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Fabio Landini

Institutional Change and Information Production

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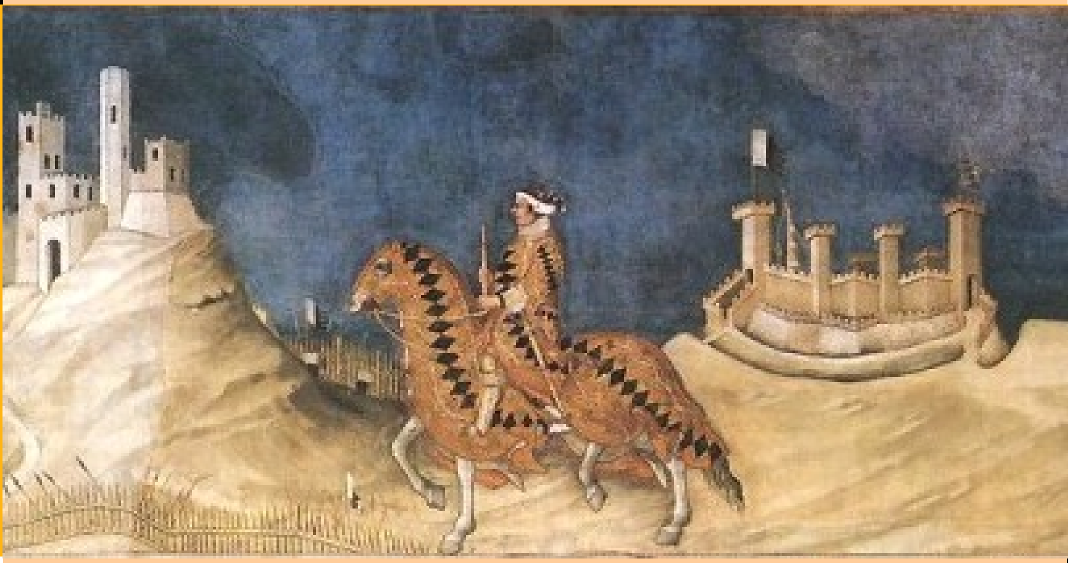

Abstract - The organization of information production is undergoing a deep transformation. Alongside media corporations, which have been for long time the predominant institutions of information production, new organizational forms have emerged, e.g. free software communities, open-content on-line wikis, collective blogs, distributed platforms for resource sharing. The paper investigates the factors that favoured the emergence of these alternative systems, called peer production. Differently from most of the previous literature, the paper does so by considering technology (i.e. digital code) as an endogenous variable in the process of organizational design. On this basis the paper argues that the diffusion of digital technology is a necessary but not sufficient condition to explain the emergence of peer production. A similarly important role has been played by the specific set of ethics that motivated the early adherents to the free software movement. Such an ethics indeed operated as a sort of "cultural subsidy" that helped to overcome the complementarities existing among distinct institutional domains, and let a new organizational species to emerge.

Key words: peer production, organizational equilibria, institutional complementarities, transaction costs

JEL Code: B52; D23; K20; L17; O34.

Fabio Landini, Department of Economics and Statistics – University of Siena

1. Introduction

Economists, since long time, have been interested in the existence of different ways of organizing production (Coase, 1937). Using as a benchmark the view according to which 'in a competitive economy it really does not matter who hires whom' (Samuelson, 1957, p. 894), several authors have gradually relaxed the standard assumptions about market completeness and discussed the viability and persistence of organizations based on different property rights regimes (Alchian and Demsetz, 1972; Demsetz, 1966; Grossman and Hart, 1986; Craig and Pencavel, 1992; Dow, 1993; Dow and Putterman, 2000). Although such a debate may seem an out-of-date residual of the economy of "grain and steal", it is not necessarily so. On the contrary, it turns out that the competition among distinct institutions of production is an issue that plays a central role in a key sector of the present networked economy, namely the information industry.[1]

Over the course of the last 150 years, the organization of information production has undergone a deep transformation. For more than a century, due to the specific investments necessary to the creation of long-distance mass distribution systems and the low marginal costs of production, the media corporation has been the predominant institution of information production. Such an institution has characterized by the combination of exclusive intellectual property rights on the one hand, and vast capital investments as well as highly hierarchical managerial structures on the other, typifying examples being Hollywood, the broadcast networks and the recording industry. Today, the move to a communication environment dominated by the Internet is changing all that. Alongside media corporations, we have observed the emergence of radically decentralized systems of production, where loosely connected communities of volunteers openly share information on the basis of non-exclusive property rights claims. These systems have been generally referred to as peer production[2] and include

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[1] By "information industry" I mean the set of all economic activities that deal with the production and distribution of information, including entertainment, advertising and marketing, computer programming, publishing and printing.

[2] The notion of peer production was first introduced by Benkler (2002a) and refers to a non-proprietary and commons-based mode of production in which widely distributed and loosely connected individuals voluntary cooperate with each other and without relying on either market signals or managerial commands, in order to produce unified intellectual outcomes. According to Benkler (2002a, 2006) three main features differentiate peer production from other organizations of production (e.g. firm): a marginal use of monetary payments and compensation, the absence of employment contract and hierarchical commands, and the application of non-exclusive property rights on produced information.

communities of free software developers (e.g. GNU/Linux), open-content on-line wikis (e.g. Wikipedia), collective blogs (e.g. Global Voices), multi-players on-line games (e.g. EverQuest) and distributed platforms for resource sharing (e.g. Flickr). In some sectors of the economy (e.g. software, on-line encyclopaedia) peer production has proven capable of generating impressive intellectual outcomes and started to represent a serious threat to the survival of media corporations.

Based on this evidence, several works have recently investigated the origins of this deep transformation (Benkler, 2002a, 2003, 2006; Lerner and Tirole, 2005; von Hippel, 2005; Baldwin and von Hippel, 2011). This literature, which relies mainly on the so-called New Institutional approach – see for instance Williamson (1985), explains the emergence of peer production by placing particular emphasis on the role played by the diffusion of digital technologies (i.e. cheap processors, computer networks, and highly modular software architectures). It is argued, in fact, that such technologies have created an environment where organizations based on non-exclusive property rights regimes have become relatively more effective than the ones based on exclusive regimes in reducing the transaction costs associated with information production.[3] This, at least for certain type of information goods, has in turn generated an efficiency advantage for peer production, which has indeed favoured its proliferation in the economy. Obviously, if this interpretation is correct, its implications for the future of information production are remarkable. A consistent application of the New Institutional approach would indeed suggest that if in the present technological environment peer production is relatively more efficient than firm production - i.e. the same output can be produced at a lower cost per unit of transaction, the former is inevitably going to displace the latter as the predominant institution of information production.

The adoption of the New Institutional approach in studying peer production, however, suffers of one important limitation. One of the key assumption of this approach is that technology represents an exogenous variable in the process of

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[3] Benkler (2002a, 2006) argues that, in a context where cheap-processor-based computer networks have dramatically reduced the cost of information sharing (and thus eliminated the incentive problem that the latter generally entails), a system based on non-exclusive property rights regime generates two main types of transaction costs savings: first, because there is very limited used of hired labor, it eliminates the monitoring costs associated with knowledge-intensive and difficult-to-measure human inputs; and second, because individual tasks are self-identified rather than hierarchically assigned, it reduces the coordination costs associated with the allocation of human capital. In addition to this, von Hippel (2005) and Baldwin and von Hippel (2011) suggest that organizations employing non-exclusive property rights enjoy a direct transaction costs advantage because they need to invest little resources in the protection and enforcement of intellectual property rights.

organizational design. Such an assumption is a necessary condition if one wants to compare the transaction costs associated with distinct property rights regimes and argue in favour of a selection process that is effectively capable of rewarding the most efficient organizations. As soon as technology becomes endogenous the transaction costs associated with each mode of organization become endogenous too and an efficiency-enhancing change in property rights is not guaranteed to occur.

Although the treatment of technology as an exogenous variable has been largely predominant in the economic literature, it seems to be inadequate when we deal with productions taking place in a digital environment. Several authors have indeed recognized that the increased adaptability of digital code to a given structure of legal relations transforms technology into a variable that is endogenous to the process of institutional design (see Lessig, 2006; Reidenberg, 1998). This point, in particular, has been made clear by Elkin-Loren and Salzberger (2000, p.578) who argue that:

> The Cyberian world is very different from Coase's example of straying cattle [...]. In the latter, technological change as a result of change in legal rules is, indeed, a remote option. In Cyberspace, [on the contrary] technologies are constantly changing the substance of legal rules that may indeed affect technological development and *vice versa*. The apparent shortcomings of the [standard] economic approach are that it takes technological development as static and overlooks the correlation and reciprocity between technological development and legal rules. [...] [In Cyberspace] technology should become endogenous to the analysis, and the economic discourse should be expanded to address it.

Obviously, the fact that such an "expansion" is effectively undertaken is not at all neutral with respect to the meaning of the theory. The treatment of technology as an endogenous variable, in fact, affects both the interpretation that is given on the emergence of peer production (e.g. it undermines the purely technology-driven explanation) and the predictions that are made on how it will evolve.

On this basis, the present paper will suggest that, rather than by relying on the New Institutional view, a better understanding of the factors that have favoured the emergence of peer production can be grasped by referring to the literature on organizational equilibria. Such literature, which was first originated by Pagano (1993) and Pagano and Rowthorn (1994), presents two main advantages: first, and most prominently, it extends the New Institutional view by considering both property rights and technology as endogenous variables in the process of organizational design; and second, it explicitly models the selection process leading to the emergence of new organizational forms. By combining these two components, this approach may offer a much better sense of the origin of peer production and eventually highlights some possible trajectories for its future development.

To simplify the analysis, the paper will present a simple model. In the model two (representative) agents are involved in the production of a composite information good and must choose how to organize production. The organization of production is defined along two dimensions: technology and property rights. The nature of technology is defined in terms of the ratio between modularity and labour commitment. Technologies for which this ratio is relatively high (low) are defined as modularity-intensive (labour-intensive). Each organizational dimension is assumed to be endogenous with respect to the other, in the sense that technology is designed in order to maximize profit taking as given property rights, and *vice versa*. In this framework the diffusion of digital technologies is modelled as a sudden increase in the malleability of technology, i.e. the extent to which the design of technology can be modularized. Overall, the model shows that when technical malleability is low and the *status quo* technology is labour-intensive, firm-based production is the only viable organizational equilibrium. Starting from this condition, an increase in the degree of technical malleability (i.e. the diffusion of digital technologies) enlarges the set of parameters for which peer production is viable. When peer production is viable, two organizational equilibria exist in the economy, namely peer and firm-based production.

The fact that within this framework the diffusion of digital technologies leads to the existence of multiple organizational equilibria poses a challenge in explaining the emergence of peer production. When multiple organizational equilibria exist, in fact, the increased viability of one of them does not by itself ensure that it will effectively emerge as a productive solution in the economy. In these cases, the emergence of new organizational species generally requires the existence of some form of protection mechanism that, by reducing the selection pressure running against hybrids organizations (i.e. organizations employing a non-optimal combination of technology and property rights), allows the new equilibrium condition to be identified. On this respect, it will be argued that in the case of peer production such a protection mechanism indeed existed and is associated with the cultural backdrop that motivated the adherents to the free software movement (in particular the GNU/Linux community). By sustaining the adoption of free software packages on moral grounds rather than actual performance such culture reduced the competitive pressure generated by proprietary packages and in turn allowed the various communities to optimize their internal organization. Once peer production could emerge within this "protected environment", it extended to other sectors of the information industry (e.g. on-line encyclopaedia, video sharing) and eventually became an effective institution of information production.

Overall, the paper adds to the previous literature in two ways. First, it models information production by considering both technology and property rights as endogenous variables. On this basis, the paper offers a much more realistic representation of information production taking place in a digital environment than previous contributions. Moreover, it suggests that the main effect of the diffusion of digital technologies has not simply been to increase the relative efficiency of peer production, but rather to expand the set of organizational equilibria. This has interesting policy implications too. Second, the paper argues that, in addition to the diffusion of digital technologies, a crucial role in the emergence of peer production has been played by the set of values that formed the early culture of the free software movement. The latter, in particular, did not only motivate programmers, but also worked as a sort of "cultural subsidy" that helped peer production to evolve as an effective institution of production.

The paper is organized as follows. Section 2 introduces the notion of organizational equilibrium and surveys the related literature. Section 3 presents the model. Section 4 discusses the main results. Section 5 focuses on the role played by the free software culture in favouring the emergence of peer production. Section 6 finally concludes.

2. Organizational equilibria

The notion of organizational equilibria was introduced by Pagano (1993) and refers to "technological-institutional equilibria" satisfying two conditions: (a) the technological characteristics of the resources used in production bring about a set of rights which is consistent with this technology; and (b) the set of rights brings about technological characteristics of the resources which are consistent with these rights. This notion results from the combination of two distinct views concerning the relationship between technology and property rights. The first one is the New Institutional view, according to which in economic organizations technology causes the allocation of property rights (i.e. only property rights are endogenous). The second one is the so-called "reversed view", i.e. the idea that it is the allocation of property rights that actually causes the design of technology (i.e. only technology is endogenous). Both views have been rather popular in the economic literature.

The New institutional view originates from the contributions by Coase (1937, 1960), and is then extended in what are sometimes called the Transaction Costs (Williamson, 1985) and Property Rights Literature (Grossman and Hart, 1986; Hart and Moore, 1990; Hart, 1995). The starting point of this approach is the recognition that, in complex economic systems, the execution of transactions is inevitably characterized by some positive costs (i.e. transaction costs). The latter reflect the resources that are dissipated during the process of negotiating, drafting and enforcing contractual agreements and can be conceived as the economic equivalent of friction in physical systems (Williamson, 1985). When these positive costs exist, the formal specification of all events that may be of relevance for a transaction becomes extremely costly and contracts result incomplete.

Under incomplete contracts, the characteristics of the resources used in production (i.e. the nature of technology) inevitably affect the attribution of property rights. Contract incompleteness, in fact, implies the existence of positive agency costs, whose relative value strictly depends on the type of assets employed in the organization. Such costs, in particular, take two main forms: monitoring costs, i.e. the costs incurred to increase the measurability of individual performances; and specificity insurance costs, i.e. the costs sustained to reduce the exposition to the hazards of opportunistic behaviour. In presence of these costs, the force of competition will push property rights in the hands of the agents who owns the most firm-specific and difficult-to-monitor assets. By doing so, in fact, the organization can save the most on agency costs, and increases production efficiency. Organizations characterized by this allocation of property rights will in turn enjoy a competitive advantage in the market, and thus tend to proliferate in the economy.

The New Institutional way of reasoning, however, can be inverted. In contexts characterized by contractual incompleteness, in fact, it could also be the case that it is the initial allocation of property rights that affects the nature of technology, and not the reverse. This view has been supported by several authors in the literature[4] and relies on

[4] See for instance Marglin (1974), Braverman (1974), and Bowles (1985)

two main points. First, the agents who hold property rights on the organization have relatively fewer inhibitions about developing resources specific to that organization compared to their non-owning counterparts, and may be thus inclined to employ a technology that is more intensive in this type of assets. Second, the very same subjects may also have a direct incentive to exploit information asymmetries to their own advantage, and thus design technology in a way that make their own individual performance relatively more difficult to monitor. The result is that also according to this view we should expect the owners of the organization to be also the owners of the most firm-specific and difficult-to-monitor assets, with the exception that this time the direction of causality is reversed. Whereas in the New Institutional view this causality runs from technology to property rights, in this approach it runs from property rights to technology.

Although these two views have been often considered antithetic in the literature - see Williamson (1985, ch.9), they are not mutually exclusive. On the contrary, as suggested by Pagano (1993), it can well happen that both causalities hold at the same time. When this is the case, economic organizations qualify as self-sustaining institutions in which for any given technology there exist an optimal allocation of property rights, and for any given allocation of property rights there exist an optimal technology. When these conditions obtain, we are in situations of "organizational equilibrium" where property rights self-reinforce via technology and *vice versa*. By relying on Aoki (2001), this self-reinforcing relation can be viewed as the source of institutional complementarities between technology and property rights, with the obvious consequence that, when such complementarities obtain, multiple organizational equilibria may exist.

The notion of organizational equilibria has been employed in several contexts to study the evolution of organizational forms. Pagano and Rowthorn (1994), for instance, use this notion to study the competitive selection of democratic and capitalist firms. Pagano and Rossi (2004) rely on a similar approach to model the complementarity between skills development and intellectual property rights (IPRs) protection, and use this model to suggest the existence of divergent trajectories of knowledge accumulation across countries. Earle et al. (2006), similarly, use the framework of organizational equilibria to investigate the relationship between ownership dispersion and the adoption of information technologies in a sample of Eastern European firms.

Recently, Pagano (2011) has expanded on the notion of organizational equilibria by studying the role of interlocking complementarities between technology and property rights in the evolution of complex institutions. In analogy with epistatic interactions for natural species, interlocking complementarities are defined as synchronic interdependences existing across different institutional domains which can be the source of built-in inertia in the process of organizational evolution. When interlocking complementarities exist, institutional speciation cannot be approached by gradual one-by-one adjustments, and necessarily requires simultaneous and complementary modifications. Such modifications, however, are very difficult to accomplish (e.g. due to mis-coordination) and *status quo* institutions tend therefore to persist. In these cases the emergence of new organizations requires the existence of some kind of protection mechanism that attenuates the selective pressure running against hybrid forms. In general, such mechanism can be of two main types: the equivalent of protectionism, which allows organizations to experiment with different combinations of technology and property rights in a "safe" environment; and some form of unintended subsidy, which helps to shift the pressure of the selection mechanism away from production efficiency. Pagano (2011) argues that similar factors indeed played a major role in favouring both the emergence of managerial capitalism in U.S. and Germany at the end of the nineteenth century, and the evolution of distinct corporate governance models in Japan and Italy after the Second World War.

So far, to the best of my knowledge, there is no contribution that applied the notion of organizational equilibria to the study of institutional change in information production. On the contrary, this is precisely the aim of the present paper.

One of the reason why the notion of organizational equilibria is particularly well suited to study information production is related to the specific way in which technology is treated. As argued above, in fact, one of the necessary condition for the theory of organizational equilibria to apply is that technology be effectively endogenous to the process of organizational design. Although such a condition has always been a controversial issue in social sciences - see for instance the debate on technological determinism (Smith and Marx, 1994), it is often regarded as one of the key features that characterized the move to a digital production environment. In virtue of its high malleability and nearly perfect enforceability, in fact, digital code is nowadays used to organize and coordinate production tasks, to structure individual interactions and monitor behaviour, to punish individual decisions as well as to reward them.[5] In a

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[5] The idea of digital code as a tool to regulate on-line behavior was first proposed by cyberlaw scholars such as Lawrence Lessig (2006) and Joel Reidenberg (1998), and captured by the well known catch

similar context, a coherent approach to the study of information production cannot avoid treating technology (i.e. digital code) as an endogenous variable, and the theory of organizational equilibria represents in this sense the most direct extension of the standard approach.

In order to apply the approach of organizational equilibria to the study of information production, I will now introduce a simple model. Such model offers a simplified representation of the way in which technology and property rights interact in the production of information.

3. A simple model

Following Pagano (1993), I define an organization of production on the basis of two domains: the first is technology (*T*), i.e. the technological characteristics of the resources used in production; the second is property rights (*R*), i.e. the set of rights on the resources employed in the organization and on the organization itself. Depending on the way R and T combines, different organizations of production may exist. The necessary and sufficient condition for these organizations to be organizational equilibria is that the allocation of property rights be optimal given the technology, and the technology be optimal given the allocation of property rights. Formally, such condition can be defined as follows. Write $\Pi(R,T)$ as the profit obtained under a particular organization of production. Then,

Definition 1. *An organization of production is an organizational equilibrium if* (a) *R maximizes* $\Pi(R,T)$ *given T; and* (b) *T maximizes* $\Pi(R,T)$ *given R.*

The application of this definition to the study of information production requires a detailed characterization of domains R and T . In domain *R*, as argued by Benkler (2002a), the nature of property rights generally extends beyond the simple licensing terms on the information good, so far as to include the use of employment contracts and the ownership of physical capital. On this basis, although some hybrid forms may exist,

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phrase 'code is law'. Although the original argument was mainly concerned with government regulation, the same principle applies to the organization of information production. Even at this layer of the Internet, in fact, the end-users' activities need to be somewhat regulated in order to ensure a sustained path of information production, and code turns out to be an extremely powerful device to this end.

I assume that only two main alternatives are available:

Definition 2. *An open property rights regime* $R^O \in R$*, which combines a marginal (or absent) use of employment contracts with non-exclusive copyrights claims and a decentralized ownership of physical capital.*

Definition 3. *A closed property rights regime* $R^C \in R$*, which combines a wide use of employment contracts with exclusive copyrights claims and a centralized ownership of physical capital.*

Both such regimes are widely used in the field of information production, and tend to be associated with fairly different organizational structures: flat communities of self-selected volunteers in the case of R^O (e.g. free software, Wikipedia, YouTube) and managerial hierarchies based on hired labour in the case of R^C (e.g. proprietary software, Encarta, broadcast networks).

In domain *T*, the characterization of the alternative resources employed in the production of information is far more complex. In such a domain, in fact, several variables ranging from publicly available information to physical equipments play a crucial role in determining how information is produced, and a comprehensive representation of technology is difficult to obtain. For this reason, in this paper, I choose to follow Landini (2012) and focus on two variables only: i) the degree of modularity of the production system (*M*) and ii) the employment of cognitive labour across production modules (*L*).

M reflects the number of dependences that exist across the different tasks necessary to produce a composite information good. In this framework by "composite information good" is meant a unified and complex intellectual outcome, such as a software package, an encyclopaedia, or a music album. When *M* is high, many tasks are independent and modules (i.e. the collections of interdependent tasks) are on average small; on the contrary, when *M* is low, many tasks are interdependent and modules tend to be large. The value of *M* can be constrained by different factors such as the intrinsic complexity of the information good that is to be produced (e.g. a movie) or the type of physical equipments employed in production (e.g. printing press). In general, *M* is a measure of how finely grained the system of production is.

L reflects instead the units of cognitive work (say, hours) assigned to each production module per unit of time (say, a day). When *L* is high it means that, on average, each production module requires a large amount of cognitive work. On the contrary, when L is low such an amount is limited.[6]

This definition of M and L allows one to treat such variables as two factors of production in the standard economic sense. Both M and L, in fact, positively contribute to production,[7] and can to a certain extent be considered substitute of each other. For a given information good, in fact, an increase (decrease) in M tends to decrease (increases) the average size of the production modules and therefore reduces (augments) the amount of cognitive labour L that is to be assigned to each module. Obviously, the extend to which M and L can be effectively substitute depends on some external exogenous component, such as the physical equipments that are necessary to produce information. Under this interpretation the nature of a generic technology i can be defined by the factors proportion (or intensity) $T^i = M^i / L^i$. Such a technology can be then defined as M-intensive with respect to a benchmark j when the following holds:

Definition 4. *Take any pair of technologies* $T^i = M^i / L^i$ *and* $T^j = M^j / L^j$. *Then,* T^i *is M-intensive relative to* T^j *if and only if* $T^i > T^j$.

Given this characterization of domains R and T, I consider an economy with two representative agents r and t who want to produce a composite information good (say, an encyclopaedia). In order to do so, and before production can actually take place, they need to decide how to organize production, i.e. they need to make a choice within two domains of the choice set S: the property rights domain $R \in S$, in which the two available options are R^C and R^O; and the technology domain $T \in S$, in which they need to set the factors proportion $T = M / L$. For the sake of simplicity I restrict the model at the design phase only, without expressly modelling actual production. I simply assume that the necessary conditions for the latter to take place are satisfied. This in turn implies that there exist a market and a demand for the information good, as well as an adequate factors endowment, especially in terms of L. When R^O is chosen in domain R the latter condition amounts to assume that there exit a community of volunteers that is willing to contribute to production (remember that no employment contract is used under R^O). The model abstracts from both the way in which such community is

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6 For a more formal treatment of M and L with specific reference to software production see Landini (2012).

7 For the positive impact of modularity on production see Langlois and Garzarelli (2008).

gathered and the way in which such community works (for more detailed work on this see Reagle, 2010).

The decision making process is modelled as follows. Agents *r* and *t* make an independent choice in the property rights and technology domain respectively. To lend some concreteness to the model we can imagine *r* as being a "financier" who owns the organization and is responsible for selecting the property rights regime to be adopted in production (e.g. an entrepreneur), and *t* as being the "production manager" who is a member of the organization and is responsible for the design of technology (e.g. a web designer). In both domains, choices are made in order to maximize individual payoff, i.e. *r* will choose the property rights regime that maximizes π_r for a given technology, while *t* will choose the technology that maximizes π_t for a given property rights regime. Notice that, abstracting from the problem at stake, *r* stands as representative of the causality mechanism that runs from technology to property rights (i.e. the New Institutional view), while *t* stands as representative of the causality mechanism that runs from property rights to technology (i.e. the "reversed" view).

Agents' payoffs depend on the costs and benefits that are associated with the distinct design options. On the side of costs, I assume that two main typologies exist: design costs and transaction costs.[8] I call *d* the design cost of modularity, i.e. the cost of modularizing the production system; *l* the transaction cost of labour, i.e. the cost of inducing actual effort from labour; and *m* the transaction cost of modularity, i.e. the cost associated with the allocation of cognitive skills within the production system. The latter, in particular, can be interpreted as the information cost that is incurred in order to obtain a good matching between the skills of the subjects who are assigned to a given production module, and the set of specific tasks that are to be performed in that particular module (e.g. the matching between the knowledge people have on particle physics, and the draft of an encyclopaedic entry on solar neutrinos). Since skills are costly to evaluate (both subjectively and from a third-party), the value of *m* can be relatively high. *l* is assumed to be monotonically increasing in *L*, while *d* and *m* to be monotonically increasing in *M*. In this sense I assume, in line with Langlois and Garzarelli (2008), that an increase in *M* generally entails an increase in the specialization of modules and thus a greater transaction cost for the allocation of cognitive skills. In order to account for asymmetric relations within the organization I

[8] For a similar approach see Baldwin and von Hippel (2011).

also assume that while transaction costs m and l enters the payoff of both agents r and t, design cost d are paid only by the agent involved in the modularization of technology, i.e. agent t.

Given this definitions, I assume that each property rights regime R^O and R^C is characterized by a different transaction cost advantage. Under R^O the allocation of cognitive skills is not hierarchically determined, but rather relies on the self-identification of community members into the modules they wish to contribute (e.g. a professor of particle physics who chooses to write an entry on solar neutrinos). For this reason, as suggested by Benkler (2002a), under R^O there tends to be a cost advantage in terms of m as compared to R^C, because community members are likely to know better than any manager which tasks they are best at doing. I will call such cost advantage x ($< m$). At the same time, as partly suggested by David and Rullani (2008), the fact that in organizations based on R^C most of the subjects are hired rather volunteer, makes it easier for such organizations to mobilize labour (i.e. to induce effort) as compared to organizations based on R^O. For this reason I assume that under R^C there is a cost advantage in terms l. I will call the latter y (< l). On this basis, I write the transaction costs function as follows:

$$C(M,L,R)=\begin{cases}(m-x)M+lL, & if \quad R=R^O\\ \\ mM+(l-y)L, & if \quad R=R^C\end{cases} \tag{1}$$

where $m > l - y$ and $l > m - x$, the latter conditions meaning that there exist transaction cost advantages in the use of different factors of production not only between but also within the same organization of production. In addition to this, I write the total design cost of modularity as dM. Such cost, however, is assumed to be the same under both property rights regimes.

On the side of benefits, I assume that the information good give rise to two main types of return. The first is the expected rents on the sale of the information good (e.g. the sale of proprietary copies of the encyclopaedia), which I call $z(L,R)$ and is appropriated by the agent who owns the organization, i.e. agent r. Since such rents exist only under R^C, I assume $z(L,R)$ to take the following form:

$$z(L,R)=\begin{cases}0, & if \quad R=R^O\\ zL, & if \quad R=R^C\end{cases} \tag{2}$$

where $z > 0$ captures the positive effects of labour commitment on the marketability of the information good. The second type of return is instead associated with any other kind of expected return that can be earned from the distribution of information apart from rents, including the sale of services, advertisement and network effects. This type of return, which exist also under R^O, is equally shared between the two agents and is captured by function $Q(M,L)$, such that $\partial Q/\partial M > 0$ and $\partial Q/\partial L > 0$. The shape of this function is assumed to be independent of the property rights regime.

Under these assumptions, the payoffs of agent *r* and *t* can be respectively written as follows:

$$\pi_r(R,T(M,L)) = z(L,R) + \frac{[Q(M,L) - C(M,L,R)]}{2} \tag{3}$$

$$\pi_t(R,T(M,L)) = \frac{[Q(M,L) - C(M,L,R)]}{2} - dM \tag{4}$$

Agents are assumed to be risk neutral and the price of the information good is equal 1. The model is solved by simply studying the associated maximization problems.

In domain *R*, given equations (3) and (4), and considering a generic technology T^j, *r* will choose to adopt an open property rights regime as long as $\pi_r(R^O,T^j) \geq \pi_r(R^C,T^j)$, which is the case if and only if:

$$T^j = \frac{M^j}{L^j} \geq \frac{y+2z}{x} \tag{5}$$

Similarly, *r* will choose to adopt a closed property rights regime as long as $\pi_r(R^C,T^j) \geq \pi_r(R^O,T^j)$, which is the case if and only if:

$$T^j = \frac{M^j}{L^j} \leq \frac{y+2z}{x} \tag{6}$$

From equations (5) and (6) the following proposition hold (proofs for all Propositions are reported in Appendix A):

Proposition 1. *In the domain of property rights R, the incremental benefit from choosing an open regime* R^O *(instead of choosing* R^C*) is greater when an M-intensive technology is selected in the domain T, i.e. when* T^M *is selected instead of* T^L*.*

Let's now consider domain *T*. Under the above described decision-making process, *t* will set *M* and *L* so as to maximize $\pi_t(R^C, T(M,L))$ and $\pi_t(R^O, T(M,L))$. Let:

$$(M^C, L^C) = \arg\max \pi_t(R^C, T(M,L)) \tag{7}$$

$$(M^O, L^O) = \arg\max \pi_t(R^O, T(M,L)) \tag{8}$$

Then, from equations (3) and (4) above and under standard assumption about the shape of the marginal product, i.e. $\partial^2 Q/\partial M^2 > 0$ and $\partial^2 Q/\partial L^2 > 0$, it follows that $M^C \leq M^O$ and $L^C \geq L^O$. From the latter conditions it is straightforward to derive the following relation:

$$T^O = \frac{M^O}{L^O} \geq \frac{M^C}{L^C} = T^C \tag{9}$$

Relation (9) in turn implies that:

Proposition 2. *In the domain of technology T, the incremental benefit from choosing an M-intensive technology* T^M *(instead of choosing an L-intensive technology* T^L*), is greater when an open property rights regime is selected in the domain R, i.e. when* R^O *is selected instead of* R^C*.*

Under some continuity conditions of function $\pi(.)$ and assuming that strategy sets $S_r = \{R^O, R^C\}$ and $S_t = \{T^M, T^L\}$ have a partial order ≥ (see Milgrom and Roberts, 1990), Propositions (1) and (2) imply that the game $G = \{2, (S_i, \pi_i, i = r, t), \geq\}$ is supermodular. Furthermore, it can be proved[9] that in *G* there exist two pure strategy Nash equilibria, namely $\{R^O, T^M\}$ and $\{R^C, T^L\}$. Each of these equilibria is an organizational equilibrium according to Definition 1. The first, $\{R^O, T^M\}$, is characterized by an open property rights regime and a relatively modular technology; I

[9] See Theorem 5 in Milgrom and Roberts (1990).

will call this equilibrium *peer production*. The second, $\{R^C, T^L\}$, is characterized by a closed-source regime and a relatively non-modular technology; I will call this equilibrium *firm-based production*. When these two equilibria exist, using Aoki (2001)'s terminology, R^O and T^M as well as R^C and T^L are institutional complements.

The technological conditions supporting the existence of distinct organizational equilibria in information production can be summarized in the following proposition:

Proposition 3. (a) *Suppose* $T^O = T^M \geq (y+2z)/x \geq T^L = T^C$. *Then in game G there exist two pure strategy Nash equilibria* $\{R^O, T^M\}$ *and* $\{R^C, T^L\}$, *i.e. multiple organizational equilibria exist.* (b) *Suppose* $T^O = T^M \geq T^L = T^C \geq (y+2z)/x$. *Then in game G there exist only one pure strategy Nash equilibrium* $\{R^O, T^M\}$, *i.e. only a peer production is an equilibrium.* (c) *Suppose* $(y+2z)/x \geq T^O = T^M \geq T^L = T^C$. *Then in game G there exist only one pure strategy Nash equilibrium* $\{R^C, T^L\}$, *i.e. only firm-based production is an equilibrium.* (d) *For any ratio* $(y+2z)/x$ *in game G there exists at least one pure strategy Nash equilibrium, i.e. there always exist at least one organizational equilibrium.*

Proposition 3 suggests that if the ratio between the cost advantages $(y+2z)/x$ falls into the closed intervals defined by the factors proportions that optimize under the different property rights regimes, two distinct ways of organizing information production exist. The key question, then, becomes to understand how likely it is that such condition obtains. Intuition suggests that the "malleability" of technology plays an important role in this respect because it ensures that, for any given property rights regime, factors proportion can be adjusted so as to minimize production costs. Under the standard assumption of decreasing marginal product, in particular, it can be proved that:

Proposition 4. (a) *For any standard production function* $Q(M,L)$ *and for any set of costs* (m, l, d), *there exists at least one triple* (x, y, z) *such that multiple organizational equilibria exist.* (b) *If the elasticity of substitution is equal zero, i.e. if M and L are perfect complements, then there exist only one triple* (x, y, z) *such that multiple organizational equilibria exist.* (c) *If the elasticity of substitution is infinite, i.e. if M and L are perfect substitutes, then any positive triple* (x, y, z) *will imply that multiple* *organizational equilibria exist.* (d) *Any increase in the elasticity of substitution between M and L enlarges the set of the triple* (*x*, *y*, *z*) *for which multiple organizational equilibria exist.*

In addition to the "malleability" of technology another variable that plays a crucial role in determining the existence of multiple equilibria in information production is the value of rent z. In particular, the following holds:

Proposition 5. *Suppose that M and L are not perfect substitute. Then, for any* $T^M \geq T^L$, *and for any set of costs* (*m*, *l*, *d*), *the set of points for which a peer production equilibrium exists is smaller the greater z*

4. Discussion

The results of the model can be usefully employed to interpret the effects that the diffusion of digital technologies had on the organization of information production. Such technologies indeed had a crucial impact on the resources used in production, thus affecting both the type and number of organizational equilibria existing in the economy.

Let's consider first the analog environment, i.e. the world as it were prior to the development of digital technologies, say up until the 1980s. In such an environment the production and distribution of information required large physical equipments such as high-volume mechanical presses, radio and television relay stations. As a consequence technology was extremely rigid and costly to modularize. The high cost of physical capital imposed the concentrated ownership of the communication equipments, which in turn constrained the possibility to decompose the production process in finer and independent modules. Most of the tasks were interdependent (low *M*), and most modules were likely to require a high involvement of cognitive labour (high *L*). The production environment was therefore characterized by a fairly inelastic (i.e. low malleability) and relatively labour-intensive production technology. This made firm-based production (i.e. the media corporation) the only viable organizational equilibrium (see Propositions 3 and 4).

Staring from this condition, the diffusion of digital technologies of the late 1980s and (especially) 1990s had a dramatic impact on features of the production environment. Following developments in data transmission, cheap-processors-based computer networks gradually replaced capital-intensive equipments as the predominant communication devices. This suddenly increased the flexibility and adaptability of technology. The fragmented ownership of computers, together with the huge improvements in computational capabilities and sophistication of software architectures, enabled the design of increasingly modular production platforms (high M). At the same time, the rising number of on-line users, created a pool of human resources that could be easily involved in the execution of short tasks (low L). The combination of these two effects radically increased the degree of substitutability between cognitive labour and modularity (i.e. high malleability), and in turn made peer production increasingly viable. As a result (in line with Propositions 3 and 4) two organizational equilibria started to exist in the economy, namely firm-based and peer production.

The increased viability of peer production as a consequence of a rise in technical malleability, however, is not by itself sufficient to explain its effective emergence as an institution of production. The reason for this is twofold. First of all, as suggested by Proposition 5, even in the presence of high technical malleability, the viability of peer production could still be constrained by the existence of high expected rents on the information good. In this sense, the progressive tightening of the legislation on IPRs that occurred in the early 1990s did surely play a role in limiting the sectors where peer production could effectively emerge (on this see Benkler, 2002b). Secondly, even in those sectors where peer production became effectively viable, the fact that incumbent organizations were primarily represented by media corporations was likely to generate strong barriers to the emergence of new (although relatively efficient) organizational forms. The reason is that when multiple organizational equilibria exist, technology and property rights tend to be affected by interlocking complementarities, which make the process of institutional change extremely difficult to occur.

The role played by interlocking complementarities is particularly relevant in the case of information production. Because the media corporation had been for long time the *status quo* institution in most sectors of the information industry, the effective emergence of peer production required not only a switch from a closed to an open property rights regime, but also a complementary change in the domain of technology, i.e. from a non-modular to a modular design. Such a change, however, could be anything but immediate, and required sometime before the new equilibrium condition could be identified. In the meantime, the media corporation could enjoy greater performances than any hybrid forms and thus exercised a strong selective pressure running against the latter. Were this selective pressure sufficiently strong, no hybrid organization would have ever had the time to make the path through the optimal design and peer production would have not probably emerged. This, independently of the productive efficiency of the two equilibria.

Obviously, the fact that nowadays peer production exists reveals that the convergence towards the new equilibrium condition was finally accomplished. The above discussion, however, is relevant in pointing out a missing link between production efficiency and institutional change. When multiple organizational equilibria exist, in fact, production efficiency ceases to be a necessary condition for institutional stability to obtain, with the consequence that relatively inefficient organizations can persist. This implies that, even if the technological environment of the early 1990s tended to make firm production relatively inefficient as compared to peer production, e.g. in the allocation of human capital (Benkler, 2002a) and/or exploitation of innovative potential (von Hippel, 2005), this is not sufficient to explain why peer production emerged. Some other factors must have necessarily played an important role.

Once again the literature on organizational equilibria can be usefully employed in identifying what these "other factors" can possibly be. As discussed in Section 2, in fact, when there exist interlocking complementarities the emergence of new institutions is favoured by the existence of some form of protectionism and/or unintended subsidy which help reducing the selective pressure running against hybrid organizations (see Pagano, 2011). In the case of peer production an external subsidy of this sort indeed existed and is related to the set of ethics that motivated the early adherents to the free software movement. As the next section will show, in fact, such an ethics tended to motivate individual decisions on software adoption more on moral ground then on actual performance, thus shifting the selective pressure away from production efficiency alone. This in turn gave the new systems the time necessary to optimize their internal structure and further expand in other sectors of the economy.

5. GNU/Linux and the emergence of a new organizational species

According to Moody (2001) the origin of free software development can be associated with a precise moment in history, namely the launch of the GNU project in September 1984. Founded by former MIT Artificial Intelligence Lab programmer Richard M. Stallman (RMS), the GNU project aimed at reproducing a non-proprietary version of many components of Unix, one of the leading operating systems (OS) of the time.[10] Although the project started as a single-person endeavour, it soon attracted the attention of a large community of programmers. As of 2010 it is estimated that more than 200 people contributed software to the GNU system.[11]

The reasons why RMS choose to start the GNU project are rooted in the evolution that the U.S. software industry was experiencing in the early 1980s. This period, as suggested by Nuvolari (2005), saw an increased commercialization of software production, which started with the AT&T's decision to begin to sell licenses of Unix. After that, a growing number of companies began to sell copies of software packages without granting full access to the underlying source code and to bound the work of hired programmers by the mean of non-disclosure agreements. This way of doing represented a substantial departure from the sharing-based culture that had characterized the world of computer programming since the 1970s. In those early days, in fact, the users of mainframe computers were primarily universities and corporate research laboratories, which saw computer programs eminently as research tools. For this reason, it was common practice among programmers to share the source code of their works, and to develop new programs by improving upon the code written by others. From this perspective, the source code of programs represented a sort of public good which was freely available to anyone in the users community to read, study and hack.

Having as a reference this cultural background, RMS and other programmers like him perceived the growing commercialization of software programs as a direct attack to their individual freedom. As members of the worldwide community of hackers, they rebelled against the idea that the underlying source code of programs could be anyhow enclosed. For them, as suggested by Moody (2001, p.4), these special texts represented 'a new kind of literature that forms part of the common heritage of humanity: to be published, read, studied and even added to, not chained to desks in inaccessible monastic libraries for a few authorized adepts to handle reverently'. As a consequence, this community started to look at the GNU project as something that went far beyond

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10 The acronym GNU stands for "GNU's Not Unix" a kind of recursion that is often used as programming technique, and applying it to words is highly popular amongst hackers.

11 See http://www.gnu.org/people/.

the simple technicalities of code programming, and had instead strict relations with the defence of individual freedom. Commenting on the origins of GNU, for instance, RMS observed that:

> the overall purpose [of GNU] is to give the users freedom by giving them free software they can use and to extend the boundaries of what you can do with entirely free software as far as possible. Because the idea of GNU is to make possible for people to do things with their computers without accepting domination by somebody else. Without letting some owner of software say, 'I won't let you understand how this works; I'm going to keep you helplessly dependent on me and if you share with your friends, I'll call you a pirate and put you in jail.' [...] I consider that immoral, and I'm working to put an end to that way of life. [...] That's what GNU is for, it's to give people the alternative of living in freedom. (Moody, 2001, p.38)

In order to strengthen the efficacy and sustainability of the GNU project, RMS extended his own range of activities beyond sole programming. In 1985 he founded the Free Software Foundation and introduced a new licensing procedure for software called General Public License (GPL). Thanks to a cleaver use of the standard copyrights legislation, GPL permits free redistribution, modification and redistribution of the modified version of the programs it covers, without depriving programmers of their own individual authorship (see McGowan, 2001). As reported by Moody (2001, p.27-28), RMS 'created in the GPL a kind of written constitution for the hacker world that enshrined basic assumptions about how their community should function. In doing so, he enabled that world to progress far more efficiently than it had in the past when all these "laws" were unwritten. [...] [And] yet for Stallman, this emphasis on inherent efficiency misses the point about the GNU project and the GPL. His essential concern is freedom, and the GNU project a means to an end rather than an end in itself.' From this perspective, 'Stallman's work is significant not only because it engendered many of the key elements [...] that made the success of what came to be the combined GNU/Linux operating system possible but also because it provided an ethical backdrop against which the entire free software and open source story is unfolding.' (p.30)

The existence of this ethical backdrop turned out to be of crucial importance for the success of free software, and more generally peer production. The characterization of free software (as the "GPLed" software came to be known) as a mean to an end rather than as an end in itself, had in fact a powerful impact on the way in which software programs started to be consumed. For a large portion of users the "free" nature of source code became a condition that was often more important than the degree of technical performance in determining the adoption of a particular program. By direct admission of RMS, in fact, the early applications of the GNU system

> had no technical advantage over Unix. [...] [Yet, they had] a social advantage, allowing users to cooperate, and an ethical advantage, respecting the user's freedom (Stallman, 2002, p.24).

The combination of these "non-technical" features created an environment where "source code freedom" rather than "technical performance" became the principal domain in which competing applications were compared. This, at least for programs that attracted the attention of hackers, generated a kind of "cultural subsidy" in favour of free software production (and as a consequence peer production), because it reduced the selective pressure that the latter had to face.

The protection ensured by this "cultural subsidy" played an important role not only during the initial launch of the GNU project, but also when the history of free software had its second important twist. On the 25th of August 1991 a Finnish undergraduate student named Linus Torvalds posted on the comp.os.minix newsgroup[12] a message concerning his work on a free Unix kernel called Linux. Although the development of a Unix kernel (eventually called Hurd) had always been in the waiting list of the GNU project, it was still lacking in 1991 and indeed represented the missing step towards the realization of a complete free system. For this reason, the degree of excitement that welcomed the first news about Linux comes at no surprise. As reported by Moody (2001, p.42), less than four hours after Torvalds's original message there were already positive reactions in the newsgroup:

> a fellow Finn wrote: 'Tell us more!' and asked: 'What difficulties will there be in porting?'. [Similarly,] a Minix user from Australia said: 'I am very interested in this OS. I have already thoughts of writing my own OS, but decided I wouldn't never have the time to write everything from scratch. But I guess I could find the time to help raising a baby OS:-)'.

As suggested by Moody, this was just 'a portent of the huge wave of hacker talent that

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[12] The comp.os.minix newsgroup was one of the many Usenet newsgroups operating at the time. The topic being discussed in this particular newsgroup concerned Minix, a Unix-like OS based on a microkernel architecture created by Andrew S. Tanenbaum for educational purposes in 1987.

Linux would soon ride' (ibid.).

Similarly to the first versions of GNU applications, also Linux did not exhibit excellent technical properties at its birth. In the comments attached to version 0.01 of the code (released in October 1991), for instance, Torvalds himself admits:

> this isn't yet the 'mother of all operating system', and anyone who hoped for that will have to wait for the first real release (1.0), and even then you might not want to change for Minix (Moody, 2001, p.45).

Also in this case, however, the appeal for programmers to start using and studying Linux was not primarily a matter of performance. In the same posting accompanying the release of this version, Torvalds in fact writes:

> I can (well, almost) hear you asking yourselves "Why?". Hurd will be out in a year (or two, or next month, who knows), and I've already got Minix. This is a program for hackers by a hackers. I've enjoyed doing it, and somebody might enjoy looking at it and even modifying it for their own needs. It is still small enough to understand, use and modify, and I'm looking forward to any comments you might have (Moody, 2001:45).

And the strength of the appeal was indeed sufficient to meet an extraordinary success. As argued by Nuvolari (2005), when Torvalds released version 1.0 of Linux in 1994, the OS could compete successfully in stability and reliability with most commercial versions of Unix. Starting from that release, Linux was further refined, incorporating a number of new features. The community of developers grew exponentially, outnumbering the thousands. In 1999 the effective potential of Linux received also its "official recognition" in the so-called "Halloween document", an unofficial document leaked out from Microsoft which mentioned Linux (and, generally, the diffusion of open-source production) as a major competitive threat to the company.

If we look at the overall period that went from the launch of the GNU project to the success of Linux, it is possible to observe a clear pattern of organizational speciation. Starting from the idea of a small group of programmers which had deep roots in the hacker culture of the early 1970s, the GNU project served as an example for an alternative non-proprietary way of developing software. The use of exclusive copyrights terms was substituted by GPL-like licenses, and the hiring of paid programmers was replaced by the voluntary participation in communities of peer developers. At the beginning, this way of producing software encountered some difficulties and the quality of “free” programs could not compete with their proprietary counterparts. Nevertheless, the attachment of strong social and ethical values to these works, compensated (at least partly) for their inferior quality and supported their diffusion in spite of the technical deficiencies. With the passage of time, and in virtue of this “cultural subsidy”, the communities of free software developers could improve their internal organization and define in a clearer way the rules that could sustain their performance - see for instance Raymond (1999). The result was the impressive success that free software enjoyed in the second half of the 1990s, with programs such as Linux (OS), Apache (web server), MySQL (relational database), and Sendmail (mail transport agent) becoming widely popular also outside the hacker world (see Moody, 2001). It is indeed with the success of these programs that peer production made its first appearance on the “stage” of information production.

This brief history of free software, however, rises some important questions. The most relevant, for the sake of the argument developed here, is whether there exist other sectors of the economy different from just software where peer production could have possibly emerged within the same period of time. If this is not the case, in fact, the role played by the specific culture of free software would be significantly undermined, because it would be indistinguishable from the one associated with purely technological factors. On this respect, although a more robust empirical analysis is required, some supporting evidence can be gained by looking at the status of information technology at the beginning of the 1990s. Such an analysis reveals in fact that, beyond the specific domain of software production, many of the technologies generally associated with peer production were already available at that time. The first proposal for the WWW system - i.e. the easy-to-use system of interlinked hypertexts that facilitates the transmission of information over the Internet, for instance, was written by Tim Berners-Lee already in 1989 (Berners-Lee, 1999). Even earlier, in 1978, Ward Christensen developed the first Bulletin Board System, which can be considered one of the technological antecedent of Internet forums, and then blogs (Stone, 2004). Similarly, as early as 1972, a group of researchers at Carnegie-Mellow University developed a system called ZOG multi-user database, which is many respects an indirect predecessor of the wiki-style web page (i.e. WikiWikiWeb) created by Ward Cunningam in 1994. Finally, with specific reference to the design of peer-to-peer (P2P) network, the Usenet developed by Tom Truscott and Jim Ellis in 1980 can be viewed as one of the first clients-server architecture where the principle of P2P servers interactions was directly employed (Fristrup, 1994). In spite of this technological *substratum*, however, highly successful and non-software-related examples of peer production such as Napster (P2P networks), Wikipedia (on-line encyclopedia), and the myriad of individual and collective blogs, did not emerge until the early 2000s. Not only, but in most of these cases (see for instance Wikipedia)[13] the evolution of GNU/Linux was indeed considered as the main example to follow in the design of the digital platforms. This, although only at an intuitive level, tends to support the view according to which peer production first emerged in the particular niche of software production, and only afterward it extended to other sectors of the economy.

6. Conclusion

Commenting on the relationship between information and institutions in modern economies, Kenneth Arrow (1999, p.25) once observed that:

> Information, one of the fundamental economic determinants, leaps over from one firm to another, yet the firm has so far seemed reasonably defined in terms of legal ownership. It seams to me that there must be an increasing tension between legal relations and fundamental economic determinants. [...] We are just beginning to face the contradictions between the system of private property and of information acquisition and dissemination.

Although in this statement Arrow was not directly referring to peer production, he still captured the essence of the institutional change that the information economy is facing. In the decade that followed Arrow's intuition there has been a dramatic diffusion of non-proprietary forms of production that spawned across different information goods. As suggested by Benkler (2006, p.5), instead of treating the latter as mere curiosities, 'we should see them for what they are, namely a new mode of production emerging in the middle of the most advanced economies in the world'.

Based on this evidence, the paper investigated the factors that favoured the emergence of this new mode of information production. Differently from most of the previous literature, the paper did so by modelling technology as an endogenous variable in the process of organizational design. In this way, it integrated the intuition derived

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13 On the role that the free software movement and in particular RMS played as a source of inspiration for Wikipedia see Reagle (2010).

from part of the cyberlaw literature, according to which the endogenity of technology is indeed one of the crucial features that characterizes the move to a digital production environment.

On the basis of a simple model, the paper suggested that the diffusion of digital technologies is a necessary but not sufficient condition to explain the emergence of peer production. The reason is that, when technology is endogenous, there may exist multiple organizational equilibria in the economy. In the latter case, the emergence of a new organizational form necessarily requires some form of protection mechanisms that, by reducing the selection pressure running against hybrids organizations, allows the new equilibrium condition to be identified. With respect to peer production, the paper suggested that such protection mechanism can be associated with the cultural backdrop that characterized the early adherents to the free software movement. By sustaining the adoption of software programs on moral grounds rather than on actual performance, this culture created a sort of protected environment where peer production could first emerge and then proliferate.

If this interpretation is correct, then there exist interesting implications for the future of peer production. The existence of multiple organizational equilibria, in fact, limits the possibility of establishing any direct link between production efficiency and institutional change. This implies that even if in the present technological environment peer production can be more efficient than standard firm-based production, this does not necessarily mean that the former will spontaneously replace the latter as the predominant institution of information production. Such a replacement depends on several factors, among which the frequency of the two institutions and the speed of the selection process. Moreover, depending on the type of institution that we believe as more valuable for the society as a whole - see on this Benkler and Nissenbaum (2006) and Benkler (2002b), it can also be affected by different types of policy interventions, such as the reform of IPRs legislation.

Appendix

Proof of Proposition 1: For a given value of x, y and z, consider two technologies T^M and T^L such that conditions (5) and (6) are simultaneously satisfied, i.e.
$T^M \geq (y+2z)/x \geq T^L$. Then, it follows directly from (5) and (6) that:

$$\pi_r(R^O, T^M) \geq \pi_r(R^C, T^M) \tag{A1}$$

$$\pi_r(R^C, T^L) \geq \pi_r(R^O, T^L) \tag{A2}$$

Adding equations (A1) and (A2) side by side and rearranging, we obtain the following relation:

$$\pi_r(R^O, T^M) - \pi_r(R^C, T^M) \geq \pi_r(R^O, T^L) - \pi_r(R^C, T^L) \tag{A3}$$

which proves the proposition.

Proof of Proposition 2: Consider two technologies T^M and T^L such that condition (9) is satisfied, i.e.

$T^M \geq T^L$. Then, it follows directly from (9) that:

$$\pi_t(R^O, T^M) \geq \pi_t(R^O, T^L) \tag{A4}$$

$$\pi_t(R^C, T^L) \geq \pi_t(R^C, T^M) \tag{A5}$$

Adding equations (A4) and (A5) side by side and rearranging, we obtain the following relation:

$$\pi_t(R^O, T^M) - \pi_t(R^O, T^L) \geq \pi_t(R^C, T^M) - \pi_t(R^C, T^L) \tag{A6}$$

which proves the proposition.

Proof of Proposition 3: Points (a), (b) and (c) follow directly from conditions (5), (6) and (9) above. Point (d) is a direct consequence of points (a), (b) and (c).

Proof of Propositions 4 and 5: See proofs of Propositions 2, 3, 4 and 5 in Pagano and Rowthorn (1994). Proposition 5 follows directly from Propositions 3 and 4.

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