Combining Inventions in Multi-invention Products: Organizational Choices, Patents, and Public Policy

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Draft: November 30, 2000

Keywords: Innovation, patents, technology policy, licensing, transaction costs

Acknowledgments: Helpful comments were provided by Bronwyn Hall, Brian Wright, participants at the Innovation Seminar in Berkeley, and three anonymous referees and participants from the Academy of Management 2000 Conference (Toronto). Somaya gratefully acknowledges research support from the U C President's Initiative for University-Industry Research and the Ryoichi Sasakawa Young Leaders Foundation.

ABSTRACT

We investigate the implications for patent-related public policy arising out of products that incorporate large numbers of inventions. Inventions may be combined in such multi-invention products using three alternative organizational modes – viz., licensing of inventions, trade in components that embody inventions, or by integrated production. An analytical framework is presented wherein the organizational tradeoffs between these modes are evaluated using a transaction cost approach. We demonstrate that patent policy not only affects incentives for innovation, but also influences these transaction costs, which in turn determine the preferred organizational mode(s) in the industry. Therefore, appropriate patent policy for multi-invention products is determined not only by tradeoffs between incentives for innovation and the ill-effects of monopoly, but also by organizational considerations in commercialization. The framework operationalizes the concerns voiced in many industries that current patent policy gives rise to dysfunctional transaction costs in multi-invention contexts. Implications are drawn for patent policy based on the framework and transaction cost analyses.

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1. Introduction

There appears to be a fundamental rift between the design of the patent system, which is based primarily on single invention products, and the nature of innovation in many modern industries, where large numbers of inventions are routinely combined in making end products. While such multi-invention products are not a recent phenomenon, they are rapidly becoming the dominant species in newer technological fields. Moreover, the continuing policy emphasis on strong patent protection (Kortum and Lerner, 1998; Scotchmer, 1996) has drawn attention to the role of patents in these multi-invention contexts.

Academic interest in patents and multi-invention products began with Kitch (1977), who felt that patent rights could facilitate coordination between owners of related inventions by creating a property interest in the inventions. Recently, attention has turned to a specific multi-invention case, namely sequential innovation. Sequential innovation has been studied in the law and economics tradition (Merges and Nelson, 1990, 1994), as well as through formal economic modeling (Scotchmer, 1990, 1996; Scotchmer and Green, 1994; Chang, 1994), with the overall conclusion that broad, strong patents could be harmful when significant follow-on improvements are made over the patented invention. Multi-invention contexts are typically more general than sequential innovation however, and often include sequentially unrelated but complementary inventions, which have not yet been studied.

Multi-invention contexts pose challenges for public policy in many industries. In biotechnology, patents over genes and research tools, which are used as research inputs in making therapeutic end products, have raised concerns about the "fencing off" of these basic building blocks (Eisenberg, 1992; Eisenberg, 1994; Eisenberg and Heller, 1998). Similarly, the strengthening of software patents in the early 90s caused fears that innovation would be stymied by impediments to the combination of new inventions with old ones (Samuelson, Denber and Glushko, 1992; Samuelson, Davis *et al.*, 1994). In semiconductors, miniaturization has made it technically feasible to put entire electronic systems on a single integrated circuit, but difficulties in transacting for the multiple designs that must be combined in such products are causing significant delays (Linden and Somaya, 2000).

Transactional problems could lead to the under-utilization of innovative resources in each of the abovementioned cases, resulting in a "tragedy of the anticommons" (Heller and Eisenberg, 1998). Some transaction costs in technology licensing have been studied in past research, stemming from disputes over patent valuation (Merges and Nelson, 1994) and concerns about the leakage of know-how (Arora, 1994; Oxley, 1998). In the public policy arena, too, the relevance of transaction costs in licensing markets is widely acknowledged, for example, in the Department of Justice and Federal Trade Commission's antitrust guidelines for the licensing of intellectual property.[1] However, to our knowledge, there has been no systematic economic analysis of the relationship between patent protection and these transaction costs.[2] Moreover, the organizational problem of combining inventions in multi-invention products has also escaped comprehensive treatment.

[1] "Antitrust Guidelines for the Licensing of Intellectual Property," U.S. Department of Justice and the Federal Trade Commission, April 6, 1995, Washington DC. On-line at: http://www.usdoj.gov/atr/public/guidelines/ipguide.htm. The guidelines recognize that restrictive licensing practices are sometimes used to mitigate transaction costs in technology markets, and that such mitigation of inefficiency is in the public interest.

In this paper, we provide a transaction cost based framework for evaluating alternative organizational approaches to combining multiple inventions. Inventions can be combined in multi-invention products using a licensing mode, a component mode, or an integrated mode. The relative effectiveness of these modes is determined by the associated organizational costs – namely, the transaction costs in licensing and component markets, and the governance costs of integration. Patent policy, in turn, can affect these organizational costs as well as the incentives available for innovation in each mode, and thus influence the choice of organization mode.

Our analysis adds two main policy insights. First, the economic consequences of patent protection in multi-invention contexts cannot be analyzed independent of organizational considerations. This calls for a different approach to patent-related public policy, one that explicitly incorporates the interactions between patent policy and organizational choice. Second, the transaction costs associated with the different organizational modes play a significant role in multi-invention contexts. The economic impact of patent policy is mediated in part by its affect on these transaction costs, and in part by its impact on innovation through incentives or other means. In turn, this suggests the judicious use of alternative policy instruments in multi-invention contexts, which may affect these two areas somewhat differently.

The rest of this paper is organized as follows. Section two outlines our basic framework for understanding organizational choice in multi-invention products. Section three examines transaction costs in components and licensing markets with a view to characterizing the tradeoffs entailed in using different organizational modes. Section four illustrates how our framework is applied to the analysis of patent-related public policy in multi-invention products. Section five

[2] Arora (1995, 1996) and Oxley (1998) made an important beginning in this area by establishing a link between patent protection and the mitigation of know-how leakage problems in licensing.

summarizes the public policy implications we derive from our analysis. Section six discusses some limitations and extensions of the framework, and concludes.

2. A Framework for Innovation and Organization in Multi-Invention Products

This paper is concerned with products made by combining large numbers of inventions, which we refer to, in short, as multi-invention products. We analyze organizational choice in such products using a generic framework, which is described below for the simple case where only two inventions are combined into a single product. The two-invention example is of course an illustrative one, and in practice, multi-invention products may be made up of hundreds, or even thousands, of inventions. We assume that the inventions are not derivatives of each other, thus allowing them to be licensed freely.[3] We also assume that the inventions can be embodied in physically separate component products. Later, we discuss the generality of these assumptions, and examine extensions of the framework when they do not hold.

2.1 Organizational Modes and Resulting Industry Structures

Three "ideal type" organizational modes can be used to commercialize multi-invention products: an integrated mode, a licensing mode, and a component mode. Using our two-invention example, a *component mode* (Figure 1) arises when (at least) one of the inventions is embodied in a component and traded across firm boundaries for integration into the final product. We label the organizational units that would be eligible for patents on the two inventions the "original inventors" of the inventions. In a component mode, the original inventors are (in) separate firms, and the two inventions are combined without any licensing. Rather, technology is transferred in "embodied" form, as a component.

[Figure 1 about here]

The two inventions can also be combined through a *licensing mode* (Figure 1), where (at least) one of the inventions is physically transferred between the firms using designs, recipes, etc. We call this "active licensing" to distinguish it from licensing that merely involves the "passive" trading of patent rights without any technology transfer. The licenser in a licensing mode may choose not to make a product from its invention, and rely only on licensing revenues.

Finally, the inventions can also be combined within the same firm, i.e. through an *integrated mode*.[4] In the simplest case, this may come about if the original inventors happen to be co-located in the same firm. Integrated modes may also arise through the conscious merger of firms that independently made the two inventions. Finally, integrated modes may result from a firm's use of its own internal versions of one or both of the inventions, even if it is not their original inventor. Each of these three integrated mode cases are illustrated in Figure 2.

[Figure 2 about here]

The last integrated mode case, where firms use their own versions of the two inventions, is an important one, since relying on fortuitous co-location or merger markets may be impractical in many industries. In practice, these internal versions may be made independently of the original invention, or they may be reverse-engineered from it. In some cases, the inventions may be made even before it becomes clear which firm owns the patents over them. If patent protection is effective, firms that use internal versions of an invention will need to obtain patent licenses from the original inventor. The center panel in Figure 2 illustrates such a case, where an integrated

[3] If an invention is derived from another, as happens in sequential innovation, the use of the derivative invention requires the permission of the parent invention's patentee. This is because, by law, a patent right is only a right to exclude others and not an affirmative right to practice an invention.

[4] A firm may subcontract the manufacturing of the product, but still fall within the integrated mode so long as it has effective control over the technologies used in the product – e.g. if the firm makes and owns the final design. Similarly, component producers may also choose to subcontract their manufacturing.

firm uses a non-original invention along with a patent license. Since such licensing typically does not entail any actual transfer of technology between the firms, we call it *passive licensing*.

2.2 Innovation, Licensing, and Components Trade in Multi-invention Products

Each of the organizational modes outlined in the previous section can be viewed as the result of implicit choices as inventions advance from an initial innovation stage towards commercialization. Figures 1 and 2 illustrated how these choices are made for component, licensing, and integrated modes. If inventions are co-located in the same firm through all stages of commercialization, an integrated mode arises. Licensing or component modes result when inventions are traded between firms at the licensing or component stages, respectively.

Figure 3 illustrates the tradeoffs between these choices. As an invention progresses towards incorporation into a multi-invention product, it passes through two main decision nodes. The first node determines if it is (actively) licensed, and the second determines if it is traded in embodied component form, resulting in a licensing or component mode, respectively. If the invention is not traded at either decision node, an integrated mode results. The relative organizational effectiveness of integrated, licensing, and components modes determines which of them is likely to prevail in any given context.

[Figure 3 about here]

Analytically, we separate the effectiveness of various organizational modes into two parts – their effectiveness in generating inventions, and their effectiveness in combining them. Later in the paper, we examine how different organizational modes might impact the creation of inventions, especially through incentives for innovation. Here, we focus mainly on the organizational costs of combining inventions, which stem from the internal governance costs of integration and the transaction costs entailed in licensing and component markets.

This approach implies that well-functioning frictionless markets, which are generally believed to have strong organizational advantages, are held as a datum. Transaction costs found in practice, then, decrease the effectiveness of the associated organizational modes relative to this datum. As Figure 3 illustrates, if transaction costs are low in component markets, and especially if transaction costs in licensing are also high, component modes are more effective, and therefore likely to be used. Likewise, licensing modes have an advantage when transaction costs in licensing markets are low, and integrated modes of production will likely be preferred when transaction costs in both markets are high.

Low transaction costs give licensing or component modes an advantage over integrated modes because of the bureaucratic governance costs of organization within firms. Moreover, we have noted that integrated modes may also entail patent licenses and mergers, which bring both the benefits and the costs of their associated markets. For example, the acquisition of highly innovative start-ups through mergers will increase the effectiveness of integrated modes if the transaction costs in merger markets are not too high. Similarly, the transaction costs of patent licensing will make integrated modes less effective if the added incentive-effects for innovation are relatively low. In sum, the different variants of integrated modes can be analyzed in much the same way, by comparing their net organizational effectiveness with other modes.

Finally, there are interactions in the framework between the organizational effectiveness of combining inventions and the innovative process itself. Highly effective downstream organizational arrangements can improve incentives for innovation by increasing the total rents available for distribution to inventors. Conversely, changes in the supply of inventions can influence the choice of organizational mode to commercialize them. For example, if many

inventions are generated outside large integrated firms, as in biotechnology, licensing-based organizational modes may become necessary to commercialize them.

3. Transaction Costs and their Impact on Organizational Mode Outcomes

When licensing and component markets function well, as in the hypothetical frictionless case, market-based incentives imply that the corresponding organizational modes are highly efficient. In comparison, integrated modes can be bureaucratic and cumbersome. Traditional transaction cost theory (Williamson, 1985) suggests that within firms, low-powered incentives and the need for equity result in inefficiencies when compared with frictionless market arrangements. Nonetheless, when integrated modes are combined with merger markets to absorb the inventions of innovative start-ups, or with passive patent licensing which provides some incentives for innovation,[5] they can access some of the benefits of market modes. More importantly, integrated modes provide coordination benefits through intra-firm governance structures, which make them more effective than markets when transaction costs are high.

We describe the nature of transaction costs in licensing and component markets below. The basic market-making costs of matching buyers and sellers, and the paper-and-ink costs of conducting transactions are excluded from our analysis, although these can conceivably be significant in some instances. For our analysis of component markets, we draw on the literature on product-market transaction costs. Transaction costs in licensing markets have only recently (and incompletely) been studied, and our analysis of them is based only partly on past research.[6]

[5] The blocking power of such patents provides general incentives for innovation because patent licenses can be traded, usually in exchange for the reciprocal right to use others' patents. However, the returns so obtained are not tightly calibrated to the value of individual inventions, and therefore not well targeted.

[6] Studies by Arora (1995, 1996), and Oxley (1997) have focused primarily on the "appropriability hazard" as a source of transaction costs, which refers to the risk that there can be a leakage of unprotected know-how in a licensing contract. Fosfuri, Arora and Gambardella (1999) have undertaken an extensive survey of the literature on technology markets, and highlight various factors that appear to promote (or inhibit) them. Our analysis specifically highlights the licensing transaction costs introduced directly by patent protection.

3.1 Transaction Costs in Product Markets

In the literature, transaction costs in component product markets have been generally attributed to three phenomena: asset specificity, "dynamic" transaction costs, and team production and monitoring.

3.1.1 Asset Specificity

Asset specificity is a primary explanatory variable[7] in the so-called governance branch of transaction cost economics (TCE) pioneered by Williamson and others. When large investments are made in transaction-specific assets, a co-dependency relationship develops between the component and integrated stages of production, which creates the need for coordinated adaptation when circumstances unexpectedly change. While markets are adept at autonomous adaptation, they are handicapped by potential opportunistic behavior when coordinated adaptation is required. By comparison, internal governance mechanisms give integrated modes an advantage in coordination when asset specificity is high.

Six types of asset specificity have been identified in past research: physical specificity, human asset specificity, temporal specificity, dedicated assets, site specificity, and brand-name capital (Williamson, 1986). In multi-invention contexts, *human* and *physical* specific assets refer to the organizational assets used to integrate a component into an end product. For example, automobile firms have been found to use integrated modes for components that have a high engineering content, indicating high human asset specificity (Monteverde and Teece, 1982). For some multi-invention products, the importance of real time responsiveness to changes in the business environment means that, even if no tangible assets are deployed, there is a pressing need for speedy coordinated adaptation, arising from so-called *temporal* asset specificity.

[7] While other variables like uncertainty and frequency are also predicted to impact transaction costs, these variables have been rather hard to operationalize.

Similarly, real time responsiveness may also require planned investments that are *dedicated* to a future need, which are generally difficult to redeploy quickly.

3.1.2 Dynamic Transaction Costs

It has been suggested that in technologically active environments, integrated modes reduce the *dynamic transaction costs* of informing and persuading all component suppliers to cooperate in combining their capabilities (Langlois, 1991; Langlois and Robertson, 1995). [8] These costs are reflected in missed opportunities and dysfunctional delays in commercialization if external component suppliers are used. Conversely, the cost of internal organization is to not have the capabilities one needs at the right time.

Dynamic transactions costs are high when the nature of innovation is such that changes in the multi-invention product require the coordination of corresponding changes in its components. Teece (1992, 1996) describes this condition as systemic innovation, which, unlike autonomous innovation, is best coordinated by "institutions with low powered incentives, where information can be freely shared without worry of expropriation, where entities can commit themselves and not be exploited by that commitment, and where disputes can be monitored and resolved in a timely way" (Teece, 1996, p. 219) – i.e., by internal organization within a firm.

The study of modularity in product design (Ulrich, 1995) suggests that the systemic nature of innovation is not a purely exogenous variable. Modular design architectures and interface standards can reduce the systemic-ness of innovation[9], and thus mitigate dynamic transaction costs. However, standards bodies can be bureaucratic and conflict-ridden, and

[8] Dynamic transaction costs may appear similar to temporal asset specificity. However, a significant difference is that the latter emphasizes opportunistic behavior, while the former also deals with the problems of convincing boundedly rational actors (in fast moving hi-tech contexts) who may only differ in their beliefs.

[9] However, this usually comes at the cost of product performance, which imposes technology-related constraints on the extent to which such decreases in systemic-ness are feasible.

standardization can come at the expense of relatively slow-moving advances in the standards themselves, which can sometimes become an impediment to technical performance.

3.1.3 Team Production and Monitoring Costs

When the production of multi-invention products has team characteristics, i.e. when the contributions of different components in economic performance are difficult to measure and monitor, integrated modes have an advantage (Alchian and Demsetz, 1972; Holmstrom and Milgrom, 1991). Market modes perform poorly due to "information impactedness" (Williamson, 1975), where information that is privately held, difficult to measure, or unknowable, hinders efficacious contracting. Comparatively, integrated modes are more successful at mitigating conflicts between internal component producing units, even with imperfect information.

Both, component and licensing (see section 3.2.6) markets exhibit measurement and monitoring costs. However, measuring the value and performance of technologies is easier when they are traded in embodied component form than when they are licensed directly. Prices and quantities set through component markets are useful metrics of value, whereas technologies are licensed as a single unit, even though running royalty payments may partly meter use or value over time. Moreover, components typically allow inventions to be used only in specific ways, which not only facilitates price discrimination between different uses, but also allows inventors to retain the residual rights to new and unanticipated applications of their inventions. Moreover, the physical performance characteristics of components are usually easier to measure than the likely performance of technologies.

3.2 Transaction Costs in Licensing Markets

A priori, it would appear that greater total rents from combining inventions should encourage licensing by firms (Kitch, 1977), but these incentives are often overwhelmed by

transaction costs. In licensing, uncertainty looms large – the returns from technologies are highly variable, the applicable patent rights are hard to identify, and even the exact boundaries of the patent rights are often unclear. Market players can strategically use these uncertainties to their advantage, giving rise to "hazards" in licensing contracts, which result in transaction costs.

Transaction costs in licensing also include the organizational costs entailed in the transfer and combination of technologies. Among all licensing-related transaction costs, these organizational costs, described in the first two sections below, apply exclusively to the active licensing of technologies between firms, whereas the others apply to both active licensing and passive, patent-only licensing. However, transaction costs in passive licensing between integrated firms are mitigated if the firms own complementary patents, which cover inventions required to make the same multi-invention product. Then, their ability to mutually block each other from producing the final product acts as a spur to licensing, which often takes the form of cross-licenses that circumvent the mutually blocking patents (Grindley and Teece, 1997).

3.2.1 Technological Interconnectedness

Inventions typically need to be adapted to ensure that they work together in multi-invention products, entailing additional development work. For example, software and semiconductor design modules must be debugged after they are combined, and biotechnology research tools must be adapted to specific research problems. Such mutual adaptation is inherently difficult in licensing modes because it entails open-ended commitments that are costly to specify and enforce through contracts. Moreover, it is often a dynamic problem, involving not only the adaptation of existing technologies, but also the coordination of technological trajectories along which inventions are made.

Some technologies may defy attempts to unambiguously codify deliverables for licensing contracts, resulting in high levels of technological interconnectedness. Consider a biotechnology firm interested in obtaining a license to a research tool that will help it splice a useful gene into the DNA of an organism. It is difficult, *a priori*, to specify the exact "technological artifact" that needs to be transferred here since many unforeseeable adaptations between knowledge about the research tool, the gene, and the organism may be necessary to make the research tool work in this specific role. On the other hand, it is easier to specify deliverables for genomic inventions that are merely the DNA sequences for particular genes.

Thus, technological interconnectedness, like dynamic transaction costs, has exogenous elements. But here too, modular architectures and interface standards can help mitigate transaction costs. However, these standards are technologically, rather than physically, defined. The standards create clear boundaries within which improvement goals for licensed technologies are addressed, while standards bodies manage the evolution of the boundaries over time. Standards can also establish metrics and techniques for measuring deliverables for licensed technologies, thus mitigating the risks entailed in open-ended warranties and after-license support that may otherwise be necessary. In the semiconductor industry, on-chip standards are helping lower transaction costs in the licensing of design modules (Linden and Somaya, 2000).

3.2.2 Transfer of Tacit Know-how

Tacit technological know-how is known to be notoriously difficult to transfer between firms (Polanyi, 1962). Primarily, this is because differences between the organizational contexts within firms make it hard to translate a knowledge base that is poorly articulated and codified. When inventions are (actively) licensed, both tacit and codified parts of the technology need to be transferred. Since the transfer of tacit know-how generally requires a cumbersome

intermediate stage of articulation (Nonaka, Takeuchi and Umemoto, 1996), impediments for licensing will be high if it comprises a significant fraction of the licensed technology.[10]

The inherent difficulty in replicating tacit know-how also affords inventors the ability to protect their inventions using trade secrets. If trade secret protection is the only appropriability mechanism available to them, inventors will be reluctant to license their inventions and run the associated risk of know-how misappropriation. Therefore, effective patent protection can encourage active licensing because tacit know-how elements associated with a patented invention are also protected, in effect, by the patent (Arora, 1995; Arora, 1996).[11] Such licensing would nonetheless be affected by the know-how transfer costs discussed above.

3.2.3 Strategic Isolation of Rents

Inventors can use patents not only to protect rents stemming from the invention itself, but also to protect the entire commercial prospect associated with it (Kitch, 1977). Importantly, the development of rent-generating organizational assets that are complementary to inventions can be protected by patents (Teece, 1986). Patents thus play a significant strategic role as "isolating mechanisms" that protect valuable firm assets from imitation (Lippman and Rumelt, 1982).

Consequently, licensing faces the challenge of compensating patentees, not only for the invention, but also for the other strategic advantages they could obtain from their patent. For example, if a semiconductor firm doesn't license a design and uses it exclusively to produce components, it also obtains rents from component manufacturing and marketing assets that are in-effect protected by the patent(s) on the design. These strategic rents are particularly difficult to contract for, since they are highly uncertain, and cease once the license is concluded. Moreover,

[10] While there are underlying connections between codification and both, tacit know-how transfer and technological interconnectedness, the two phenomena are different. While the former entails problems with the "how" of technology transfer, the latter grapples with specifying boundaries for the "what".

licensees are often concerned about adequate compensation for their own investments in organizational assets required for commercialization. As a result, there may be a bias away from licensing, although this is sometimes mitigated by the need to access complementary assets (Teece, 1986; Arora and Fosfuri, 1998a), and by competition from rival technologies (Arora and Fosfuri, 1998b).

3.2.4 Diffuse Entitlement Problems

When many inventions need to be licensed for use in a multi-invention product, some transaction costs are introduced by the diffuse nature of patent entitlements – i.e. it is difficult to determine which technologies have a legitimate bearing on the product, and who the relevant patent holders are. Firms that own the possibly relevant patents not only have an incentive to misrepresent the validity of their claims, but also to hold out for the most rents.[12] Separating legitimate patents from bogus ones can be both costly and time-consuming, and even if all current patents are identified, patents that are in the pipeline may only be discovered later.[13]

Diffuse entitlement problems are similar to problems in oil field "unitization" (Libecap and Wiggins, 1984; Libecap and Wiggins, 1985; Wiggins and Libecap, 1985), [14] where "the principal sources of contractual failure are imperfect and asymmetric information that prevent[s] agreement on lease values, and holdout strategies of firms to increase their share of unit rents" (Libecap and Wiggins, 1985). Diffuse entitlements, and the valuation problems examined in the

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[11] Similarly, IP rights also provide safeguards against know-how leakage in R&D alliances between firms (Oxley, 1999), mitigating so called "appropriability hazards."

[12] If the final product has already been commercialized, the hold out strategy may be substituted for a "haul in" strategy, where the patent owner threatens to shut down the firm's production early, and thus extract the most rents. Later claimants may be constrained by a perceived need to ensure the viability of the licensee's business.

[13] To counter these uncertainties, semiconductor cross-licenses are defined by field of use and include a "capture period" for patents that are in the pipeline (Grindley and Teece, 1996).

[14] *Unitization* refers to the efficient exploitation of a common pool of oil by a single operator, where the pool itself is covered by multiple field leases. Unitization is not commonly observed in oil fields, and is generally achieved only late in the life of the field, suggesting deep contractual problems in negotiating unitization arrangements.

next section, can make licenses cumbersome and haggle-ridden. If both patent entitlements and the value contributed by each invention were clear *ex ante*, licensing could be more efficacious.

But absent such clarity, licensees are concerned about *royalty stacking*, where multiple patentees lay claim to excessive rents from the same multi-invention product. Licensees are worried by both cross-sectional and longitudinal uncertainties – i.e., there may not only be other unknown patents that "read" on the product, but commercialization of the product may also require new technologies that have not yet been considered. [15] These uncertainties in assessing future claims decrease their willingness to share rents from multi-invention products, and therefore increase transaction costs in licensing.

3.2.5 Valuation Problems with Technological Assets

Technologies are typically subject to large technical and commercial uncertainties, which can make it very difficult to resolve differences in beliefs about an invention's value, introducing substantial transaction costs (Merges and Nelson, 1990, 1994; Merges, 1994). Moreover, experimental evidence suggests that individuals exhibit self-serving biases in assessments of fairness in bargaining (Loewenstein, Issacharoff *et al.*, 1993; Babcock, Loewenstein *et al.*, 1995), which only exacerbates the valuation problem because it means that licensers will be systematically more optimistic than potential licensees about the value of inventions.

In addition to overall technological uncertainty, the value contributed by any individual invention to a multi-invention product is also often unclear. In part, this is because each invention is an indivisible joint input into a final product, and in that context, the economic problem of allocating rents between the inputs is indeterminate. Moreover, since inventions are highly idiosyncratic and cover unique domains in technology space, it is difficult to determine a

[15] Heller and Eisenberg (1998) refer to these as *"concurrent fragments"* and "*royalty stacking [sic]"* respectively.

fair value by comparing them with similar inventions. However, if the licensee can choose between rival technologies, valuation problems are likely to be less severe.

Valuation is also often difficult because, in addition to inherent technological uncertainty, patent rights have *fuzzy boundaries* – i.e., their meets and bounds are not clear *ex ante*. The problem is exacerbated when the quality of issued patents is poor, as is alleged for U. S. patents in new subject matter like software (Merges, 1999). Since the true validity and extent of property rights conferred by a patent may only be ascertained after lengthy and expensive legal proceedings, this leads to more strategic games and transaction costs during licensing negotiations.

3.2.6 Monitoring and Measurement Problems

In theory, accurate measures and transparent monitoring could solve many of the transaction cost problems discussed above. For example, valuation differences may be reconciled by basing the returns to inventors on the actual contribution of their inventions to the commercial success of a multi-invention product. Strategic concerns can be resolved by using measures that determine the actual rents forgone by inventors on account of their licenses. Even diffuse entitlement and technological interconnectedness problems could be mitigated if perfect monitoring and perfect measures were available.

In practice, perfect measures – objective, observable, and non-manipulable – typically do not exist. Moreover, there are often conflicts between the goals addressed by these measures.[16] Perfect monitoring is also impractical because many outcomes are inherently unobservable, and firms have incentives to misrepresent private information. Therefore, licensing arrangements must generally make do with the most practical monitoring and measures available. These are

inherently imperfect, and introduce transaction costs by creating rigidities in licensing contracts and exposing them to hazards. For example, one practical way to address strategic concerns about protecting rents from an inventor's established business, and from new unexpected applications, is to include field-of-use restrictions in the license contract. But using this somewhat crude measure implies that licensees may sometimes not have the flexibility to address changing market needs, while licensers also bear the risk that the specified field-of-use may include some major unanticipated future application of the invention.

As noted earlier, monitoring and measurement problems are generally more endemic in licensing markets than in component markets due to the inherently inchoate nature of the technological domain. But, the advantages of component modes do come at a cost – there is far less flexibility when combining components, as against licensed technologies.

4. Applying the Framework

We illustrate the use of the framework to assess the impact of policy changes by examining two multi-invention contexts in this section – viz., the combination of semiconductor design inventions in systems-on-a-chip (SOCs), and the combination of biotechnology research tool and genomic inventions in the discovery of disease therapies.

Relentless miniaturization has made it possible to put entire electronic systems on a single semiconductor chip (Linden and Somaya, 2000). Market demand for the advantages in size, power consumption, and production cost that such systems-on-a-chip (SOCs) promise has also been growing rapidly. Large semiconductor firms, with broad portfolios of in-house designs, were the first to address the emerging SOC opportunities, using predominantly integrated modes.

[16] For example, inventors may prefer fixed license fees so that licensees have incentives to expend (unobservable) effort in commercialization, even though running royalties are better at measuring the actual value generated by their inventions (Gallini and Wright, 1990).

Simultaneously, a number of other firms began a cooperative effort to use licensing modes based on tradeable design modules (DMs), which is gaining momentum. However, design module licensing still faces many challenges, and patent-related public policy will likely play an important role in determining its success.

In the biotechnology industry, research tools and genomic inventions are critical inputs in the development of new therapeutic end products. Two pioneering research tools, recombinant DNA and monoclonal antibodies, were literally the foundation upon which the industry was built in the late 70s.[17] As research tools and genomic inventions have proliferated, the patents covering them have raised concerns about a *tragedy of the anti-commons*, resulting from the under-utilization of those inventions due to high transaction costs (Heller, 1998; Heller and Eisenberg, 1998) [18]. The role of exclusive rights in biotechnology innovation is extremely complex, and spans private firms, sponsored research, and the clashing cultures of academic and commercial science (Eisenberg, 1987; Eisenberg, 1989; Eisenberg, 1994; Eisenberg, Massaro and Sage, 1996). Here, we will focus almost exclusively on one issue in this domain – the impact of stronger patent protection on the effective creation and use of inventions.

4.1 Salient Features of Alternative Organizational Modes

The potential advantages and drawbacks of different organizational modes are central to the impact of policy changes in multi-invention contexts. These are summarized in Table 1. In addition to the transaction costs discussed earlier, these advantages and disadvantages are also determined by features of the appropriability mechanisms available to obtain returns from

[17] The two tools were widely available to other researchers – the former was licensed on relatively lax terms by the patent owners, Stanford University and the University of California, and the latter was placed in the public domain.
[18] Heller (1998) defines anti-commons as a situation where "multiple owners are each endowed with the right to exclude others from a scarce resource, and no one has an effective privilege of use. When there are too many owners holding rights of exclusion, the resource is prone to underuse – a tragedy of the anticommons" (p. 624). In

inventions. Not only do different organizational modes generally rely on different mechanisms to appropriate returns on innovation, but they also lead to different effects on the innovative process itself. With well-functioning market (licensing and component) modes, the modularity literature (Langlois, 1992; Langlois and Robertson, 1992;Langlois and Robertson, 1995) suggests that powerful benefits for innovation can be reaped.

[Table 1 about here]

These benefits stem from at least three sources. First, specialization creates targeted incentives for making and commercializing inventions in an autonomous fashion. Second, decentralized innovation results in greater experimentation and trial-and-error learning, increasing the chances of discovering different market needs and finding superior solutions. Finally, licensing and component trade can save on costs of excessive reinvention, and make best-in-class inventions available to the entire industry.[19]

4.2.1 Licensing Mode

Licensing modes facilitate the independent commercialization of inventions, and thus access the benefits of market-based organization discussed above. Moreover, because few complementary assets are required for the commercialization of inventions in licensing modes, they target incentives even more specifically at inventions than component modes. However, these benefits can only be reaped by licensing modes if inventions, once made, can be protected from imitation. Since secrecy and complementary assets are generally ineffective as appropriability mechanisms with licensing, the reliance on formal intellectual property rights, like patents, is greater. Absent such appropriability guarantees, licensing modes are unable to

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biomedical research, "the tragedy of the anticommons refers to the … complex obstacles that arise when a user needs access to multiple patented inputs to create a single useful product" (Heller and Eisenberg, 1998, p. 699).

[19] It has been argued that stronger patents in software will have precisely this effect (Lemley and O'Brien, 1997).

access their potential market-driven advantages, while at the same time being burdened with transaction costs.

As described earlier, there are many sources of transaction costs in licensing, but their levels vary depending on the circumstances. For example, know-how associated with some inventions may be particularly difficult to transfer, or inventions in some products may be very strongly interconnected. Transaction costs associated with licensing modes tend to be high because the technology domain is generally unfriendly to measuring and monitoring contractual performance. But, transaction costs associated with know-how leakage hazards can sometimes be mitigated by related patents, which provide safeguards in such licensing transactions. Nonetheless, in some cases, transaction costs in licensing are so high as to render licensing modes unviable, irrespective of their positive effects on innovation.

4.2.2 Component Mode

Like licensing modes, component modes also enjoy the benefits from being market-based. However, unless components are commercialized with only generic complementary assets, the incentives provided tend to be more diffuse than with licensing since they are targeted jointly at inventions and their co-specialized complementary assets. In component modes, secrecy and firm-specific complementary assets[20] can also work as appropriability mechanisms. In comparison to integrated modes however, component complementary assets are related to intermediary markets and therefore typically less valuable. Moreover, since secrecy is also imperfect, patents are important appropriability mechanisms in component modes as well.

[20] Firm-specific complementary assets (so-called "resources") can serve as appropriability mechanisms in the absence of patent protection because, even if the inventions themselves are imitable, the associated assets, which are required for commercialization, are not. Firms obtain returns on their inventions because the inventions increase the marginal product of these complementary assets. However, since only firms that own complementary assets have incentives to innovate, widespread experimentation and learning is generally not encouraged.

Component modes often enjoy lower transaction costs than licensing due to their advantages in measurement and monitoring, but sometimes, even these transaction costs may be too high, favoring integrated modes. In particular, the systemic-ness of a technology domain may contribute significantly to dynamic transaction costs. In some cases, these may be mitigated by technology standards, but in others, publicly negotiated standards may be impractical.

4.2.3 Integrated Modes

Integrated modes lack the targeted incentives and other advantages enjoyed by market modes, but they can overcome transaction costs by coordinating multi-invention products using internal governance. Secrecy and complementary assets are also more effective with integration, making patents somewhat less important for appropriating returns. In addition, integrated modes are able to access some of the benefits of market modes through passive licensing and merger markets, but these entail other transaction costs. Passive licensing only becomes necessary when patents are effective, reflecting the resulting claims on rents from inventors. However, rent allocation to inventors is quite imperfect in passive licensing. Since such licensing is typically based on the need to trade blocking patent rights, incentives are not well-targeted at inventions, and firms appropriate rents primarily by commercializing end products and restricting entry to only those firms that have complementary blocking patents.

Passive licensing markets are free of the costs of transferring tacit know-how between firms, and the difficulties associated with making licensed technologies work with internal ones, but other types of licensing transaction costs are relevant. However, when firms hold mutually blocking patent rights, commercial necessity helps mitigate these transaction costs. Integration using mergers may preserve some targeted incentives for innovation, but it also must bear the transaction costs in merger markets. These costs can be quite substantial, stemming not only

from the costs of completing the transaction, but also from the substantial organizational costs of assimilating the merged firm and its technologies. Despite these costs, when licensing and component markets are also plagued by high transaction costs, and blocking patent rights pose a one-time problem, mergers have been used as a workable solution.[21] Moreover, merger markets may avoid some of the costs of transferring tacit know-how since the organizational units where the know-how resides are integrated (through merger) within the same firm. The increasing influence of venture capital in high technology industries also creates a bias in favor of merger markets due to its attractiveness as an exit option.

4.2 Impact of Policy Changes

Since economic outcomes in the framework are primarily a result of tradeoffs between organizational advantages and costs, we treat any policy domain that affects them as a legitimate instrument of patent policy. Patent related public policy can influence outcomes in two ways. First, by affecting transaction costs in various markets, it determines the effectiveness with which inventions are combined. Second, it influences the size and share of rents appropriated by various players, including inventors, and thus determines incentives for innovation.

Consider how changes in the strength of patent protection may affect the invention and use of research tools and genomic inventions. As patent strength increases, the ability of inventors to bargain over the available rents also increases because other firms find it harder to invent around, overturn a patent, or get away with low damages for infringement. The

[21] For example, when disagreements over patents held by Marconi and de Forest were holding up development of the radio, the U.S. government intervened and created the Radio Corporation of America (RCA) by merging the two firms in 1919 (Merges and Nelson, 1990). More recently, long-running legal conflicts over microprocessor patents held by Intel and Digital were resolved through a sale of Digital's semiconductor manufacturing division (along with a patent cross-licensing arrangement) to Intel [Caisse, Kimberly, and Kelly Spang. "All's quiet on the Intel-Digital front." Computer Reseller News, no. 761 (Nov 3, 1997):12.]

remarkable success of private genomic firms in sequencing the human genome alongside the publicly financed Human Genome Project reflects the incentives provided by these rents.

Without patents, the market-based advantages of licensing and component modes for innovation (which we label simply as "incentives") are severely compromised due the weak bargaining position of inventors. But, with stronger patents, these "incentive" advantages grow more quickly for licensing and component modes than integrated modes, reflecting their market-based advantages. In figure 4, we illustrate these incentive effects for licensing, which grow much faster with patent strength than those for integration.

[Figure 4 about here]

Increasing patent strength also has an impact on transaction costs in various markets. Stronger patents can increase licensing transaction costs through their interactions with strategic isolation, valuation disputes, and diffuse entitlements. At the same time, they may also sometimes reduce transaction costs by decreasing the risk of know-how misappropriation. Stronger patents also imply that integrated firms are more likely to need (patent) licenses, which entail transaction costs in addition to the governance costs of integrated modes.

In figure 4, the level of organizational costs (the sum of transaction and governance costs) without patents (zero patent strength) is lower for integrated modes than licensing. But as patent strength increases, the organizational costs of integration rises at a faster rate than licensing because we assume some salutary effects from patent safeguards for licensing. This would result, for example, if stronger patent protection encourages firms to license know-how intensive research tools that they would otherwise protect as trade secrets. Nonetheless, the organizational cost of licensing is always higher than integration.

By adding the effects of patent strength on organizational costs and incentives for innovation, we obtain the net organizational advantage that separates the two organizational modes. Without patents, we observe a net advantage for integrated modes, but as patent strength increases, licensing eventually becomes the superior mode. The organizational advantage of integrated modes decreases with patent strength in absolute as well as relative terms, which is consistent with the criticism leveled at strong patents. However, licensing modes eventually catch up with the absolute advantage (the difference between organizational costs and incentives for innovation) initially enjoyed under integration. Figure 4 also illustrates that when organizational choice favors licensing, the switch comes at the expense of higher organizational (transaction) costs, which are offset by better incentives for innovation.

Ultimately, the specifics of organizational choice depend on the assumptions about how incentives for innovation and organizational costs respond to patent strength. In some cases, increasing patent strength may increase organizational costs for both modes at a faster pace than incentives for innovation, and thus lead to an organizational disadvantage. In other cases, incentives may rise fast enough to increase the organizational advantage for both modes, but integration may continue to be superior. Component modes were not included in figure 4 to reduce confusion, but a similar analysis could be conducted if they were.[22]

Patent parameters like strength are not the only public policy tools available for multi-invention contexts. For example, a number of policy interventions could alter the effectiveness of licensing modes for combining design modules in SOC semiconductors. A lenient antitrust view could help firms set up cooperative patent dispute resolution mechanisms, or government

[22] The most relevant types of components in this domain are research materials. While trade in these components may be the most effective mode in some cases, it is important to point out that some of the traditional benefits of component modes, which stem from their ability to measure the value of an invention through market prices and volume, may be less effective with research tools, which are only used in the discovery of the final products.

intervention may speed-up the development of standards that help to mitigate technological interconnectedness problems. In Figure 5, the impact of a reduction in licensing transaction costs arising out of such policies has been examined. When organizational costs are thus reduced, there is also a positive feedback effect on incentives through an increase in the level of rents available (see Figure 3 and accompanying discussion). Thus Figure 5 depicts both these effects.

[Figure 5 about here]

As Figure 5 shows, the reduction in licensing transaction costs not only makes licensing modes superior to integration at much lower levels of patent strength, but it also makes licensing clearly more advantageous in absolute terms. Here, as in the previous case, the actual effects are sensitive to the assumptions about organizational costs and incentives.[23] In addition, component modes, which are not shown in Figure 5, may be more effective than either licensing or integration in some instances.[24] Finally, it is important to note that although transaction cost interventions do not entail a negative impact on incentives for innovation, they typically involve trade-offs in other spheres – e.g. forced standardization could compromise potentially useful competition between standards.

We have seen that public policy can alter the optimal form of organization in commercializing multi-invention products. In turn, this implies that it would be inappropriate to evaluate policy options based purely on existing organizational modes of commercialization. Moreover, we have observed trade-offs between the benefits of incentives for invention created in one organizational form and the lower transaction costs offered in the other. If it is clear that the transaction costs in market modes will be too high, it may be prudent to design public policy

[23] For example, diffuse entitlement problems may cause organizational costs to grow much faster for licensing than integration because the latter can rely on low-cost, hold-up induced patent licensing.

that favors integrated modes with low transaction costs. But in other cases, it may be sensible to live with higher transaction costs if the incentive benefits in licensing or component modes are worthwhile. There has been a long tradition in patent policy to try and strike a balance between these two effects – encouraging innovation on the one hand, and facilitating its use on the other.

5. **Lessons for Public Policy**

Overall, our conclusions for public policy are generic, and appropriately so – specific recommendations require an in-depth understanding of the technological, institutional, and commercial context in which public policy guidance is sought. The analysis of organizational challenges in commercializing multi-invention products has yielded two main ideas in this paper. First, licensing modes, component modes, and various integrated approaches to commercializing multi-invention products can be viewed as alternatives to each other. Second, organizational costs, including the transaction costs in licensing and component markets, play an important role in multi-invention products, not only affecting the efficacy with which inventions are combined, but also determining which organizational modes will prevail.

5.1 Policy Goals and Organizational Choice in Multi-invention Products

Policy goals in multi-invention contexts are unlikely to be the same everywhere. Nonetheless, they will generally involve tradeoffs between two main objectives – fostering innovation, and encouraging its effective use. In any given context, myopically focusing on one of these goals to the exclusion of the other will invariably result in poor policy decisions. Our analysis specifically incorporates both goals by examining the impact of public policy through its effects on incentives for innovation, and on the organizational costs of combining them.

[24] In particular, such component modes can be implemented using multi-chip modules (MCMs). Although MCM is a technically inferior technology than SOC, organizational advantages gained from using component modes may

Recent criticism about the deleterious effects of strong patent rights has centered not on the irrelevance of incentives in multi-invention contexts, but on the impediments that patents pose for the combination of inventions. However, a dispassionate examination of tradeoffs may find that maintaining the strength of patent rights is worthwhile for at least three reasons. First, stronger patents may induce a shift in organization mode, away from integration. The resulting licensing or component modes may provide overall organizational advantages, despite higher transaction costs. Second, even with an integrated mode, the innovation engendered by stronger patents may make higher organizational costs worthwhile. Finally, stronger patents may actually reduce some forms of transaction costs in component and licensing markets – for example, by safeguarding transactions from leakage of tacit know-how – which may compensate for the other transaction costs created by stronger patents in some cases.

An important variable in any analysis of patent policy tradeoffs is the impact of incentives created by stronger patents on innovation. Strong patents not only provide incentives for the creation of new inventions, but, according to some patent theories, they also encourage their development and disclosure (Mazzoleni and Nelson, 1998). Nonetheless, incentives are ultimately demand side instruments for encouraging innovation. If innovation is substantially supply-driven,[25] incentives provided through patent rights may be less important, and in some cases even harmful. In our analysis, this would imply that the advantages of incentives for innovation, as depicted in Figures 4 and 5, would not rise as rapidly with patent strength.

The debate about the importance of supply-side and demand-side factors in innovation needs to be resolved in a context-specific manner. For example, in biotechnology, where the link

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offset its technical disadvantages.

[25] Naturally, when incentives are provided for innovation, one is led to conclude that investments will be made in improving the supply of inventions. However, it may sometimes not be possible to significantly increase the pace of

between science and commercial research is strong, an environment charged with incentives may impede the vibrant combination and recombination of knowledge among scientists and affect supply. Prior research has commented on how such changes to the "culture of science" have undermined long established norms of collegial cooperation, and may have retarded innovation (Eisenberg, 1987; Eisenberg, 1989). Ultimately, if incentives are ineffective in encouraging the creation and development of inventions, it would not be wise to encumber their use through stronger patents. Instead, economic arguments would favor supply side efforts (such as government funding and university research) to increase the flow of inventions. However, incentives are critical for innovation in many areas, and take on particular importance when there is a reluctance to use public finances to support research.

5.2 Choosing between Alternative Policy Instruments

In response to transactional problems in multi-invention contexts, the instinctive remedy sought is often a weakening of patent rights. Although this solution does address the transaction cost problems, it also means a weakening of incentives for innovation and the reinforcement of integrated modes of production. Therefore, it may not be the optimal response in many cases.

While stronger patents can make integrated modes less effective, component and licensing modes benefit from the resulting incentives, and in some cases, even from lower transaction costs. Evaluation of these alternative organizational forms is essential in any attempt to rectify organizational problems in multi-invention contexts. In addition, these problems can be addressed directly by using other instruments to reduce transaction costs in specific markets, instead of resorting to weaker patent rights. Since these instruments do not bring with them the incentive problems of weak patents, they may actually be preferable in many cases.

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innovation through additional investments, or the incentives for innovation may not translate into such investments

An understanding of the problems that impair licensing and component markets can help one identify these alternate policy instruments. As mentioned earlier, the fuzzy boundaries of patent rights can introduce valuation-driven transaction costs in licensing markets. As a practical matter, it may be too costly to delineate the exact boundaries of each patent, and therefore more efficient to be precise for only the most important patents, which is typically done in litigation. However, there may be room for improvement over the current situation in the U. S. Patent and Trademark Office, where the quality of issued patents appears to be driven more by expedient staffing considerations than the social costs and benefits of clearer patent rights (Merges, 1999).

Transaction costs in licensing and component markets can also be lowered through supporting institutions that provide context-sensitive assistance in addressing specific problems – for example, in managing interface standards, in identifying relevant patents and resolving disputes over them, and in monitoring and measurement. Merges (1996) and Arora, Fosfuri and Gambardella (2000) have found that private institutions for licensing exist in many industries. Standards setting institutions, which can help lower transaction costs in either licensing or component markets, are also common in many contexts.

However, private entities are often unable to internalize the benefits of building these institutions, and sometimes, a subset of firms may even block such efforts in their own self-interest. Public policy may therefore have a limited role in helping overcome the resulting collective action problems. This is not a new idea. In the past, public policy has played a key role in fostering patent pools (e.g., in the aircraft industry), in merging firms with irreconcilable differences over blocking patent rights (e.g., the creation of RCA), and in forming collective

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because they entail high risk or exhibit public good properties (e.g. higher education).

rights organizations for trading intellectual property rights (notably, ASCAP and BMI for trading copyrights in the entertainment industry) (Merges, 1996; Bittlingmayer, 1988).[26]

Ultimately, if neither licensing nor component markets can be made to work effectively, and strong patents continue to impede integrated approaches, a reduction in patent rights may be the best way to achieve public policy goals. But, it is important that the other alternatives be carefully examined first, before such a solution is implemented. Where possible and necessary, reductions in patent rights should also be offset by supply-side initiatives to foster innovation.

5.3 Implications for Antitrust Analysis

Private institutions that foster licensing and components transactions cannot function well if their legitimate efforts are stymied by antitrust and patent misuse laws. Similarly, suspect provisions in bilateral contracts between firms may also reflect a legitimate need to reduce transaction costs. Consistent with the Antitrust Guidelines for the Licensing of Intellectual Property, [27] it would be appropriate to evaluate these features through a "rule of reason" lens. In fast-moving, innovative industries, Schumpeterian competition from new technologies tends to drive out inefficient collusive practices pursued by incumbent firms. By comparison, the organizational impediments to creating and using inventions are likely to be more problematic. The analytical framework and sources of transaction costs described in this paper suggest concrete ways in which the rule of reason can be applied to evaluate if the practices in question play a legitimate role in facilitating the use of inventions in multi-invention contexts.

[26] However, we share Professor Merges' concerns about the political and bureaucratic inflexibility of publicly run institutions (Merges, 1996). Therefore, public policy efforts should be directed primarily at helping private industry overcome its own collective action problems, rather than substituting public institutions for private ones. For example, public policy may choose to support private industry in efforts like RAPID (Reusable Application-Specific Intellectual Property Developers) and VCX (Virtual Component Exchange), which seek to facilitate trading in semiconductor design modules, as well as VSIA (Virtual Socket Interface Alliance), which is trying to develop interface standards for such design modules.

[27] See note 1, supra.

The organizational modes used to combine inventions in multi-invention products have implications for industry structure. This is especially true in highly innovative industries where the organization of innovation is often synonymous with the organization of productive activity. A predominance of integrated modes in multi-invention products suggests greater industry concentration along the vertical value chain. Conversely, licensing and component modes indicate vertical fragmentation. The proliferation of such market modes can encourage entry into an industry through specialized component or technology niches. Patent rights can be critical for the survival of these innovative entrants, who lack complementary assets, but are a vital source of Schumpeterian competition in high-tech industries.

In some cases, component or licensing modes may become so successful as to emerge as a distinct industry in its own right (e.g., the computer disk-drive industry, and the emerging "chipless" semiconductor industry that produces design modules for SOC). Multi-invention products thus produce new challenges for conventional industry analysis since industry definitions and structures become somewhat fluid concepts in this domain.

6. **Discussion and Conclusion**

In this paper, we have described the main challenges presented to patent policy by multi-invention contexts, and suggested a somewhat simplified approach to analyze such contexts. The complex circumstances of real-world multi-invention products add some wrinkles to our neatly arranged framework, and we suggest some practical approaches to extending the framework to these situations below.

6.1 Broadening the Framework

To simplify our analysis, we have assumed a rather specific definition of multi-invention products so far – the inventions are non-cumulative and product related, they can be embodied in separable components, and can be protected by patents. In practice, multi-invention contexts may be of many other types – the inventions involved may be cumulative, or difficult to separate into components; they may be process rather than product related, or covered by some other form of intellectual property (IP) right than patents. Despite the simplicity of our framework, it can be extended to cover at least some of these contexts.

Our basic multi-invention model is one where the inventions are "complementary" to each other, and not cumulative as in other research (Scotchmer, 1996; Green and Scotchmer, 1995; Chang, 1995). In the latter case, the use of derivative downstream inventions requires a license from the owners of up-stream parent patents. Since follow-on inventions cannot be legally embodied in independent components, component modes are unworkable in the cumulative context, which allows only a truncated application of our framework. Similarly, in contexts where components are infeasible for technical reasons, integrated and licensing modes are again the only organizational alternatives for commercialization.[28]

In practice, multi-invention products often include both complementary and cumulative elements. For example, a semiconductor device may be comprised of complementary sets of inventions, such as those related to central processing and graphics, but each set may include many cumulative inventions. The organizational choice set may be restricted to licensing and

[28] Sometimes, alternative production technologies may exist that allow the use of separable components, but are not technically optimal. The component mode enabled by such alternative production approaches can be included in the analysis, if its organizational advantages are likely to outweigh the technical drawbacks. For example, even though SOC technology does not permit separable semiconductor components, a different technology called multi-chip modules (MCMs) can be used in component mode. MCMs lack many of the technological advantages of SOCs, but the access to component markets can provide off-setting benefits.

integrated modes among the cumulative inventions *within* such complementary sets of inventions, but at the interfaces *between* them, the framework can potentially be applied in full.

This innovation in extending the framework implies the selection of progressively higher levels of analysis in sequentially nested steps. Thus, many cumulative or technologically non-separable inventions may be subsumed within a larger "invention unit", which is in turn integrated into a multi-invention product. However, application of the framework at the latter, aggregate stage must take into account the licensing arrangements, if any, at the prior stage. For example, licensing remains an option with an aggregate invention unit that includes licensed inventions only if the licenses at the prior stage permit it. Extension of the framework in the manner suggested above can prove to be very powerful, especially if the aggregate invention units follow the "natural fault lines" along which the choice of organizational mode is economically significant in multi-invention contexts.

Extending our full framework to process inventions is a more difficult challenge since it is typically hard to define the components in which process inventions may be embodied. In some contexts, these inventions can be embodied in components that are traded in the capital goods market (e.g. specialized equipment) or used in a process (e.g. catalysts, or research materials). In general however, organizational choice in process inventions may primarily be between integrated and licensed modes.

With non-patent forms of IP protection, there are differences not only in the nature of what is being protected, i.e. in subject matter, but also in the type of protection available. For example, copyright is used to protect technology as "expression", which is at a less abstract level than the inventions protected by patents. Moreover, trade secrets can only be protected from misappropriation, so that independent invention (including legal reverse engineering) is immune

from trade secret enforcement. Ultimately, these differences present an opportunity to use the framework to address questions about what form of IP protection is most appropriate in a given context, but we do not undertake such an exercise here.

6.2 Discreteness of Organizational Alternatives

Thus far, we have maintained an assumption that inventions are available in precisely two discrete forms – either as "abstract" technologies, or as "fully embodied" products (components). Abstract technology can be thought of as the "idea" behind the invention, the true inventive step if there is one. Similarly, embodied technology can be thought of as an immutable physical form that enables only one highly specific use of the technology. In practice, many intermediate stages of embodiment (or abstraction) of an invention may be possible – e.g. technologies may be "reduced to practice" by incorporating them in detailed designs, or components may incorporate various degrees of flexibility for adaptation in integration.

We accept as conceptually and empirically accurate the availability of a "continuum" of embodiment for technologies. Correspondingly, there is also, in practice, a range of organization forms between the extreme licensing and component modes we have assumed. However, using "abstract technology" and "fully embodied products" as representative polar extremes has helped us shed light on the primary trade-offs involved, even between intermediate cases of lesser or greater embodiment.

There are also many intermediate organizational forms between licensing and component modes on the one hand, and integrated modes on the other. For example, joint ventures are often formed between firms to combine their technologies and develop new products. In some cases, inventions can be licensed exclusively to one firm, rather than being licensed non-exclusively to many. Similarly, close, exclusive relations often develop between firms to trade components,

which incorporate many governance structures similar to an integrated firm. Again, our analysis has not sought to address all these possibilities, but merely to illustrate the possible tradeoffs by examining the polar extremes.

6.3 Concluding Comments

The ability of economics to inform public policy in the area of IP has often been considered suspect. In a congressional report, Fritz Machlup once famously stated:

> "If we did not have a patent system, it would be irresponsible, on the basis of our present knowledge of its economic consequences, to recommend instituting one. But since we have had a patent system for a long time, it would be irresponsible, on the basis of our present knowledge, to recommend abolishing it"[29]

However, it may no longer be necessary to accept this dismal conclusion. Our understanding of the economic features of intra-firm and market-based organization has considerably improved. Empirical studies of innovation in different contexts have also advanced our real world understanding of the role of patents. In this paper, we have drawn on these advances to provide an integrative framework for a set of problems that appear to be increasingly common in dynamic innovative industries. In turn, we hope that the framework we have laid out will help public policy arbiters who have frequently had to formulate patent-related public policy with no systematic guide but precedent.

[29] Machlup, Fritz. 1958. "An economic review of the patent system," Congressional Report No. 15, Washington DC: U.S. Govt. Print. Off. (pp. 80).

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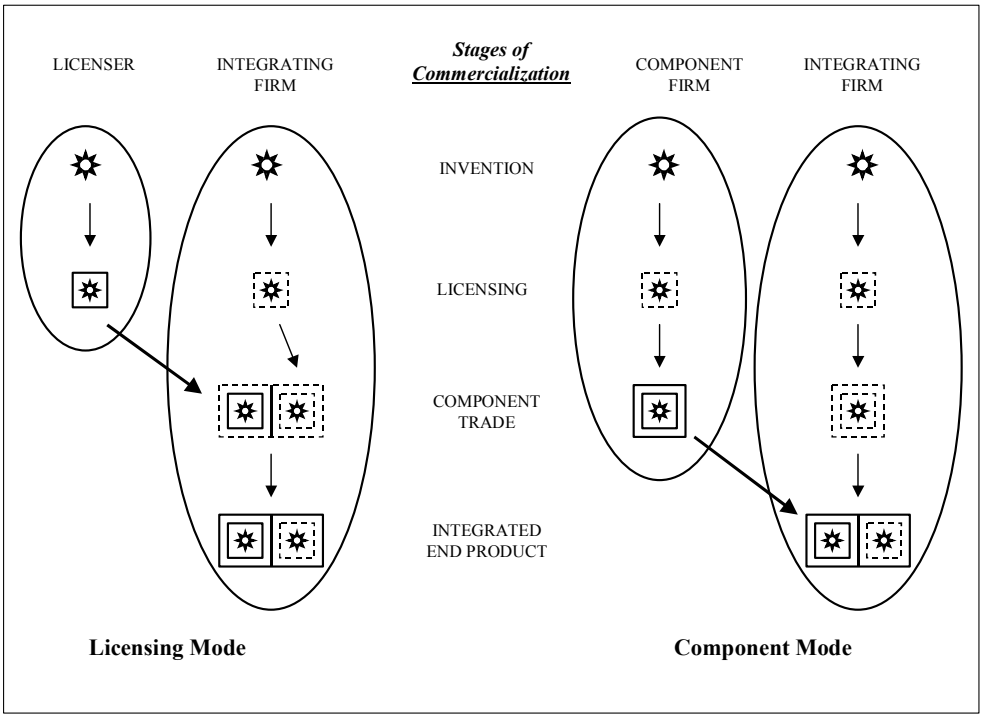

Figure 1: Licensing and Component Modes of Organization in Multi-invention Products

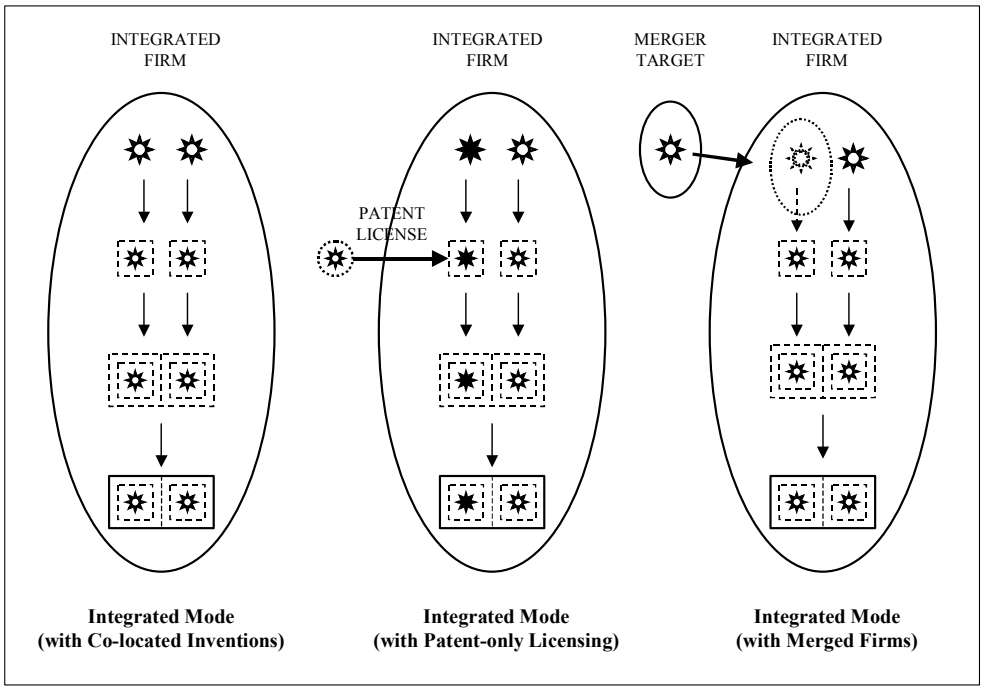

Figure 2: Different Integrated Modes in Multi-invention Products

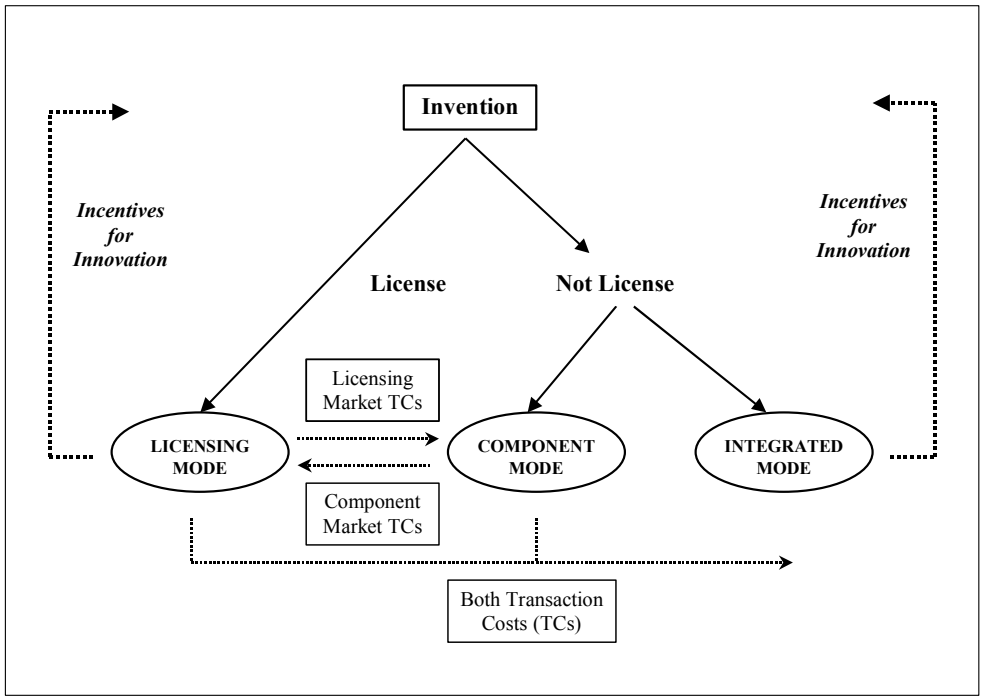

Figure 3: A Framework for Organizational Choice in Multi-invention Products

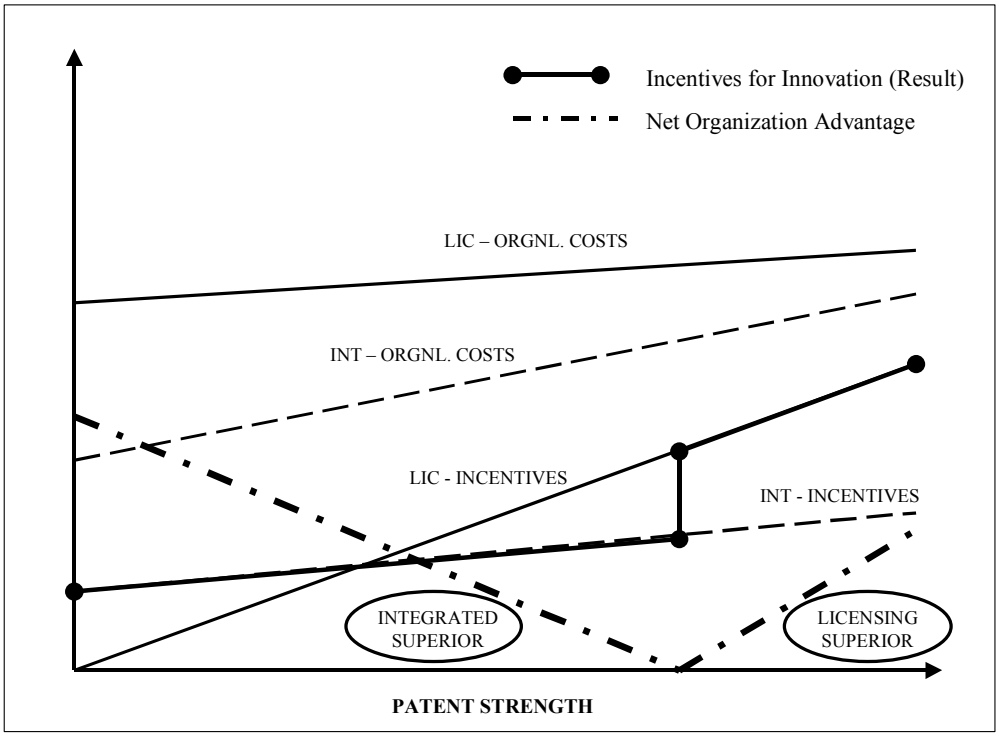

Figure 4: Impact of Patent Strength on Organization in Multi-invention Products

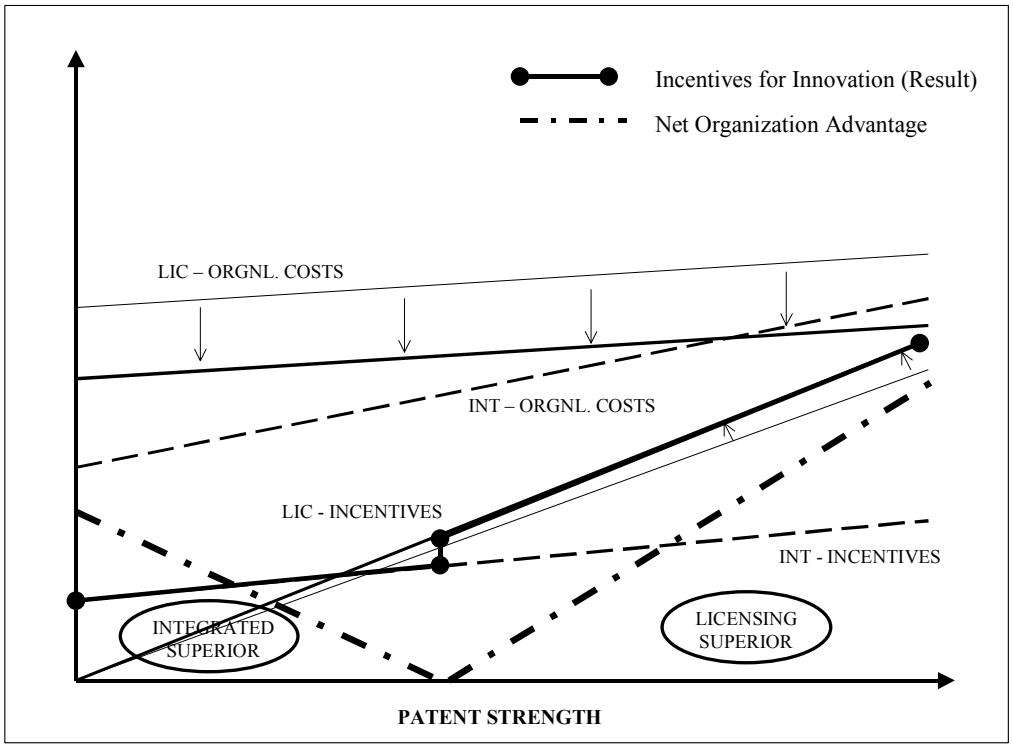

Figure 5: Impact of Transaction Cost Changes on Organization in Multi-invention Products

Table 1: Organizational Modes and Their Associated Organizational Costs and Benefits

Organizational Mode	Organizational Costs	Effects on Innovation	Impact of Patents
(Active) Licensing Mode	Transaction costs arising from many sources. Generally, higher than components due to imperfect monitoring and measurement.	Highly targeted incentives, greater experimentation, and widespread access to best-in-class inventions.	Increases transaction costs from strategic isolation, diffuse entitlements, valuation differences, and monitoring and measurement. May decrease costs of transferring know-how. Critical to realizing incentives for innovation.
Component Mode	Transaction costs arising from specific assets, dynamic transaction costs (systemic-ness), and measurement and monitoring.	Well targeted incentives, although returns accrue to complementary assets as well.	May increase transaction costs due to patentee's better negotiating position. Important for innovation incentives, although secrecy and complementary assets can help with appropriating returns.
Integrated Mode:	Mainly governance costs arising from intra-firm organization.	Diffuse incentives targeted generally at the entire product. Some incentives from secrecy and complementarities with other firm assets.	Generally renders this integration mode unviable since the probability that original inventions are co-located is low.
with (Passive) Patent Licensing	Additional transaction costs in licensing, arising only from strategic isolation, valuation, diffuse entitlement, and measurement problems.	Additional targeting of incentives from trading value of patent rights.	Increases patent licensing costs, but also provides some incentives for innovation by improving patentee's negotiating position.
with Mergers	Additional transaction costs in merger markets, before and after the transaction. Potential mitigation of know-how transfer costs.	Best targeting of incentives among integrated modes, realised in market price of target innovative firm.	Increases merger negotiation costs by providing target with viable component and licensing options, but also reinforces incentives for innovation.