently greater implementation expertise than small ones.	According to proponents of object orientation, to obtain expected benefits from object oriented programming organizations must simultaneously adopt object oriented analysis and design, and then build up a library of reusable components; this is expensive, takes time, and impacts most IT job categories.
4. Packaging	When the subcomponents of a technology can not be tightly bundled into a turnkey product that can be introduced into organizations unchanged, users are confronted with learning the operational details of each component and their potential interactions.	Successful adoption of integrated CASE tools involves developing expertise in many related components, including: underlying analysis and design methodologies; technical use of the tool; procedures governing how and when the tool is used; and design of project teams.

a bonus for adopting firms, but *must* occur for most SPIs to become worthwhile innovations over the long term.

Second, we believe that these increasing returns will be driven more by rates of *assimilation* than by rates of simple *adoption*. Past studies of innovation diffusion have focused almost exclusively on the phenomenon of adoption, which is typically defined as physical acquisition of technical artifacts, or as a "commitment" (psychological or financial) to implement the innovation. Yet, in the case of SPIs, the more telling question may be whether the innovation ever becomes fully assimilated within organizations, where assimilation might be defined as state of widespread, routinized, and/or effective use [15, 16, 22]. Obviously, adopters of SPIs must assimilate them if they are to get benefits themselves. But beyond this, organizations that do not assimilate an SPI will not be engaging in a vigorous process of learning by using; they are unlikely to buy the additional licenses, upgrades or add on products and services that sustain economies of scale and learning by doing for producers; they are unlikely to buy complementary products that support the innovation's infrastructure; they are unlikely to have a useful story to tell other adopters about how to make the innovation work; and they will not be contributing to the emerging network of trained employees, user groups or other network-related resources. Previous experience with SPIs (e.g., CASE tools) suggests that assimilation need not follow adoption.

Third, we believe SPIs will be especially prone to an *assimilation gap* (a large gap between the rate of adoption and the rate of assimilation across the same population of potential organizational adopters) during its *early adoption cycle* (i.e., the first few years following commercial introduction where uncertainty about the future of the technology is high). During the early adoption cycle, stakeholders intensely sell a vision of an innovation's main features and benefits based on what it will be like to use the technology in the future not the (largely unknown) practical realities of currently available vintages. Many organizations who rapidly adopt based on this positive vision, may be unable to assimilate the SPI. This is because the organizational knowledge needed to generalize, scale up and institutionalize a technology (assimilation) dwarfs the knowledge needed to evaluate and acquire the technology (adoption). In addition, while organizations can partially offset knowledge barriers during initial projects by using small teams of talented people, selecting favorable applications and users, hiring external consultants, etc., eventually adopters must reach the point where *average* employees can use the technology effectively on larger projects for genuine assimilation to have been achieved.

Fourth, we believe that when a large assimilation gap occurs during the early adoption cycle, a *stalled bandwagon* (defined as a situation where "critical mass" is not achieved, and both adoption and assimilation plateau at levels far short of what was originally expected or would have been "optimal" based on the network potential of the innovation) will usually follow, because slow or failed assimilation among early adopters delays the learning by using and other forms of increasing returns needed to make the SPI attractive to a mass market of potential adopters. Although we believe a stalled bandwagon is most likely to occur in these situations, we can imagine instances where robust and innovative institutions for lowering knowledge barriers might be able to overcome a large assimilation gap, resulting in a *sustained bandwagon* of adoption and assimilation. That is, heavy speculative investments in learning by doing and learning by using among vendors, sponsors, and mediating institutions, together with technology standardization and sharing arrangements might sometimes lower knowledge barriers sufficiently, even in face of initial assimilation problems, to provoke a sustained bandwagon.

5. CONCLUSIONS

To summarize, our basic argument is as follows:

1) SPIs are strongly subject to all five sources of increasing returns to adoption, meaning there is a wide disparity between initial performance of the innovation and the network potential of the innovation.

2) SPIs, when first introduced, also have attributes which impede deployment: they are highly abstract and scientific, fragile, difficult to trial, and unpackaged. This means they impose a substantial knowledge burden on would-be adopters.

3) When we put (1) and (2) together we get an interesting situation where SPIs have high network potential, but when first introduced, high adoption barriers and low performance relative to current best practices.

In such a situation, we believe a new conception of diffusion dynamics is called for where new explanatory variables (e.g., sponsorship, standardization, expectations, adopter heterogeneity, institutions for lowering knowledge barriers), and new patterns of diffusion (e.g., assimilation gaps, stalled bandwagons) may become central to understanding and modeling adoption and diffusion.

REFERENCES

1. Arthur, W. B. (1988) "Competing Technologies: An Overview." In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds.), *Technical Change and Economic Theory,* London: Pinter Publishers, 590-607.
2. Attewell, P. (1992) "Technology Diffusion and Organizational Learning: The Case of Business Computing." Organization Science, 3, 1, 1-19.
3. Barnes, D. J.; Buckland, B. K.; and Brancheau, J. C. (1992) "Methodological Issues in Emerging Technologies Research: Experiences and Recommendations." *Proceedings of the Twenty-Fifth Annual Hawaii International Conference on Systems Sciences.* Hawaii, 325-336.
4. Christensen, C. M. (forthcoming) "Exploring the Limits of the Technology S-Curve." *Production and Operations Management.*
5. Cusumano, M. A.; Mylonadis, Y.; and Rosenbloom, R. (1992) "Strategic Maneuvering and Mass-Market Dynamics: The Triumph of VHS Over Beta." *Business History Review.*
6. David, P. A. (1985) "Clio and the Economics of QUERTY." *American Economic Review, Proceedings,* 75, 332-337.

7. Farrell, J.; and Saloner, G. (1987) "Competition, Compatibility and Standards: The Economics of Horses, Penguins and Lemmings." In H. L. Gabel (eds.), *Product Standardization and Competitive Strategy*, North-Holland: Elsevier Science, 940-955.
8. Fichman, R. G. (1992). "Information Technology Diffusion: A Review of Empirical Research", *Proceedings of the Thirteenth International Conference on Information Systems*, Dallas, 195-206.
9. Fichman, R. G.; and Kemerer, C. F. (1992) "Object-Oriented and Conventional Analysis and Design Methodologies: Comparison and Critique." IEEE Computer, October, 22-39.
10. Fichman, R. G.; and Kemerer, C. F. (1993) "Adoption of Software Engineering Process Innovations: The Case of Object Orientation." *Sloan Management Review*, 34, 2, 7-22.
11. Gatignon, H.; and Robertson, T. (1985) "A Propositional Inventory for New Diffusion Research." *Journal of Consumer Research*, 11, 3, 849-67.
12. Katz, M. L.; and Shapiro, C. (1986) "Technology Adoption in the Presence of Network Externalities." *Journal of Political Economy*, 94, 4, 822-41.
13. Kwon, T. H.; and Zmud, R. W. (1987) "Unifying the Fragmented Models of Information Systems Implementation." In J. R. Boland, and R. Hirshheim (eds.), *Critical Issues in Information Systems Research*, New York: John Wiley, 227-251.
14. Markus, M. L. (1987) "Toward a 'Critical Mass' Theory of Interactive Media: Universal Access, Interdependence and Diffusion." *Communications Research*, 14, 5, 491-511.
15. McKenney, J. L.; and McFarlan, F. W. (1982) "The Information Archipelago—Maps and Bridges." *Harvard Business Review*, September-October, 109-119.
16. Meyer, A. D.; and Goes, J. B. (1988) "Organizational Assimilation of Innovations: A Multilevel Contextual Analysis." *Academy of Management Journal*, 31, 4, 897-923.
17. Rogers, E. M. (1983) *Diffusion of Innovations*. New York: The Free Press, (3rd edition).
18. Rogers, E. M. (1992) "The 'Critical Mass' in the Diffusion of Interactive Technologies in Organizations." In K. L. Kraemer, J. I. Cash, and J. F. Nunamaker (eds.), *The Information Systems Research Challenge: Survey Research Methods, Volume 3*, Boston: Harvard Business School Research Colloquium.
19. Rosenberg, N. (1976) "On Technological Expectations." *The Economic Journal*, 86, September, 523-535.
20. Swanson, E. B. (1991). "Information Systems Innovation Among Organizations", Anderson Graduate School of Management, UCLA Working Papers, August.
21. Tornatzky, L. G.; and Eveland, J. D. (1990) "The Deployment of Technology." In L. G. Tornatzky, and M. Fleischer (eds.), *The Processes of Technological Innovation*, Lexington, Massachusetts: Lexington Books, 117-148.
22. Zmud, R. W.; and Apple, L. E. (1989) "Measuring Technology Incorporation/Infusion." *Journal of Product Innovation Management*, 9, 148-155.