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How innovation commons contribute to discovering and developing new technologies

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Abstract: In modern economics, the institutions surrounding the creation and development of new technologies are firms, markets and governments. We propose an alternative theory that locates the institutional origin of new technologies further back in the commons when self-organizing groups of technology enthusiasts develop effective governance rules to pool distributed information resources. The ‘innovation commons’ alleviates uncertainty around a nascent technology by pooling distributed information about uses, costs, problems and opportunities. While innovation commons are mostly temporary, because the resource itself – the information about opportunities – is only temporarily valuable, they are a further addition to the Pantheon of commons, and suggest that the institutions of the commons – and the common pool resource of information about applications of the technology – may be far more important in the study of innovation than previously thought.

Keywords: Commons, entrepreneurship, information, innovation, innovation problem, uncertainty

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I. The commons at the origin of a new technology

The *first generation* of commons was in the real world of shared physical natural resources such as fisheries, grazing pastures and forests that extended to artificial resources such as irrigation systems (Ostrom 1990). But a *second generation* of commons studies has developed the field ever towards intangible common pool resources of information and knowledge, such as science (Boyle 2007; Schweik and English 2012) and culture (Ostrom and Hess 2007; Frischmann et al. 2014). These days, most new commons are the intangible sort, and are on a larger, more global scale (Ostrom et al. 2002; Hess 2008; Stern 2011; Epstein et al. 2014). Research on knowledge commons have focused on a wide variety of topics and resources, including: open source software (Schweik 2007, 2014); roller derby's (Fagundes 2014); the airplane industry (Meyer 2014); and genetic information and research (Lucchi 2013; Contreras 2014). This shift, however, has required commons scholars to devise new methods and refine previous concepts about what constitutes a common pool resource and common property regime (Poteete et al. 2010). Analysing commons based on 'ideas' rather than commons of 'things' is more difficult for two reasons: first it is sometimes difficult to understand what the resource is because such resources are often substantially more intangible and dynamic; and second because there is a further actor within a knowledge commons who produces the resource (Madison et al. 2010; Cole 2014). In this paper, we introduce a new type of commons – an innovation commons – that exists at the very beginning of a new technology, at the point when a group of people, often technology enthusiasts, come together in order to discover opportunities for the use and development of the technology. But this is not a technology commons. It is an innovation commons because the common pool resource is not the technology *per se*, but information and knowledge about the technology that subsequently facilitates its development, where by other users or stakeholders, including entrepreneurs, for whom uncertainty has been sufficiently reduced that they are able to confidently act. We suggest this constitutes a *third generation* of commons, a higher order form of information and knowledge *about* information and knowledge.

There are two substantial contributions we seek to make in identifying and elaborating this new class of commons. First, we introduce the fundamental importance of the commons into innovation economics. Innovation economics, as we will show, has systematically neglected the institutions of the commons by the very definition of the innovation problem as one of market failure (resolved with government) rather than as a collective action problem (resolved with governance). Our second contribution goes in the other direction, by developing a study of a new and somewhat exotic species of commons that emerges spontaneously at the origin of a new technology. Such a commons arrangement is efficient in coordinating knowledge because uncertainty makes other institutional forms – such as firms and markets – comparatively costly (in a transactions cost sense). It follows that innovation commons tends to collapse once the uncertainty surrounding an

opportunity has resolved. We further argue that the pattern by which a technology evolves into society – and whether it becomes a private good, or a public good – is substantially shaped by its early pathway through the commons.

The first institution that forms about any new technology, we argue, is not usually a firm or a market, but rather a commons – hence, an innovation commons. However, this is not the standard model in innovation economics in which the founding institutions are centred on path-breaking public research, government-granted intellectual property, and innovating firms led by bold creative entrepreneurs, and supported by venture finance. Often, those individual and commercial phases are actually not what the early stages of a new technology looks like. In contrast, the early stages of new technologies are often characterised by the grouping actions of a community of mostly amateur enthusiasts. Those enthusiasts pool and share information – that is, create a common pool of information – in order to discover the outlines of a potentially valuable opportunity. That opportunity need not be in the form of a start-up firm or a sellable property right, it is simply something *new*. Institutionally considered, the cooperative commons forms before the subsequent emergence of competitive firms and markets, and indeed, the very possibility of firms and markets will often emerge from discoveries made in the commons. The lone genius of technological innovation is an almost entirely mythological creature. The development of a technology – from nascent idea to widespread use – is fundamentally a collective process (Allen 1983) because in the beginning of a new technology uncertainty is extremely high and different people will know different things. Different people have different information about the potential uses, costs, possibilities and opportunities of that technology. We suggest that a commons can often be a highly efficient institution for gathering and combining such information in order to create a valuable common pool resource.

The key resource in an innovation commons is not the technology itself, but the distributed, partial and heterogeneous information that surrounds it. Much of this information is experimentally acquired, often tacit and of little value by itself, but of high value when combined with other information that reveals how the technology might be applied, and by whom, to do what, in combination with what, and so on. This is the information that distinguishes invention from innovation (Schumpeter 1934). From the steam engine, to electricity, to the internet, it takes time to discover socially and economically valuable uses for technologies. Coordinating institutions are necessary to gather and make sense of the information about costs and problems. Institutions of hierarchy (whether firms or governments) or the institutions of the market (property rights, price signals) are often poor at dealing with this combination of a highly distributed, tacit and uncertain resource. Therefore our claim is not that *all* innovative discoveries will occur in the commons. Rather, the institutions associated with the common property regimes – for instance, flat hierarchies and dynamic structures – may be comparatively efficient processing mechanisms, especially in the early stages of a new technology.

The innovation commons are a species of cultural and knowledge commons because they are, at their core, a pool of knowledge (Ostrom and Hess 2007; Madison et al. 2010; Frischmann et al. 2014). An innovation commons faces similar free rider problems to knowledge commons, and opportunism is an ever-present problem. Innovation commons need to develop rules to screen participants and to punish both free-riders and opportunists.¹ A common property regime with some form of exclusion is often necessary to maintain a balance between these dual concerns.

Unlike natural resource commons or other new commons, which can be long-lived and stable, a peculiar but characteristic feature of innovation commons is that they tend to be a transient institution. An innovation commons will coalesce around a new technology and then later collapse when its purpose disappears. Perhaps this is why the innovation commons around new technologies have remained undiscovered until now. The reason an innovation commons emerges is because of its relative efficiency as a governance structure for sharing and pooling distributed knowledge for opportunity discovery. Because early stage innovation is an environment where you don't quite know what you're producing, or how you're going to do it, or who you're going to do it with, a flexible and flat governance structure is amenable to opportunity discovery. But the very thing a successful innovation commons does – pooling distributed information to overcome uncertainty about the prospects of a new technology – provides the conditions for other institutions to outcompete it (as uncertainty falls). Alternative institutions – for instance, entrepreneurial firms and governments – who rely on reduced uncertainty and stable expectations in order to make plans and investments over property, gain a foothold. An innovation commons will often collapse at this point, replaced by institutions that render the technology as distinctly private or public good.

Why does this matter? On one hand, this is just another extension of the science of the commons into a new space where it was previously not thought relevant (*viz.* Ostrom 1990). But this extension is of significance, and perhaps contentiousness, because we claim to have discovered a new class of commons at the locus of what economic theory reliably informs us is the single most important factor determining the wealth and prosperity of nations: the growth of new technologies (Solow 1956; Romer 1990). Since Richard Nelson (1959) and Ken Arrow (1962) (see Stephan 1996; Martin and Scott 2000; Bleda and Del Rio 2013) economists have claimed the existence of market failure at the point of investment in developing new technologies. In consequence, large-scale and global suites of government policy – ranging from intellectual property, through R&D tax credits, to targeted procurement, through publically funded research, high technology industry policy, including especially military spending, and a raft

¹ The purpose of the current paper is not to discuss the specific mechanisms by which an innovation commons overcomes such problems. Rather, our purpose is to focus on the underlying resources and potential characteristics of an innovation commons.

of other programs amounting to typically around 3 or 4% of GDP in each nation, adding to several trillions of US dollars worldwide – address this market failure.

The innovation commons hypothesis suggests that we might have overlooked the role of the commons in this innovation process. As such, analysis of the innovation commons may simultaneously extend and enrich commons theory, and inform the application of innovation policy.

2. The innovation problem: beyond firms and states

The contemporary status of innovation economics, and with it innovation policy, looks remarkably like the state of commons research prior to Elinor Ostrom's (1990) systematic rebuttal of Garrett Hardin's (1968) pessimism about the 'tragedy of the commons'. While the specific problem differs – from under-produced innovation resources to over-exploited natural resources – the underlying diagnosis and treatment is the same. Both stories – of innovation and of a common pool resource – began with a supposed market failure that was resolved along a dichotomy of solutions amounting to privatisation on one hand, or state regulation and ownership on the other. Ostrom taught us how to analyse and understand the ability of civil society to overcome such social dilemmas, and that not only is there a third option beyond Coasian property rights solutions or Pigouvian government interventions but that the third option – the commons – is under certain circumstances the most efficient or first-best institutional possibility. We seek to elaborate how that same argument also applies to innovation economics – to 'the innovation problem' – which has not yet had its 'Ostrom moment' and still occupies an institutional universe of firms, markets and states.

The 'innovation problem' as an economic problem was first clearly defined by Nelson (1959) and Arrow (1962) who diagnosed new (scientific) knowledge as a public good, and therefore subject to market failure when privately produced. The implication of this particular framing was that new knowledge either had to be enclosed within private property (e.g. with strong intellectual property) or broadly recognised as the responsibility of government to produce (e.g. large scale public science). By construction, there was no prospect of a community-level governance solution because the innovation problem was never recognised as a collective action problem in the first place. Public (government) or private (markets) were, along with various hybrids such as R&D investment subsidies and industry policy, the fundamental forms of the public-policy solutions to the innovation problem under the market failure diagnosis. What is striking is the complete oversight of community level governance models – including common property regimes – as possible institutional solutions to the innovation problem.

We can easily unpack the microeconomics of the innovation problem to show that there is nothing in the logic of the problem that excludes institutional meso-level (i.e. network-level, community-level, industry-level) solutions in the commons. The innovation problem is fundamentally one of misaligned microeconomic incentives in a group activity. Because of the fixed costs and

uncertainty associated with discovery, as well as the public goods characteristics of knowledge, individuals may worry about opportunism and exploitation in their private investment of resources to innovative activities (Arrow 1962). From a social welfare perspective, investment in producing new knowledge that has fixed costs and is appropriable suffers a market failure because the marginal cost will always be below the average cost, and whoever accrues those fixed costs will be outcompeted by new entrants (Jones and Williams 1998; Bleda and Del Rio 2013). A frictionless competitive market will dedicate too few resources to innovation than is socially desirable (Romano 1989). This is the innovation problem, conventionally defined: innovation is incompatible with perfect competition.

With that diagnosis, the problem is perfect competition. The different ways of removing innovation from perfect competition constitute the modern systems of innovation policy (Nelson 1993; Freeman 1995; Soete et al. 2010; Dodgson et al. 2011). Governments impose innovation policy through two broad categories: market-based interventions or planning-based interventions (Bleda and Del Rio 2013). Intellectual property statutes create monopoly rights over innovations (Boldrin and Levine 2008). This Coasian solution attaches property rights so that innovation may be bargained to equilibrium (Coase 1960). States also create and direct non-market organisations, such as public science institutes. Between these extremes of market and state institutions are hybrid mechanisms operating through both markets and planners, such as R&D tax credits, which are fundamentally Pigouvian subsidies. Innovation policies are institutions with different costs and benefits at different margins (Goolsbee 1998; Davidson and Potts 2016).

These different forms of innovation policy contribute institutional diversity to the overall innovation system. Given the levels of uncertainty associated with different new technologies, this perspective is certainly in line with modern new institutional approaches (Ostrom 2005). It is also not out of place to recognise there are no panaceas when it comes to the institutions of innovation policy, even given the widespread presumption that underwrites innovation policy around the world that the state will succeed where the market was assumed to fail (Davidson and Spong 2010; Lindsay and Dougan 2013).

The more striking point to note is what is missing from the modern diagnosis of the innovation problem. Without any damage done to its underlying assumptions about fixed costs of investment, the innovation problem can be recognised as equivalently a collective action problem. The hidden assumption is the one that takes the new idea immediately to the realms of a global public good – and therefore within the province of government action – without recognising that the innovation problem begins as a local public goods problem well before it ever gets to the stage of a global public good. As a collective action problem, the innovation problem can be re-diagnosed as one in which a community of interest – nominally the enthusiasts for the new technology – need to develop institutional rules of governance to enable them to effectively pool and contribute innovation resources.

Intervention-based innovation policies centred squarely on market failure ignore the possibility that individuals can collectively govern themselves. Just

as Ostrom (1990) claimed privatisation and government-control solutions are ‘too sweeping in their claims’, so too we argue for the governance of innovation resources. Just as the tragedy of the commons was a misdiagnosis for natural resources, innovation policy may have been misdiagnosed. We need to move beyond markets and states in the governance of innovation resources. Innovation economics – and in its application, policy – must move beyond the narrow market failure argument in innovation – which only renders solutions through markets and states – towards viewing innovation as a collective action problem over the coordination of innovation resource.

3. Entrepreneurial opportunities and innovation resources

To appreciate the significance of the innovation commons to a modern economy and society, we start by appreciating the role of the entrepreneur and the fundamental difficulty the entrepreneur faces. The entrepreneur is the economic driver of change – the agent who introduces novelty and newness to economic life (Schumpeter 1934, 1942).² The Schumpeterian approach focused on the role of dispersed knowledge, uncertainty and institutions for coordinating this knowledge into a new economic order. The entrepreneur, in this view, is an agent who acts in an environment of uncertainty, exhibits judgement, alertness or skill in making those decisions, and coordinates or allocates scarce resources based on those judgements (Lachmann 1976; Kirzner 1978; Casson 1982; Shackle 1992; Earl 2003; Foss and Klein 2012).

The fundamental problem entrepreneurs face is uncertainty.³ Entrepreneurship means making decisions over events with few, perhaps no, similar past events on which to base expectations, yet creating or identifying new ends and means relationships that were previously undetected or underutilized (Gaglio and Katz 2001; Eckhardt and Shane 2003).⁴ Entrepreneurs face ill-structured problems of search and discovery of market opportunities (Dosi 1988), and consequently those who correctly identify the value of innovation resources and other market factors will be rewarded with profit (Kirzner 1978). Indeed, when framed this way, this problem applies to any group engaged in an innovative process, whether for profit or otherwise.

The inputs into the entrepreneurial process – innovation resources – are any resources that entrepreneurs acquire to deal with this uncertainty in order

² Note that entrepreneur refers not only to profit-seeking entrepreneurs in private markets, but also to social, cultural and political entrepreneurship, as a general statement about the agent who seeks to develop a new idea (Baumol 1990).

³ Following Knight (1921), uncertainty is about unique events over which outcomes are not only unknown, but are fundamentally unknowable (Shackle 1992).

⁴ Uncertainty is a two-sided coin for the entrepreneur – both the problem they must overcome and their source of profit. With perfect knowledge and foresight there would be no entrepreneurial profit, as all market opportunities would be costlessly and instantaneously exploited (Knight 1921; Rumelt 2005).

to discover market opportunities (Shane and Venkataraman 2000). This is not limited to money (i.e. financial investments). The most valuable resources for the entrepreneur are *knowledge about market opportunities*. This is because no entrepreneur can access or process, within any reasonable time frame or cost, the complete set of information needed to perfectly assess a market opportunity in respect of how a technology works in particular circumstances. This bounded rationality constraint extends to regulatory barriers and political uncertainty they may face; the way consumers use the technology in differing circumstances; the price points of competing technologies; the forward marginal costs and revenues of production; the sourcing of physical resources for production; the prospect of potential investment including venture capital; the problems that may arise when scaling up; the sources of expertise which they may seek and purchase; and so on. Obviously they would seek to gather that information, and its possession would be exactly as valuable as the opportunity it represents. Yet for the most part, this information is inherently unknowable *ex ante*, hidden within a cloud of uncertainty.

Entrepreneurs may improve their situation, and reduce uncertainty, by accessing information held by others. While no one person may have all that information, many people might – the information sufficient to describe the opportunity is distributed (Shane 2000). Just as different entrepreneurs will discover different opportunities because they possess different prior knowledge (Venkataraman 1997), entrepreneurial agents may seek to reciprocally pool their knowledge in the hope of mutually discovering a market opportunity. As the pieces of knowledge that describe a market opportunity are distributed over many agents in an economy there is an important possibility for the entrepreneur: coordinating this information through institutions. Several characteristics of entrepreneurial information, however, make institutional coordination difficult. Knowledge about market opportunities is generally only acquired by experiment and experience – through trial and error experimentation. This is because the value of such knowledge only emerges when assembled and combined with other complementary resources. The value of the overall entrepreneurial opportunity remains unclear before all of the parts are coherently synthesised. Entrepreneurial information exhibits heterogeneous value. This is why many entrepreneurial theories focus on judgement, or synthesis, or making connections. So what institutional governance structures are best to coordinate dispersed entrepreneurial information: is it markets, firms, governments, or the commons?

In established markets prices do much of this coordinating work, as Hayek (1945, 526) explained: "... in a system where the knowledge of the relevant facts is dispersed among many people, prices can act to coordinate the separate actions of different people in the same way as a subjective values help the individual to coordinate the parts of his plan." However, in new markets – where the structure of the future industry is unclear and uncertain – it is difficult to price such information, and with such uncertainty contracting is risky. The price system is often efficient in re-coordinating extant economic activity, yet "prices

fail to provide information on how new markets could be served, how a new technology could be used to improve a production process, or how a new way or organizing will generate value... [prices do not] accurately guide the discovery and exploitation of entrepreneurial opportunities” (Eckhardt and Shane 2003, 337). It is only *ex post* that a price may take into account the innovative value. As a coordinating institution, the price mechanism does not carry information that relieves entrepreneurial uncertainty.

The entrepreneur could also exist within an established hierarchical firm, or create a new start-up firm. This is where conventional innovation economics suggests the innovation process, and the coordination of entrepreneurial information, occurs. A hierarchical firm, however, is a poor governance structure to coordinate highly uncertain entrepreneurial information for two reasons. First, firms have boundaries. It is unclear whether the complementary information required to discover a valuable opportunity is within, or outside, the boundaries of the firm. And second, firms carry knowledge at the level of the ‘team’ or ‘project’ or suchlike, and this information is not dispersed throughout the firm. Similar deficiencies exist with governments – namely through public science – whereby discovery is a directed process.

The characteristics of entrepreneurial information – and the ability of different institutions to coordinate that information – plays no role in the market failure view of innovation. Further, it is only when we investigate the comparative efficiency of different institutions in coordinating entrepreneurial information that the commons is even raised as a possibility. This is where we turn now: to the ability of a common property regime to coordinate and combined dispersed contextual information about market opportunities.

4. Comparative properties of an innovation commons

4.1. How innovation commons are similar to other commons

An innovation commons requires a *rule-governed institutional space* to resolve the social dilemmas inherent in pooling the underlying resource. The common pool resource of an innovation commons is not just technology, it is the information that facilitates the use and application of that new technology to discover and create value. This information is both user relevant and entrepreneurially relevant. Innovation commons are thus a subset of, and similar to, the recent work on *knowledge and cultural commons* (Hess and Ostrom 2003; Lessig 2004; Benkler 2006; Madison et al. 2010; Frischmann et al. 2014). Both are contributory commons that function to create new knowledge as the common pool resource, rather than governing access to an already existing resource. Moreover, an innovation commons can be read in the various literatures on user innovation, democratised innovation, open innovation and collective invention (von Hippel 1986, 2007; Allen 1983; Chesbrough 2003; Nuvolari 2004). The innovation commons is part of the broader study of cooperative institutions for knowledge creation.

In contrast to other knowledge commons, however, the innovation commons place a greater emphasis on the assumption that the relevant knowledge is both *distributed* and *latent*. While much official information in an economy is centralised and codified, information about the *use* and *application* of a new technology – including its problems, costs, aspects of demand and local context – is also of high value. This information, however, is usually dispersed, embedded, and difficult to coordinate by hierarchical or market institutions forms. We claim that an innovation commons can be an efficient institutional technology to pool entrepreneurial information to create a valuable resource.

Our case studies furnish preliminary evidence that innovation commons exhibit the same basic design rules as those first discovered by Elinor Ostrom and subsequently revealed to be structural features of most successfully functioning commons (Ostrom 1990; Dietz et al. 2003; Stern 2011; Wilson et al. 2013). One example of an innovation commons are hackerspaces: small social organisations where individuals meet, work with others, and learn. Hackerspaces have been hubs of innovative activity, particularly around new technologies such as 3D printing. These spaces lack specifically designed goals, and operate with indeterminate and dynamic processes (Seravalli 2011). They have been described as intermediaries between scientific knowledge in laboratories and everyday problems (Kera 2012), a place of creative interaction through informal gathering (Moilanen 2012; Kostakis et al. 2014). Most recently, Williams and Hall (2015) examined a hackerspace in the context of common pool resources, focusing on how technology is used to manage the space and satisfy three of Elinor Ostrom's design rules. One key aspect of the hackerspace movement is that they are developed and run by hackers, for hackers (Maxigas 2014) – that is, they have collectively developed rules, often based on meritocracy (Kostakis et al. 2014). Hackerspaces are also reliant on reputation mechanisms, have been known to eschew the concept of money-making, and are centred around the 'hacker ethic' (Moilanen 2012). Hackerspaces seem to closely follow the design rules relating to distinct group boundaries, collectively developed rules and cheap-talk coordination, and relatively flat hierarchies. Although more extensive analysis is required, we can also point to a number of other innovation commons in which similar governance design rules are apparent: namely at the origin of new sports such as windsurfing (Potts and Thomas 2015); in the early stages of the wine industry in Australia (McIntyre et al. 2013); and the nascent blockchain industry collaborations, such as co-working spaces (Waters-Lynch et al. 2016).

4.2. How innovation commons differ from other commons

Yet the innovation commons has eight (and maybe more) features and characteristics that distinguish it from other knowledge commons.

- First, the innovation commons *processes uncertainty*.
The basic function of an innovation commons is to pool and process distributed information in order to reduce uncertainty about the prospects and pos-

sibilities of the novel and new technology. A new invention comes shrouded in uncertainty, with the extent of the uncertainty proportional to the novelty of the invention. In other words, the value of an innovation commons to the commoner's who participate in it is directly related to the quality of the resource in the common pool – conditioned of course by their access to it – to reduce uncertainty, and to thereby facilitate confident action, such as investment, adoption, or forming expectations and making plans.

While the innovation commons share similar enabling factors to the knowledge commons – namely new forms of communication, especially social media, leading to falling transaction and coordination costs – they are different because of the ongoing presence of uncertainty. Contemporary examples include the enthusiast groups coalescing around 3D printing technology, drones, cryptocurrencies, or software. User communities associated with new technologies – including the growing hackerspace movement (Kostakis et al. 2014) – are also instances of organisations surrounding pools of innovation resources – innovation commons (Franke and Shah 2003).

- Second, innovation commons will tend to be *ad hoc* and *temporary*. This is a direct consequence of their prime function being the alleviation of uncertainty, such that when uncertainty dissipates, the basic rationale for the commons substantially weakens. Unlike natural resource commons – which tend to perpetuate if the rules of the commons are effective – innovation commons tend to be temporary. Unless some other forces hold it together or prolong it – one of which we will meet in point seven below – the commons will tend to collapse at this point, or transform into an alternative institutional form (such as an industry or technology association). Note of course that the value of the commons continues, but the rationale for it weakens. The reason innovation commons will tend to collapse is due to the value of the underlying common pool resource. The resource in an innovation commons is pooled information that resolves uncertainty, particularly over use applications, barriers and costs, and market opportunities. While the innovation commons are born of fundamental uncertainty about innovation opportunities, addressing this problem successfully will collapse the functional rationale for the commons. Uncertainty is what engenders their creation; and the resolution of that same uncertainty instigates their collapse.
- Third, this means that innovation commons will tend to form at the very earliest stage of an *innovation trajectory*. The upshot is that an innovation commons is not an economy-wide substitute for other innovation institutions, but a complementary institution that emerges at the beginning of an innovation trajectory, where uncertainty is highest. In the Schumpeterian model, an innovation trajectory has three phases: (1) entrepreneurial origination; (2) adoption and diffusion; and (3) retention and institutional embedding (Dosi 1982; Dopfer and Potts 2007). An innovation commons is thus a zero-th phase that forms before the entrepreneurial phase

can begin, because it gathers the information necessary for the discovery of the entrepreneurial opportunity from a nascent new idea or technology. This zero-th phase is where ill-defined and dimly perceived opportunities are beginning to gather and coalesce.

Interestingly, natural resource commons also often emerge out of uncertainty, but this does not lead to them being temporary, but the opposite. A common pool resource will often be efficient where there is natural uncertainty about supply of the resource (such as grazing pastures, or a fishery). Private or public property institutions are often inefficient in such circumstances. A commons may thus emerge for the term of the uncertainty, which in the case of nature-generated uncertainty owing to weather or natural resource flows may be indefinite, as a perpetually more effective institution than their market and state alternatives. But the reason for existence of the innovation commons is to reduce uncertainty, and once the uncertainty passes, so does the efficiency case for the commons.

- Fourth, this prospect of uncertainty alleviation, collapse and phase transition into an industrial trajectory highlights that an innovation commons is not necessarily an institution for the *social provisioning* of innovation (Benkler 2006).

In one possible interpretation of this model, the innovation commons is an efficient institutional mechanism in a market-capitalist economy because of its particular effectiveness in dealing with high levels of uncertainty that can be resolved by creating a common pool resource. In this model, the innovation commons is an institutional mechanism to facilitate the process of entrepreneurial discovery (Hayek 1945; Hausmann and Rodrik 2003; Bakhshi et al. 2011). It is this unique property of furnishing information that reduces uncertainty which then enables entrepreneurs to act in other institutional forms – such as firms and markets, or in the state – that makes the innovation commons not just about social provisioning, or peer production *simpliciter*. However, the transition of the processed technology – with the innovation commons stripping uncertainty from it – does not necessarily result in subsequent adoption into a market-capitalist trajectory. What we think this highlights, rather, is that a modern Schumpeterian economy is still reliant on the commons at a fundamental, yet widely unappreciated, level.

- Fifth, in consequence, an innovation commons will exist at *many locations in an economy at once*, with those locations continually shifting, perhaps frequently.

Innovation commons are spatially and temporally mobile. An innovation commons will not exist across an entire economy, sector or region. Its location is emergent with respect to the social organisation of the development of a technology. These are not general spaces; much of their value comes from their sorting ability in whittling away uncertainty. Thus innovation commons exist on many scales and levels of organisation as a function of the need for

pooled information about the new technology by various users, adopters and entrepreneurs. An innovation commons is predicted to emerge along an innovation trajectory, within an economy, where uncertainty is highest about the pathways through which to develop a new idea or technology.

- Sixth, one of the distinct uncertainties that troubles a new technology is the best institutions within which to develop it. An innovation commons also facilitates *institutional matching*.

New ideas and technologies have a variety of characteristics that make them differentially suited to develop in different institutional forms. That is, some ideas may be better developed in public research institutions, for example, while other ideas may be better developed through the private technology start-ups, for example. The innovation commons provides a crucial institutional component in pooling information to make those decisions. As such, we place no particular emphasis on the optimal institutional structure of innovation *ex post* the discovery of an opportunity: it may be developed within a firm, a government, or a market. But by pooling information, an innovation commons potentially furnishes an efficient sorting and matching mechanism to increase the likelihood that a new technology subsequently develops under the most effective institutional environment.

- Seventh, one distinct prospect is that the best place to develop a technology is to actually keep it in the commons. The logic of this is *defence against enclosure* into alternative institutional forms.

A common property regime within a commons (as opposed to a private or a public good) may act defensively as institutions to minimise the risk that the technology will not find a viable market niche, or that it is locked on a particular path. Technologies and markets exhibit path dependency; the commons provides a mechanism to experiment with the correct path by keeping the pathway open. This mechanism can be observed in the efforts of those committed to open source software to maintain an innovation commons less as a service to potential entrepreneurs, but rather precisely to prevent alternative institutions (in this case private property rights) enclosing the technology and locking it into one particular path of development (Von Krogh et al. 2012). An innovation commons can emerge as a defensive institutional mechanism against entrenched economic interests. The very beginning of an industry, market, or product faces the prospect of political destruction by those who would see it as competition. An innovation commons can act as a bulwark against resistance from incumbent technologies and other entrenched interests with rents to protect. But, of course, it is also possible that these innovation commons may later form into rent-seeking interest groups (Olson 2008).

- Eighth, the optimal period for an innovation commons may be relatively long, on the order of decades perhaps, in order to best discover or *shake-out* all the hidden and unintended consequences and costs latent within a new technology.

These can be devastating when discovered once private property institutions have attached to a technology, or once the technology is fully in the public domain, because of the destruction of investment, or the tendency to constrain a technology through global regulation. A commons serves as a space of ‘permissionless innovation’ (Thierer 2014). An innovation commons can often quickly and at relatively low cost discover unintended consequences by facilitating small-scale experimental adoption, often understood by pooling distributed information. This is less costly and less risky than a full product launch or mass deployment. That is, it may be an alternative institution for the ‘trial’ stage of a technology, where the reciprocal sharing and testing between individuals over time may fulfil this role.

5. Conclusion

We claim to have identified a new type of commons – an innovation commons – that is a subspecies of knowledge commons (Ostrom and Hess 2007; Frischmann et al. 2014), but with several distinct new properties, particularly that of being highly spatially and temporally dynamic. We suggest the innovation commons is in effect a third-generation type of commons, and so contributing to the literature on the commons; and that the institutions of the commons represent the ‘zero-th phase’ in the standard three phase Schumpeterian trajectory that unfolds along the institutions of firms, markets and governments, and so contributing to the literature on innovation.

While initially commons scholars focused on natural resources (first generation) there has been a movement towards intangible common pool resources such as the knowledge commons (second generation). An innovation commons consists of a higher order form of information and knowledge about information and knowledge, and is in this sense a third generation model. The pooled resource at the heart of an innovation commons is knowledge about the potential uses, costs, problems, complementary resources, and so on latent in a new technology – that needs to be revealed in order to overcome uncertainty inherent in discovering valuable opportunities. The participants in an innovation commons – from entrepreneurs to enthusiasts – pool together contextual information about the *uses of technology* to overcome the *uncertainty inherent in opportunity discovery*.

While the innovation commons are not direct competitors to other intuitional forms – such as firms, markets, and governments – they are often precursors to them because they emerge at the beginning of new technologies and industries. The multitude of empirical examples of organisations governing innovation commons – from amateur sports clubs, hackerspaces to bitcoin co-working spaces – are temporary organisations because, if they are successful, instigate their own decline. That is, the questions that the participants seek to answer – about the uses, costs and possibilities of a technology – are most effectively dealt with in a commons, but the subsequent development of the opportunity discovered is not necessarily so.

Contrary to standard innovation policy – based on market failure models of innovation – the innovation commons are fundamentally about collective action in the governance of innovation resources. A systematic study of the innovation commons, using updated analytical frameworks, may shed new light into both innovation economics and the commons literature. This extension from knowledge commons to innovation commons however will not be easy, as it overlaps commons, entrepreneurship, and comparative institutional economics research. What we have provided here is a first analytical pass of defining the playing field of this new research domain: collaborative organisations in early stage technologies and industries. Further study of the innovation commons suggests a new research domain sitting between innovation economics and commons research, focusing specifically on the very early stages of entrepreneurial discovery and the emergence of new firms and industries. But this same domain of study may help us better understand the pathways by which a new technology may move into the public domain, something of particular global importance in technologies for healthcare, food production and sustainable energy.

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