National Science Foundation Proposal

Information Value, Productivity And Property Rights

by

Marshall W. Van Alstyne
Assistant Professor
University of Michigan

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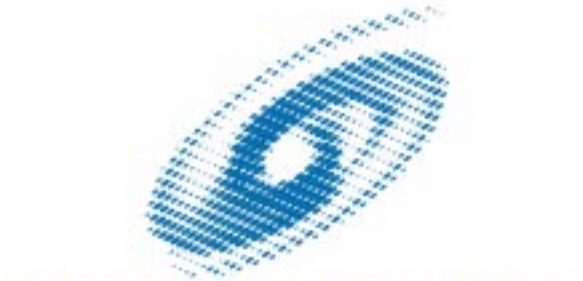

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Career Development Plan: Research and Education Overview

The developed world is rapidly transitioning from the industrial age to the information age (Drucker '88). While significant developments in information technology and management have been demanded -- and therefore supplied -- to keep managers, organizations and governments one step ahead of explosive growth, it has proven difficult to take the longer view, and ask whether the theory and practices developed over a century for use in an industrial economy -- with tangible goods -- still accurately apply to an information economy based on information and therefore intangible goods.

This career development plan seeks to address the widening gap between the needs of an information economy and the body of existing research and theory through a combination of computer, economic, and organizational treatments of information. The importance of this work is highlighted by a national Research Council publication, which argues traditional engineering disciplines need to "increase contact ... with other disciplines ... [and] increase traffic ... among academics, industry, and society at large" [NRC, 1992 p. 141]. Research from this proposal will address the critical questions facing organizations in the new economy, such as (1) how to manage information assets within and between firms, (2) how to price information goods when distribution and duplication are no longer significant factors, and (3) how to value a firm's information assets when evaluating a sale or acquisition.

This work also seeks to address the organizational and social implications of information sharing: (1) under what conditions does sharing of information increase productivity, and what are the implications for access and organizational design? (2) Does centralized control facilitate standardization at the expense of flexibility and innovation? (3) When should a firm maintain a monopoly for competitive advantage -- or share that information for collaborative gain?

The need for a rigorous exploration of information economic theory is also demonstrated by the unique properties of information goods. Unlike tangible goods, information is non-rival, it is abstract, it exhibits non-monotonicity, and it is subject to the "inspection paradox" -- a prospective buyer cannot examine an information good prior to purchase without acquiring its value through the process of inspection.

This proposal outlines a five-year integrated program of research and education to investigate critical questions, teach and mentor students, and engage colleagues on these issues.

Research projects are proposed along three main themes: how to determine and measure *information value*, how to evaluate and increase *information productivity*, and how legal mechanisms impinge on organizational and social policy questions of sharing information and other *intellectual property*. Each contributes to better information design practices along managerial or social policy dimensions.

Educational projects are proposed to develop a new program to teach these issues, to involve students in practical engagements as well as research, and to develop joint degrees between the School of Information and schools of computer science, business, and public policy.

The University of Michigan School of Information (SI) is an ideal environment to conduct and support this research. SI's philosophy is integrative and inter-disciplinary, and faculty colleagues have been assembled from the disciplines of computer science, economics, cognitive psychology, information science, archives management, and law. I have contributed to the development of a new graduate study track within the school, the Information Economics, Management and Policy (IEMP) program, and have been encouraged to pursue joint ventures with other university departments.

(734) 647-8028, mvanalst@umich.edu

1. Research Activities

The three research activities – on information value, information productivity, and intellectual property – contribute different perspectives to a long term program on the advancement of information economics. The first study contributes a theoretical perspective on how to measure and value a critical resource that is often overlooked in the traditional economic accounting of land, labor, and capital. Balancing this academic focus, the second study provide an empirical perspective by attempting to gather data on information management practices and statistically evaluate their contribution to business productivity. Intel and Lotus have endorsed this work as important to improving business practice. The third study seeks to contribute to governing structures in intellectual property law that might promote both innovation and distribution in the software market, in contrast to proposals that have tended to focus on one or the other. An expression of support for this research is included from the President of the Software Patent Institute, who also served as an expert witness in such landmark cases Apple Computer v. Microsoft, Lotus v. Paperback Software and Lotus v. Borland. Contributions thus span academic theory, business application, and social welfare aspects of information economics.

A. Project Objectives and Rationale

INFORMATION VALUE

The goal of this research is to provide a modest improvement in the measures of information value by combining computational and economic models of information. Traditional tools from decision theory have difficulty expressing the value of many goods that we commonly think of as information – software, blueprints, musical scores, and process know-how, for example – in a managerially useful way. The significance is that both capital markets and day-to-day management decisions might benefit from having better tools for evaluating information assets that have typically been left off the balance sheet for lack of tools.

The proposed approach is to augment the traditional Bayesian model of information used in economics with a procedural model of information contributed from computer science. Economic models contribute key concepts of utility and time dependent discounted value. Information is represented as a reduction in uncertainty, a declarative statement about the state of the world. In contrast, computational models represent information both declaratively and procedurally: information may represent both a reduction in uncertainty and an instruction, interpreted as a directive for action. This information model is used both in the computational process steps of a Turing Machine and in stored data computers that use the same representation for op-codes as for data. The benefits can be seen by considering the basic models.

A traditional Bayesian model (cf. Blackwell ‘52, Arrow ‘86, McGuire, ‘86, Laffont ‘90) represents information as a signal on the prevailing state of nature for which an associated probability indicates the level of certainty that the signal is accurate. Typically, a decision maker queries their environment to learn the prevailing state condition and, upon receiving a signal, he or she updates prior beliefs. Based on his or her new beliefs, a decision maker then decides on the best course of action. Multiple signals merely help beliefs converge (or diverge) on greater (or lesser) degrees of certainty about the prevailing state condition, before the decision maker takes some action.

Under the new representation, let information be represented not just as a (state) partition but as a (state, action, state) partition tuple for which an associated probability indicates the level of certainty for successfully moving between states. It can be shown that this model easily represents

the standard Bayesian model by allowing the possibility of null actions (Alstyne '97). The benefit, however, is that a decision maker now has the capability to move through multiple states, not merely to describe the current one. Multiple signals can change the posterior distribution of beliefs but they can also give directions for producing useful outcomes.

The fundamental insight is that by treating information as a chain of instructions, it is possible to view the decision to use it as an option for arriving at a particular result. If the chain of instructions represents a literal option on an outcome – a procedure invoked by a decision maker when it is valuable to do so – then the value of choosing to act on the chain can be estimated using options theory (Black & Scholes, 1973; Merton, 1973; Pindyck, 1993). The knowledge provides a claim on an outcome, a type of resource, for which the right to execute has value. In particular, it has option value. The proposal is thus to use a procedural model of information from computer science and an option model from economics to develop indices of information value. The information "good" can then be valued much the same as if it were a financial "good."

Through this line of reasoning, it is possible to employ the standard hedonic methods, used in marketing for valuing numerous kinds of basic goods (Kotler, 1988). These methods were originally developed for use with automobiles (Court, 1939) but have since contributed much to consumer value theory (Lancaster, 1966) and been applied to a wide range of consumer goods. Given a set of attributes, or hedonic features, value is assigned to each one as in the case of safety, mileage, and acceleration for cars. The manner in which the proposed theory differs from a more traditional hedonic approach, is that the bundle of characteristics used to set value is assigned not to the resource itself but to the states on which the resource provides a claim. It therefore gains leverage by examining the nature of the outcomes rather than the nature of the resource – a problem that has proven notoriously difficult for information.

A typical information problem is that of records management. As data gathering increases, both corporations and universities face a serious difficulty in deciding what to keep and what to cull. Seldom used but crucial data may ultimately have more value than frequently used but peripheral data. An option model, that accounts for variability in data value (standard deviation on hedonic features), delay time until it's needed (exercise date), the cost (or strike price) of using it, and the implicit opportunity cost (or interest rate), may usefully articulate these tradeoffs to decision makers. By treating information as an option, this theoretical framework may offer significant applications value to firms, libraries, universities, and governments. The problem of value becomes more tractable as principles of options theory used in financial management can be adapted for use in information management.

Moreover, in addition to improving our understanding of the information value problem, the combined framework offers at least two supplemental benefits. The classical economic models of information generate interesting problems in inspection and monotonicity.

The inspection paradox is that the "value for a purchaser is not known until he has the information but, then, he has in effect acquired it without cost" Arrow (1962, p. 615).1 Having examined the information, a buyer learns its content and cannot in good faith return it while claiming to know nothing of what he has seen. Moreover, if a buyer had perfect prior knowledge, he would have no need of the information purchase. The inspection paradox then contributes to market failure as numerous welfare enhancing transactions fail to occur.

A procedural framework provides an alternate basis for avoiding this difficulty. Engaging the information resource to produce a desired outcome provides evidence of its existence. To the extent that buyers can observe outcomes while instruments remain obscure, sellers have an opportunity to market their information with reduced fear of disclosure. Drinking a Coca-Cola, for

1 Arrow characterized this as the problem of "demand determination."

example, provides very little insight into the formula used to produce it. Distinguishing between the product and information markets, a seller might offer either the product or the information for sale, so long as the product does not make explicit the manner in which it was produced. This sales strategy is not available under a traditional Bayesian framework. In that case, the outcome is a posterior distribution of beliefs which, if revealed, is sufficient for buyers to infer summary statistics for whatever quantity of signals is to be sold. Under the alternative framework, competitors may witness results but not necessarily methods or processes.

Similarly, if information is treated solely as a reduction in uncertainty, then the value of specific information depends non-monotonically on what else is known. Receiving more data can invalidate previously useful data or make invaluable that which was previously obscure. This non-monotonicity problem implies that quantity is orthogonal to value: More data can make a decision-maker better or worse off. Adding instructions to a Bayesian signal model, however, it is possible to cause individual signals to exhibit non-monotonicity – to rise or fall in value as they become important or obsolete – and yet the total knowledge base exhibits value monotonicity as the capabilities of the decision maker expand in what they learn (Alstyne, 1997). Learning a computer language, for example, enables a programmer to instruct a surrogate, in this case a computer, to perform useful tasks on his or her behalf. The expanded process model allows a decision-maker not only to change their level of uncertainty but also to influence their space of opportunity.

Finally, this research represents a useful complement to the empirical proposal that follows in that the derived measures and information value metrics may be correlated with indices of productivity.

INFORMATION PRODUCTIVITY

Almost every major consulting firm offers a variation on IT benchmarking to help companies position themselves along a spectrum of investment levels and to gauge the efficacy of their IT investments. Despite the perceived importance that such ubiquitous offerings imply, general evidence for any productivity enhancements did not appear until 1996 (Brynjolfsson & Hitt). The continued absence of productivity evidence in the face of high investment was even characterized as a "productivity paradox" (Strassman 1990, Berndt & Morrison 1991, Brynjolfsson 1993, Loveman 1994, Landauer 1995).

Even the statistically significant studies, however, have tended to provide evidence that IT investments *do* enhance productivity rather than suggesting *how* they enhance productivity. Decisions at the managerial level have generally not had the benefit of statistical support for judging which practices actually boost output.

The purpose of this study is to gather and test data at a large number of business units to uncover information management practices that contribute to productivity at statistically significant levels.

Gathering internal data on actual practice should provide distinct advantages in three areas. (1) Instead of attending to how *technology* influences productivity, it would attend to how *information management* practice influences productivity. A majority of the literature examining the productivity of IT considers whether the adoption of the technology per se (and not management practice) influences corporate output. (2) It would use novel measures of information usage and access that have recently been developed including measures of balkanization developed for the dissertation research of the PI and published in *Science* (Alstyne & Brynjolfsson, 1996) and measures of connection length and clustering published in *Nature* (Watts & Strogatz, 1998). Information value metrics developed from the first research project could also be used to guide the empirical study so that the first and second projects are reciprocally beneficial. Then finally, (3) data would be gathered by monitoring actual information flows in systems in addition to gathering

data from financial statements and interviews. Accounting statements, the traditional source of productivity data, typically provide less direct evidence of how organizations use information than system level measures. In addition, interviews should provide a rich context to explain how information systems were used.

Initial hypotheses would examine, for example, do balkanized and decentralized database systems reduce output? Does universal intra-organizational access matter? Do corporate-wide standards foster access and thus output? Do incentives that promote information sharing result in more internal data capture? Does external data capture complement internal data capture? Does data mining actually increase output? Do organizations investing in modeling and simulation gain from their investments?

In addition, the search for hypotheses can be guided by recent modeling completed in conjunction with the PI's dissertation research. Relative versus absolute incentives, for example, tend to motivate more competitive versus more cooperative information sharing. Although derived from an axiomatic model, the intuition is motivated by a case study on groupware showing that in a competitive up-or-out environment, junior consultants refused to put information into the groupware system for fear of losing strategic advantage (Orlikowski, 1992). In contrast, senior consultants were rewarded on the absolute performance of the firm. There an open environment of information sharing prevailed. Hypothesis testing will therefore examine combinations of incentive structures and information sharing behaviors that influence profitability.

Using theoretical research on contracts (Grossman & Hart, 1986; Hart & Moore, 1990), the PI has also modeled the incentives to invest in information systems when control is centralized versus decentralized (Alstyne, Brynjolfsson & Madnick, 1995). This research predicts that local business units will invest more in local data gathering when control is decentralized rather than centralized. Whether this occurs, and if so, how much it contributes to output will provide useful empirical data on a long-standing debate regarding the virtues of centralization versus decentralization. A survey of network organization literature (Alstyne, 1998b), identified this as one of the most common themes in studies of IT and organizations.

There are several types of results and extensions from this study. Confirmation or rejection of one or more hypotheses may help improve managerial practice. Since few results are firmly established, even failed hypotheses are likely to add value. By ruling out seemingly logical practices (for which no supporting evidence can be found), useful results could be obtained that indicate what not to try. On the other hand, affirmative results – indicating what managers should do – would likely be highly valuable. Either way, the study provides at least potential benefit.

A second result could lead to implementable software among current and future corporate sponsors for this research. Data gathering from internal systems will rely on programmed monitors, as well as interviews, so that lessons learned might lead to tools for enhanced decision support. Finally, a significant aim of this research is to contribute to the scholarly understanding of these issues. The academic evidence for productivity enhancement is strong but recent. Given that information technology appears to be effective, there remains much to be understood about how and why this happens so that there appear to be numerous opportunities to develop the theories for why the various results obtain.

Letters of endorsement and collaboration are included from Intel Corporation, The Lotus Institute, and from Charles King, an economics professor at the Harvard Business School.

INTELLECTUAL PROPERTY

In 1983, the Free Software Foundation (FSF) introduced the concept of “copyleft," a copyright licensing scheme designed to reshape copyright law for application to computer software. Copyleft was motivated by the observation that proprietary software copyrights limit the freedom of developers to build on the works of others. The intellectual property protection on works of expression – books, plays, and paintings, for example – function badly in industries that depend on incremental innovation and reuse for product improvement, customer satisfaction, and network expansion.

Under the copyleft alternative, programmers render their source code to the public, then use existing copyright law to ensure that anyone redistributing the code, even with enhancements, does so without adding restrictions on further distribution. Copyleft limits the rights of developers to limit others’ rights of redistribution. According to the FSF General Public License:

You may modify your copy or copies of the Program or any portion of it, thus forming a work based on the Program ... provided that you also ... must cause any work that you distribute or publish, that in whole or in part contains or is derived from the Program or any part thereof, to be licensed as a whole at no charge to all third parties under the terms of this License. (ß2.0 - 2.b)

While the copyleft approach has helped several popular UNIX-based programs enjoy distributed development and widespread use, it introduces a new problem. It limits the economic incentives to make follow-on investments. Freedom from copy restrictions can imply freedom from income. While, in principle, copyleft permits a software developer to charge a distribution fee for the bundled software good and its derivative innovation, in practice, the requirement of full disclosure prevents an author from deriving income from more than a single sale. Having sold the software once, a seller must then compete with source code available from the first buyer. Such a seller has no market power selling against an identical copy of his or her own product. For software, this results in a price at or near marginal cost which approaches zero.

This research proposes a middle road between traditional copyright and the Free Software Foundation’s “copyleft." The former is widely exclusionary, promoting (short term) proprietary profit maximization, while the latter is widely distributive but lacks incentives for innovation. A more flexible approach might both increase software innovation and long term revenues, but it has yet to be fully articulated either in the marketplace or in economic theory.

For software, past precedent is a difficult basis for intellectual property law, particularly in the area of enablement and disclosure. Patents require both a high threshold of innovation, which is frequently not met by software developers, and full disclosure of the method of operation. Owning the rights to the method of operation, however, is little protection if the effect can be achieved by other means. IBM, for example, lost their 1984 suit against Phoenix Technologies, attempting to protect the Basic Input Output System (BIOS) (Galler, 1995). Current copyright statutes, on the other hand, covering the “look and feel” do not require disclosure. In either case, lack of disclosure or enforced proprietary restrictions limit the ability of programmers to build on established subroutines.

The goal of this research is to suggest a possible market mechanism that dynamically adjusts the exclusionary period for building derivative works in software to an efficient level from the lengthy

and awkward periods currently in force.2 For, hidden in the copyleft logic is a powerful and little recognized business strategy of flexible copyright licensing or simply "copyflex." The intuition is straightforward: software companies often find themselves in a race both to rapidly grow their user network and to quickly upgrade their software products. Many of these companies cannot keep pace on their own and would be willing to turn to other firms for assistance. In short, these early firms recognize that they are better off winning a small percentage of a larger market than they are hoarding control over a smaller one. A 5% stake in a $1,000,000,000 network pays more than a 95% stake in a $1,000,000 network.

Accordingly, the proposal is to introduce a profit incentive period into a copyflex license that an innovator uses to distribute their software and promote complementary investments in product and network growth. Under the copyflex licensing strategy, an innovator would permit the creator of a derivative work to retain interest in the subsequent improvements for a reasonable period – seven years, for example – before shifting to copyleft. Upon expiration of the copyflex license, the contract would specifically eliminate all restrictions on redistribution, ensuring that both customers and third party innovators could enjoy free access. All parties would then be free to incorporate second tier innovations in their own third tier enhancements without fear of hold-up. Whereas copyright maximizes one-time innovation through the promise of durable monopoly rents and copyleft maximizes perpetual distribution through the promise of free access, copyflex strikes a balance through a combination of rents and access.

The social welfare analysis that then trades the monopoly incentives to innovate against the inefficiency of monopoly sourcing can also be informed by recent development in the theory of incomplete contracts (Grossman & Hart, 1986; Hart & Moore, 1990). If a "complete" contract specifies the disposition of assets under all possible future scenarios, then an "incomplete" contract is one for which certain contingencies were unforeseen and the resource owner exercises decision rights by default. The general argument holds that, due to the high likelihood of unanticipated events, owners will tend to invest more efficiently than non-owners in projects to which their assets contribute. Ownership influences investment, maintenance, and future enhancement as in the care exercised by a car or condominium owner relative to that of a mere renter. The effect of flexible copyright is to provide virtual ownership via access to source code and the ability to profit from one's own investment in enhancements. For software, unlike cars or condominiums, can be accessed, used, and enhanced, without the original owner ever losing these same privileges for their own initial copy. The theory of incomplete contracts can then be used to explore governance and contracting mechanisms that promote both innovation and access via changes in ownership rights.

From a broad societal perspective, copyflex licenses can be quite attractive. First, it harnesses market forces to dynamically shorten the effective period of exclusion and to increase investment. This strategy has the unusual advantage that an inventor, in this case a first author of software, may find it economically rational to forgo monopoly rents during the tail of the statutory period on a first generation product. In exchange, he or she stimulates demand from an expanded network of co-investors and consumers who also represent a larger market for a second generation product. Although long periods of exclusion limit complementary investments for all copyrightable subject matter, the problem is particularly acute for software. New functionality is more easily developed on the basis of reusable subroutines – as in the process model of information described in the first project. Moreover, proprietary interests in the form of copyrights hinder the computer community's ability to settle on standards.

Second, copyflex helps solve the problem of enablement. Under existing statutes, a copyright petitioner may block out segments of the source code thereby keeping the key intellectual property

2 Oddly, under current copyright practice, protection on software for the first digital computer dating from 1946 would still be in force today.

secret. This stands in contrast to both the requirements of patent law and the expectations of traditional copyright law. For patents, the inventor must file a "written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art ... to make and use the same." (35 U.S.C. ß112). For copyright on traditional publications, a work itself establishes on the face of it the nature of its contribution. The bargain implicit in most intellectual property law is that society grants an innovator a limited monopoly in exchange for revealing to society the nature of the innovation. Copyflex suggests that an inventor's best interest may lie in enabling others to enhance and build upon an original work.

Third, consumers improve their access to existing products when the product becomes freely distributable. They also benefit from earlier introduction of new products. Both effects imply a strict Pareto improvement in consumer welfare. The copyflex strategy might therefore represent a more balanced approach to intellectual property that accounts for both efficient distribution under a static framework and efficient innovation under a dynamic framework.

Letters of interest and collaboration have been included from Bernard Galler, President of the Software Patent Institute, and from Douglas Lichtman, a Professor of Law in intellectual property at the University of Chicago.

B. Plan of Work

This section outlines the integrated activities, resources, and timelines for the three research projects. The more theoretical projects will involve axiomatic derivation and simulation while the more empirical project will involve substantial on-site data gathering and econometeric analysis. Overlap in the three research programs also helps integrate the research as the theories can guide the search for data while the data help develop the theory.

The information value study will extend the Bayesian signal models, such as those elaborated in (Arrow, 1986; Blackwell, 1953; Laffont, 1990; McGuire, 1986), to account for instruction tuples. Since the expanded model will include these Bayesian models as a starting point, effort will first be made to rederive and confirm (or disconfirm) existing propositions regarding comparability of information sets, depressed social welfare due to transactions failure in information markets, and low levels of investment by information monopolists. These derivations will provide context for the proposed model before moving to applications. The next activity will be to derive new propositions on monotonicity of value, investment in discovering new information under uncertainty, and in valuing information using options. Both activities will build on the recently completed dissertation research of the PI. The audience for this research will include academics in organizational theory, managerial economics, and the economics of uncertainty as well as managers interested in measuring information capital. As part of the process of validation, the PI will seek to present intermediate results at conferences and academic seminars, to discuss developments with managers contacted for the productivity study, and to recruit graduate students into this line of research. The principal resource requirements are computer support for mathematical simulation, a modest travel budget to support interaction with colleagues, and funding for a research assistant whose activities can be spread over all three projects.

The information productivity study is proposed as a pilot project at a single multi-departmental firm (such as Intel) followed by a large-scale external project. The research would proceed as an empirical analysis of data gathered from measuring information systems usage and access within business units at several dozen firms. Data would also include on-site interviews with key personnel to characterize their knowledge management practices. Thus data collection would cover both IS computer usage at the system level and staffing behaviors at the survey level. A pilot study

would also be used within Intel or other large corporation to generate and test initial hypotheses before moving to a larger study.

Preparation for the pilot study will consist of two primary activities – software programming and additional hypothesis generation – with a number of subordinate activities. Hypothesis generation will proceed starting form existing literature and the propositions from the previous section. These will be augmented on the basis of managerial interviews to provide a robustness check on overlooking important practices. Software programming will be used to monitor information flows within an organization to record actual rather than simply recollected behaviors.

The pilot study is intended to contribute to the overall project in several ways: by helping to generate and test initial hypotheses, by providing a beta test phase for the development of software monitors, and by providing a point of review and assessment before committing resources to a full study.

Proceeding with the full study will involve contacting a stratified random sample of companies in multiple Standard Industrial Codes. Introductions and contacts made through the Harvard Business School will also greatly enhance access and a letter of interest in this project has been included. Participants will be interviewed and monitored for declared and actual information management practices. Data on actual behaviors can then be correlated with data from financial statements using standard econometric techniques.

The pilot study is planned for one year to allow for design planning, software coding, meetings with managers to get their agreement, implementation, and then assessment of the results to revise the software and methods before deploying the full-scale project. Six months to a year will then be required to negotiate access to a statistically significant sample of host sites and install software. The follow-on study with longitudinal data gathering and periodic analysis is expected to last two years. Publication activities should commence beginning with the results of the pilot study. Resources for the project will include 1-2 programmers, 2 doctoral students, a travel and phone interview budget, and minor infrastructure support. The target audience for publication includes persons interested in information flows and IT effects on organizational design in both industry and academia.

Intel Corporation has expressed their support for this research project as noted in an enclosed letter of interest. Charles King, a member of the Harvard Business School faculty, is also interested in collaboration in this project and will facilitate access to corporations through their alumni relations program as well as providing additional statistical expertise, and support through a graduate research assistant.

To benefit producers *and* consumers, my goal in the intellectual property study is to generate and test several alternative models of software creation and network growth that balance fidelity and parsimony. The more parsimonious models are easier to use in getting strong results but they are also frequently less faithful in describing complex real world phenomena. The process of model building will therefore be iterative, requiring roughly one year to develop and iteratively refine. It will also draw on the PI's experience in building simulation models for corporate clients and in teaching simulation. The general process will require proposing mathematical descriptions of the interesting tradeoffs, testing their implications, and then reexamining any assumptions that generate the model's behaviors. If a model disagrees with *expected* real world behavior, are the assumptions wrong and if so how can they be improved or if the assumptions are right, how can we learn from deviations and make better plans?

Interesting tradeoffs include innovation versus revenues, that is, how much of a software good should be released? Releasing all source code to the public (copyleft) permits innovation but eliminates profit. Releasing nothing to the public (copyright) captures short-term profit but

eliminates complementary investments and innovation from third parties. Another concern is the degree of substitutability between initial software goods and follow-on goods. If follow-on goods are complements, they increase demand, but if they are substitutes, they decrease demand for the initial good. How can the disclosure process be structured to encourage complementary rather than substitute investment? Still another tradeoff is the time horizon. Shorter horizons tend to emphasize efficiency of distribution while longer horizons emphasize efficiency of innovation. Exponential growth in the long run can compensate for a lot of distributive inefficiency in the short run.

The theoretical modeling will also have direct application to practice. An additional six months will be spent comparing these results to existing case law and working with software companies to test the theories for practical implementation. The PI will work with Douglas Lichtman, an intellectual property scholar from the University of Chicago Law School, to compare findings to implementable principles in existing law. In addition, Bernard Galler, the President of the Software Patent Institute and an author of a text on software protection, has expressed support for and interest in collaboration on this project. He will also facilitate introductions to software companies to explore the implications for practice.

2. Education Activities

The proposed educational activities are cross-disciplinary and integrative, and are fully supported by the philosophy and the faculty of the School of Information. Responsibilities of the PI include direct teaching and mentoring of graduate students, development of new courses and curricula, and establishing ties to other departments through cross-listed courses and joint-degree programs.

The PI's dissertation research specifically modeled methods of closing the gap between the information "haves" and "have-nots," as well as examining questions of information "balkanization," the degree to which information resources exist in isolated communities. Initial forays into these subjects have already been published in *Science* (Alstyne '96) and have been the subject of public radio broadcasts in the US (IOTA '98) and Canada (CBC '96). In addition, two of my research studies have already been adopted for teaching purposes in classes at MIT, Stanford, NYU, Boston University, the University of Pittsburgh and the University of Toronto, among others.

My research on balkanization and on communication among networks of information sources (Alstyne '96 '98) has strongly influenced my desire to build bridges between disciplines. A number of important breakthroughs – Watson and Crick's studies of DNA (through their training in zoology and physics), Kuhn's theories of scientific revolution (blending physics and history), and the Alvarez theory of comet destruction of the dinosaurs (which relied on both paleontology and astrophysics) – developed from bridging disciplines. The study of information economics is by definition cross disciplinary, and aligns well with SI's interdisciplinary approach to training future information professionals to excel in an evolving field.

The School of Information is deliberately inclusive and integrative, bringing together scholarship in information science, economics, public policy, computer science, archives management, and human-computer interaction -- all with a focus on information. It was designed as an exploratorium in knowledge management for purposes of researching knowledge networks, digital libraries, and virtual education structures (Duderstadt, 1997). The School is designed to break down barriers between scholarly disciplines and has hired faculty from economics, political science, information science, and other backgrounds to address questions of how to maximize access to information, how technology and human systems interact, and how information practice and policies can help work toward both commercial and non-profit betterment of society. I chose to

join SI over half a dozen other academic posts because of the integrative focus, the opportunity to help construct a new specialization in Information Economics, Management and Policy (IEMP), and the mixture of theory with practical application and commercial with non-profit interests.

Evaluation of the educational activities will be directly related to growth in enrollment in both IEMP and the School of Information, to success in placing students in their chosen professions, to student involvement in research and publication, to changes in earnings potential of these same students, and to overall satisfaction in their education as measured by course evaluations.

Student evaluations of the PI's first two courses came back overwhelmingly positive. Several students have declared interest in the IEMP specialization even prior to its final approval by university administration. A number of students have also reported that they secured employment directly as a result of their exposure to this material. In short, there is preliminary evidence that the educational objectives will be met, the educational influence will be strong and the social significance positive.

A. Course Development, Direct Education and Mentorship

The PI teaches the core course in information economics – the content of which is directly aligned with and supported by the research questions posed in this proposal. The course develops concepts of information from economic and computer science perspectives, then uses these perspectives to show how rational actors (individuals and organizations) use information across a variety of situations. It covers, for example, choice under uncertainty, information asymmetry, pricing, control, and information markets from an economic perspective.

The PI is also developing and teaching courses in comparative simulation methods for policy problems and in electronic commerce. The simulation course trains students from a variety of disciplines and backgrounds how to use the computer as a simulation tool. Students learn a cross-section of econometrics, system dynamics, agent modeling, linear optimization, and axiomatic theorem proving. These last two approaches directly apply to the methods of the ongoing research proposed here.

In teaching, the initial courses taught by the PI have received overall ratings of 4.7 and 4.8 out of a possible 5, a level of student satisfaction which is rare for first time offerings.

At least three students have reported that they have received job offers directly as a result of material taught in these courses. Students from the information economics class are engaged in formulating business models and pricing information goods for the Interuniversity Consortium for Political and Social Research (ICPSR), one of the largest academic repositories for research data in the world. Another student, from the class in simulating policy problems, is working for state government and continuing her simulations of the factors that influence movement onto and off of state welfare rolls.

In addition to classroom teaching, the proposed research will directly educate a number of Ph.D. students over the course of this 5-year proposal. The School of Information is well-positioned encourage and support this cross-disciplinary doctoral training. Our faculty possesses the requisite range of disciplinary expertise, and the school demonstrates its commitment to this approach through a track record of successful multi-disciplinary interactions in both research and education. Under direct mentorship of the PI, graduate students will be individually involved in the research projects (included in the budget below), and will gain hands-on experience conducting interviews, programming, and analysis. They will also become familiar with research under a corporate context.

B. Curriculum Development: The IEMP Track

The PI is one of several faculty developing a multi-disciplinary track in Information Economics, Management, and Policy (IEMP) within the School of Information. The purpose of this track is to provide future managers and information professionals with analysis tools for measurement and management on the one hand, in order to answer high-level questions of efficiency and equality on the other.

Since the economics of information do not necessarily follow the economics of traditional goods, this emerging discipline is focused on understanding the costs and benefits of measuring, pricing, managing, and sharing information. The questions common to education and research include, when should a firm give its information goods away for free? How should information be priced? Does the Internet require a new regulatory paradigm? And how can we devise solutions to make it "safe, fun, and profitable" for strangers to interact -- even share information -- at a distance?3

The new curriculum is intended to prepare those interested in becoming information product and service managers, CIOs, government information policy analysts, and information system consultants, among other career possibilities. Course offerings will include: Information Economics, Information and Network Policy, Electronic Commerce, Computational Market Systems, Entrepreneurship, Web Security and Trust Systems, Comparative Computer Modeling, Advanced Management, and Organization in the Information Age, as well as student labs and seminars.

The IEMP track is designed to be open, integrative and friendly to other specializations. The intent is to offer a significant fraction of courses that are accessible to all students within the School of Information who have completed the requisite Foundations courses. Based on the students participating in the first Information Economics course, we also expect that the IEMP course offerings will serve the needs of Public Policy and Business School students who have an interest in information policy and management.

Although preliminary indicators come from work-in-progress, the evidence for success potential is high. The School of Business and the School of Public Policy at the university have already expressed active interest in interdisciplinary collaboration. The proposal for development of the IEMP track received a nearly unanimous vote for approval by the governing faculty and has been forwarded to the Academic Dean's office for final approval. The School of Information as a whole, including the pending IEMP program, has just been reaccredited by the American Library Association. Several students have already declared their interest in registering, pending final approval of the IEMP track. Establishing an IEMP specialization at SI will provide a more natural and desirable interface for joint efforts with the Schools of Business and Public Policy, and should thereby increase our cooperative education efforts.

C. Interdisciplinary Education and Joint Degree Programs

The PI is the primary advocate for developing ties to other disciplines, including the cross-listing of courses and the establishment of joint degree programs. These activities are expected to contribute substantially to enriching the academic opportunities of students and the intellectual

3 Contributed by Paul Resnick, co-developer of the Platform for Internet Content Selection (PICS).

climate of the research community. In progress, for example, are joint degree offerings in law and information, with potential for contributing to intellectual property law and antitrust in electronic commerce. Another effort underway is the development of a joint degree in information and public policy, with implications for telecommunications regulation, information policy, and universal access. Joint activities are also planned with the electrical engineering and industrial engineering schools to integrate offerings in human-computer interaction, distributed systems, and electronic commerce.

3. Relationship to Current knowledge in research and education

Information Value, Information Goods, and Supporting Theories

A large literature contributes to the current understanding on information resources. Forays into the value of information are developed in (Stigler, 1961) and (Marschak, 1971). Analysis explaining inefficient investment in information appears in (Arrow, 1962) with additional perspective on rewards to inventive activity appearing in (Hirshleifer, 1971). Pioneering work on the non-comparability in the value of unrelated information sets appears in (Blackwell, 1953) with simplifying clarification in (Cremer, 1982; McGuire, 1986). Arrow (1986) and McGuire (1986) provide an analysis of why entropy measures correlate poorly with value. Using expected utility theory, there is also a huge literature on the value of signaling and screening, under (in)complete and (im)perfect information. Very little of this work, however, uses a procedural model of information, the innovation introduced here from computer science. The processing step concept of an algorithm was conceived by Turing (1937). The idea of a stored data computer was pursued by von Neumann [, 1946 #570], and articulation of lambda calculus, a programming language representing data and function as equivalent classes, fell to McCarthy (1982). Option theory derived from equilibrium models is first derived in (Black & Scholes, 1973; Merton, 1973) and extended to more general commodity bundles in (Dixit & Pindyck, 1994; Pindyck, 1993). The use of hedonics to value goods is attributed to Court (1939), while the conception of goods as collections of features is further developed in (Lancaster, 1966). The bundling literature was first applied to information goods only recently by (Bakos & Brynjolfsson, 1997), while important contributions to pricing and differentiating information goods appear in (Varian, 1995; Varian, 1997; Varian, 1996). Quite useful but atheoretical practices for valuing information are collected in Sveiby (Sveiby, 1997) for use by managers. The contribution of the present proposal is to combine the theoretical tools from computer science and economics in a manner that may also have practical applications.

Information Technology and Productivity

The productivity paradox, that managers continued to invest in IT despite apparent lack of evidence for any return on investment, is described in (Berndt & Morrison, 1991; Brynjolfsson, 1993; Landauer, 1995; Loveman, 1994; Strassmann, 1990), however, strong positive evidence using more recent data is reported in (Brynjolfsson & Hitt, 1996). In more general terms, numerous articles have characterized IT's influence on efficient organizational design. These are included in but not limited to (Applegate, Cash & Mills, 1988; Clemons, Reddi & Row, 1993; Davenport & Short, 1990; Galbraith, 1974; Huber, 1990; Marschak & Radner, 1972; Quinn, 1992). Coordinating problem solvers is also discussed in (Gasser & Hill, 1990). IT's influence on transaction costs appears in (Malone, Yates & Benjamin, 1987), suggesting a move toward market mediated transactions. IT's influence on incomplete contracts is discussed in (Alstyne et al.,

1995; Brynjolfsson, 1994), suggesting that decentralized control fosters complementary investment. Tracking information flows has been studied in organizations relative to personal influence (Markus, 1983) and in societies relative to growth in media (Pool, 1983). Numerous forms of information gathering in organizations is surveyed in (Huber, 1991). Recent and novel measures of organizational fragmentation, interconnectivity, and clustering have been introduced in (Alstyne & Brynjolfsson, 1996; Watts & Strogatz, 1998) and will be used in the proposed research. The advantage is that the new studies can use the same econometric techniques as existing research only it will monitor internal information flows and use new metrics in addition to the accounting indices based on financial data aggregated over all a firm's activities. Guided by the theories on efficient organizational design, it can then test for influential practices.

Software & Intellectual Property

A survey of the general issues in scope and enforceability confronting intellectual property scholars is well articulated in Besen and Raskind (Besen & Raskind, 1991). A broad discussion of the legal principles governing various forms of information -- software, images, music, print, and privacy data -- is also treated in Branscombe (Branscombe, 1995). A thorough treatment of intellectual property problems and the history of pivotal cases can be found in Galler 1995, who also founded the software patent institute at Michigan. Many of the strongest arguments in favor of freedom to innovate on the basis of existing third party software have been articulated by Richard Stallman and further developed in the literature of the Free Software Foundation (http://www.fsf.org). An alternate perspective balancing computer science, intellectual property law, and economics is presented in (Davis, Samuelson, Kapor & Reichman, 1996). It treats software as a "machine in text" and argues for using copyright laws developed for semiconductor fabrication as the basis for software protection. Several of the basic arguments and their variations are also explored in (Samuelson, 1991; Samuelson, 1992). More general economic treatment of patent coverage is addressed in (Gilbert & Shapiro, 1990) who argue for lengthy and strong but very narrow patents as a stimulus to innovation although they do not examine software specifically. A perspective on treating patents as options on outcomes is also presented in (Pakes, 1986). The distinguishing feature of the proposed research is to take a process model of information and balance the enablement and co-investment properties of widespread disclosure against the innovation incentives of enforced monopoly.

Integrated Education and Research

A call for integrating diverse research disciplines such as computer science, organizational theory, HCI, economics, cognitive psychology, and others appears in at least two National Research Council publications (Research Council, 1992; Research Council, 1997). The establishment of the School of Information to serve this role is described in (Duderstadt, 1997). A good distillation of multiple seminars at Carnegie Mellon on teaching, graduate student research, and mentoring in science and engineering appears in (Davidson & Ambrose, 1994). A review of educational practices also appears (McKeachie, Pintrich & Smith, 1986). Herb Simon presents a brief discussion of teaching problem solving in (Simon, 1980) while the presentation of quantitative information appears in (Tufte, 1983). A general discussion of IT's influence on academic productivity is treated in (Massy & Zemsky, 1995). At present, a number of these practices are being integrated into the proposed curriculum in information economics, management, and policy.

Letters of Interest, Support, or Collaboration

i) Douglas Lichtman, Professor of Law at the University of Chicago, includes a letter of interest in collaboration on the intellectual property study for its ability to influence debate over adjusting the Uniform Commercial Code and the regulation of cyberspace.

ii) Bernard Galler, President of the Software Patent Institute, has provided a letter of interest in the results of the intellectual property study and offered his support for work on this project. Dr. Galler will also facilitate introductions to software companies to discuss strategic business implications for software protection. He is Professor Emeritus of the Electrical Engineering and Computer Science Department at the University of Michigan and a past president of the Association for Computing Machinery. He is author of a text on intellectual property protection for software and he served as an expert witness in the important intellectual property cases Apple v. Microsoft, Intel v. NEC, Lotus v. Paperback Software, and Lotus v. Borland.

iii) A letter from Intel Corporation describes their interest in the work on intellectual property as a stimulus to software innovation and on information productivity as it could improve the design of information management practices among purchases of computer systems. Intel is also considering supporting the information productivity study, with a decision due in August.

vi) The Lotus Institute has expressed their interest in the productivity study and offered potential support through their expertise and staff time.

v) Charles King III, an economist and professor at the Harvard Business School, has provided a letter of interest in collaboration on the information productivity study. Professor King will also prove valuable in gaining access to companies for the productivity study.

vi) Robert Axelrod, MacArthur Fellow and Professor of Public Policy, has provided a letter in support of the proposed joint degree program between the School of Information and the School of Public Policy.

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