Taking technological infrastructure seriously

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Title: Taking technological infrastructure seriously
Issue Date: 2017-06-29

CHAPTER 3

VISIBLE AND INVISIBLE HANDS: IP, SUBSIDIES AND OPEN ACCESS IN THE EU INNOVATION SYSTEM

I. INTRODUCTION

The previous two chapters have focussed on a qualification of 'technological infrastructure' that encompasses *de facto* and cooperatively-set interoperability standards. *De facto* standards have been described as emerging from the market due to demand-side network effects. Cooperatively-set standards emerge via a different process, becoming entrenched by horizontal agreements and specific investments made by competitors. Both these forms of technological infrastructure have been argued to fall under an 'infrastructural approach' to the enforcement of EU competition law.

The present chapter focuses on a third category of technological infrastructure: 'pioneering' inventions (or 'general purpose technologies') that result from publicly subsidised Research and Development ('R&D') programs. The chapter examines why an exclusive rights approach to the management of R&D outputs (such as in the European 'transplant' of the US 'Bayh Dole' regime[450]) may lead to suboptimal social welfare outcomes. It proposes that rather than relying on the ex post application of EU competition law to ensure the openness of technological infrastructure, the subsidy system itself can structure incentives to drive knowledge resource management regimes towards open access outcomes, such as royalty-free or FRAND licensing. The key to this proposal has two features. First, that where subsidised R&D results in IP-protectable outputs, these outputs are highly likely to qualify as technological infrastructure. Second, that the best way of managing this technological infrastructure is to create strong incentives for the subsidy recipient to make these outputs open access, for example, by ramping up available subsidy intensities, even where the output is 'close to the market'.[451] This proposal embodies a variation of the 'infrastructural approach' of the previous chapters, by recommending changes to the institution of subsidy grants, so that the rule, 'if infrastructure, then open access', becomes institutionally entrenched.

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450. The 'European transplant of Bayh-Dole' refers to the default allocation of IP rights to the subsidy recipient, as set down in Regulation (EU) No 1290/2013 of The European Parliament and Of The Council of 11 December 2013 Laying Down The Rules For Participation And Dissemination In "Horizon 2020 - The Framework Programme For Research And Innovation (2014-2020), Article 41
("Ownership Of Results: Results shall be owned by the participant generating them.")

451. Currently, close to market activities (e.g prototyping) R&D projects max out at 70% of the total costs for large companies. See, <http://ec.europa.eu/competition/state_aid/modernisation/rdi_framework_faq_en.pdf> accessed April 20 2017 One interesting issue is whether or not the subsidy caps in State Aid or H2020 apply at all if the access regime is royalty-free. The Communication from the Commission Framework for State Aid for Research and Development and Innovation (C(2014) 3282), Article 19(a) would seem to suggest not, as it would not then be considered an 'economic activity'. However, it is quite clear that the caps would apply if the IP is licensed under the open access regime of 'FRAND 'licensing.

The above arguments are developed in three main moves. After this introduction, the first move (Part II) lays the groundwork. It begins by developing the concept of an 'innovation institution'. It then introduces and explains the approach of 'comparative institutional analysis' which will be used to guide the argument. The subsequent subsection develops the key concept of 'intellectual infrastructure', its close relationship to open access licensing, as well as the concepts of 'scientific infrastructure' and 'technological infrastructure'. It explains why the mixed subsidy/IP Bayh-Dole regime is likely to give rise to information assets of this character. The second move (Part III) begins by digging into the economic foundations of intellectual property, including deploying some useful tools from game theory to highlight the regulatory nature of the IP system, such as the 'assurance game' and the problem of 'property traps' in high technology. The nerve of this part is to apply pressure to the idea that an exclusive rights regime is the best institution for stimulating the transfer and commercialisation of technological infrastructure, such as is assumed by the Bayh-Dole model of allocating sponsored R&D results (and any IP) to the subsidy recipient. The third move (Part IV) distils the insights from the previous section into policy recommendations by first briefly reviewing the EU subsidy regime as it now is, then offering a simple approach to ensure greater openness with respect to technological infrastructure. This approach takes the form of ramping up R&D subsidy intensity in cases where subsidy recipients make their outputs available on open access terms.

II. GROUNDWORK: ORIENTATING THE ARGUMENT

A. Innovation Institutions and Comparative Analysis

Innovation institutions can be conceptualised as any economic mechanism that organises incentives in order to encourage R&D and commercialisation.[452] But this definition immediately begs the question: why does innovation need to be encouraged? The textbook answer to this question recruits the concept of 'market failure' to do the heavy lifting: that the unaided market's allocation of resources diverges from what is socially optimal to drive investment in R&D. There are at least two arguments commonly used to explain the market failure of information production: the spillover argument (as already briefly discussed in the introduction) and uncertainty.

1. Spillovers

As developed in the work of Harold Demsetz, the spillover argument is analytically identical to the more familiar 'public goods' argument.[453] The public goods argument runs that

452. Daniel Jacob Hemel and Lisa Larrimore Ouellette, 'Beyond the Patents-Prizes Debate' (2013) 92(2) Texas L Rev 303.
453. Demsetz, 'Information and Efficiency'; Brett M Frischmann, 'Evaluating the Demsetzian Trend in Copyright

since R&D outputs[454]- mostly information goods- are non-excludable and non-rivalrous, their private appropriability can be weak[455], resulting in relatively weak private incentives to invest.[456] The value that is not appropriated by the company engaging in R&D enters society in the form of spillovers[457]: unintended third party benefits that are not factored into an individual's decision to engage in information production. As already mentioned, although R&D spillovers are difficult to measure accurately, their value to the economy has been calculated econometrically at several times that of the private value appropriated by the company engaging in the R&D.[458] This extra value shakes out micro-economically, by driving efficiency gains across an industry[459]; and macro-economically, by contributing to economic growth,[460] making them a central goal of policies addressing the innovation system.

The upshot of the 'spillovers' argument is that since a company's R&D investment decisions only focus on the appropriable *private benefits* and not the wider *societal benefits* of R&D, the 'invisible hand' of the unaided market fails to align the privately optimal level of R&D investment with that which is socially optimal: spillovers are less than what they could be because R&D investment is less than what it could be.[461] In other words, the reason why the invisible hand may sometimes be invisible in information production, is because in the unaided market it is often simply not there.[462] The invisible hand may require the 'helping hand' of bespoke innovation institutions, such as IP and subsidies, whose design and purpose is to help private incentives track socially optimal goals.

As will be discussed in more detail in Section B and also in Part III, intellectual property is a form of 'socially created property', which is designed to create artificial scarcity in information by permitting exclusion. [463] This artificial scarcity allows innovators to internalise

Law', (2007) 3(3) Rev L & Econ 2.

454. R&D outputs are here considered as all the intangible outputs that result from R&D, including know-how and intellectual property.

455. Teece, 'Profiting from Technological Innovation'.

456. Ibid.

457. Frischmann and Lemley, 'Spillovers'. See also Gerald A Carlino and Jake Carr, 'Clusters of Knowledge: R&D Proximity and the Spillover Effect', (2013) (Q3) Business Rev 11.

458. Griliches, 'The Search For R&D Spillovers'.

459. Ibid.

460. Robert M Solow, 'Technical Change and the Aggregate Production Function' (1957) 39(3) Rev Econ & Stats 312 ("Solow, 'Technical Change'"). See also J Doyne Farmer and Francois Lafond, 'How Predictable is Technological Progress?', (2016) 45 Research Policy 647 ("Farmer and Lafond, 'How Predictable is Technological Progress?'")("[t]echnological progress is widely acknowledged as the main driver of economic growth").

461. Phedon Nicolaides, 'The Economics of Subsidies for R&D: Implications for Reform of EU State Aid Rules' (2013) 48(2) Intereconomics 99 ("Nicolaides, 'The Economics of Subsidies for R&D'").

462. Joseph E Stiglitz, 'Economic Foundations of Intellectual Property Rights' (2008) 57(1776) Duke LJ 1693 ("[o]ne of the important results of my work, developed in a number of my papers, was that the invisible hand often seemed invisible *because it was not there*.")

463. *i.e.,* in contrast to the 'natural right' arguments which often motivate real property. See Edward L Rubin, 'The Illusion of Property as a Right and Its Reality as an Imperfect Alternative' (2013) Wisconsin L Rev 573 ("Rubin,'The

a greater proportion of the value of spillovers, which can then function as incentives for R&D investment. At its core, the IP system constitutes a *regulatory choice* as to what types of information should be protected and what cannot and represents a 'social bargain' of high complexity: IP should only attach to information that would not otherwise be produced (or disclosed) but for the IP[464], and which has high social value; and where such social value (in the form of spillovers) is *enhanced* by the exclusivity provided by IP, rather than diminished by it. In short, the driving force of the IP system is the creation of social value, and it is designed 'to benefit the public as a whole', rather than individual inventors.[465] Hitting this sweet spot is a difficult task, and a substantial literature has emerged which focuses on cases where the IP system fails to meet these conditions, leading to unjustified social cost.[466] Where IP-protected information assets also constitute intellectual infrastructure, these shortcomings may be exacerbated further, as discussed in Part III.

The institution of R&D subsidies attempts to solve the spillover problem in a different way. By providing for greater relative value appropriation via the ex ante grant of (a percentage) of R&D costs. Again, there is a complex bargain at the heart of the subsidy system: that subsidies should only be granted where the innovation is of high social value, and only when the market cannot produce the information asset on its own, or where the terms of access to the asset would be sub-optimal if the market were to produce it.[467] One key condition under which subsidies may be an optimal institutional choice is when the desired information asset fails to be produced by reason of high risk or uncertainty, as discussed below.

2. Uncertainty

Information production may be hampered by 'uncertainty'. This argument takes a different tact from the spillover argument, by suggesting that the divergence between private and social levels of *risk aversion* leads to chronic underinvestment, even where value appropriation mechanisms (such as IP) may be present. [468] The concept of uncertainty may be further decomposed into 'risk' (where the uncertainty is known and can be roughly calculated[469]) and

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Illusion of Property'"), 578 ("[w]ith respect to intangibles or socially created property, such as a patent or a government position, the pattern emerges once again with clarity, since these kinds of property are generally brought into existence by explicit governmental action. In all these cases, property—the private ownership of resources—was a government policy designed to achieve specific and identifiable purposes…")

464. Or produced in socially sub-optimal levels.

465. Contreras, 'Market Reliance' 486 ("The patent system as authorized by the U.S. Constitution is endowed with a public character: "To promote the Progress of Science and useful Arts." Its primary purpose is not to reward individual inventors, but to benefit the public as a whole.")

466. See the discussion in Benjamin N Roin, 'Intellectual Property Versus Prizes: Reframing the Debate' (2013) 81 U Chicago L Rev 999.

467. As discussed further in Part II, Section A(2) and in Part II, Sections B(3) and (4)

468. Link and Scott, *Public Goods, Public Gains.*

469. Mariana Mazzucato, The Entrepreneurial State (Demos 2011) 49-50 for discussion of risk and uncertainty.

'Knightian[470] uncertainty' (where the uncertainty cannot be known because of the uniqueness of the project[471]). Depending on the market structure,[472] this divergence between the level of private and socially optimal risk aversion may lead to a bias in private investment away from radical innovation and towards incremental innovation. Alternatively, radical innovation may still go ahead but only under conditions where the ex post revenue streams are assessed as extremely high, such as has been argued by Joseph Schumpeter and proponents of 'dynamic competition'[473], as in the case of *de facto* standards 'wars' (see Section B(3)).

In cases where risk and uncertainty prove an insurmountable obstacle to private R&D, the 'risk gap' may be addressed by public R&D subsidies, which aim to cover (a percentage of) the total costs in order to help make R&D go through which otherwise might not.[474]

Given the challenges to innovation institutions posed by both spillovers and uncertainty, the task of incentivising R&D often involves an institutional choice of some form, for example, between the market (IP) or direct Government involvement (subsidies). The tool of comparative institutional analysis can help in clarifying the various costs and benefits involved in these different innovation institutions.

3. Comparative institutional analysis

In general, the innovation institutions identified above operate by narrowing the gap (whether financial or risk) between the privately and socially optimal levels of R&D. But the way these two innovation institutions operate is very different; involve different costs, benefits and trade-offs; and often derive their raisons d'etre from divergent economic theories on the nature of innovation and efficiency. Each of these institutions furthermore has well-known draw-backs.

In the case of IP, which attempts to reinstate the 'invisible hand' of market forces, these drawbacks relate to the fact that propertising information (particularly of an infrastructural character[475]) may lead to monopoly pricing, the potential choking of downstream and cumulative innovation[476] and the creation of intellectual property anti-commons in the form

470. Ibid. Deriving from the name of economist, Frank Knight.
471. Ibid, 42.
472. There is a dense literature on the effect of market structure on incentives to invest in R&D, see for example the concept of "Arrow's replacement effect", as discussed in Daron Acemoglu and Dan Vu Cao, 'Innovation by Entrants and Incumbents' (2010) National Bureau of Economic Research NBER Working Papers 16411 <http://www.nber.org/papers/w16411.pdf> accessed 14 October 2016.
473. Baker, 'Dynamic Competition'; Arthur, 'Competing Technologies'.
474. Commission Communication on the framework for State aid for research and development and innovation [2014] OJ C198/01, 21-23.
475. See discussion in section B below.
476. Paola Giuri and Salvatore Torrisi, 'Cross-Licensing, Cumulative Inventions and Strategic Patenting', 5th Annual Conference EPIP Association, Maastricht, 20-21 September 2010) ("Giuri and Torrisi, 'Cross-Licensing'").

of, inter alia, 'patent thickets' caused by the strategic use of IP.[477] In addition, an IP system may bias creative and inventive activity towards outputs which are more easily commercialisable and away from both basic research and high risk (and uncertain) R&D, with high social value but limited (risk-discounted) private appropriability. The use of IP as a vehicle for technology transfer also has well-known deficiencies, in many cases stemming from a faulty analogy between real property and IP. The technology transfer aspect of IP is generally understood to motivate the Bayh-Dole regime in relation to subsidised R&D. Part III of this chapter hones in on this aspect by deploying useful tools from game theory.

The draw-backs associated with R&D subsidies take a different form. While theoretically capable of incentivising R&D without engendering social deadweight losses as well as being able to target high risk/uncertain R&D, subsidies may suffer resource allocation problems due to information poverty.[478] Unlike the IP system, which is able to harness the price system as a conduit for demand signalling and other crucial R&D investment decision-making information, the allocation of subsidies is generally subject to the very 'visible hand' of centralised decision-making and agenda-setting. The centralisation of R&D resource allocation decisions is therefore more likely to involve both false negatives and false positives, leading to 'crowding out'[479] of private investment, the risk of 'double-subsidisation', as well as distortionary directional R&D incentives.[480]

Importantly, these two institutions do not operate as viable substitutes in all cases, but have preferred scopes of application. In cases where the IP system is thought to operate well, subsidies may be distortionary or have negative wealth distribution effects.[481] Likewise, in cases where subsidies are deemed necessary, the IP system may lead to unjustified dead-weight losses and losses in dynamic efficiency caused by access problems. But these two institutions do not merely function as 'imperfect *alternatives*'; they may also, in some cases operate as *complements*.[482] As already mentioned, under both the US Bayh-Dole Act and its European transplants, IP arising from subsidised R&D are allocated to the subsidy recipient. The effect of this IP allocation is that the private party gets exclusive rights over an information

477. Georg von Graevenitz, Stefan Wagner and Dietmar Harhoff, 'Incidence and Growth of Patent Thickets: The Impact of Technological Opportunities and Complexity' (2013) 61(3) J Indus Econ 521 ("von Graevenitz, Wagner and Harhoff, 'Incidence and Growth of Patent Thickets'").
478. Demsetz, 'Information and Efficiency', 12 ("[h]ow would such a system produce information on the desired directions of investment and on the quantities of resources that should be committed to invention?")
479. Néstor Duch-Brown, José García-Quevedo and Daniel Montolio, 'The Link between Public Support and Private R&D Effort: What Is the Optimal Subsidy?' (2010) Institut d›Economica de Barcelona Working Papers 2011/12.
480. Paul A David and Bronwyn H Hall, 'Heart of Darkness: Modeling Public–Private Funding Interactions Inside The R&D Black Box' (2000) 29 Research Policy 1165 ("David and Hall, 'Heart of Darkness'").
481. Nancy Gallini and Suzanne Scotchmer, 'Intellectual Property: When Is it the Best Incentive System?' (2001) Economics Working Paper E01-303.University of California, Berkeley ("Gallini and Scotchmer, 'Intellectual Property'").
482. One key question that will be considered in Parts 2 and 3 is the extent to which such complementary use may compound or mitigate the drawbacks in the two institutions.

asset that it would otherwise not have even been able to produce, but for the subsidy. The economic logic underlying this complementary use of IP and R&D subsidies is driven by a technology transfer story of the function of IP. Essentially, policy makers side-step the usual incentivisation argument in support of IP and invoke the argument that the subsidy recipient (often a private company, but also universities and research institutions[483]) would likely make more productive use of the information asset than either Government ownership or its commitment to the public domain. In the first case (Government ownership of resulting IP), the argument runs that IP risks languishing in filing cabinets, like the ninety-five per cent of patents recorded on US Government files before the passing of the Bayh-Dole Act in 1980.[484] In the second case (commitment to the public domain), the assets may simply disappear from view once committed to the public domain, due to information problems and the lack of any one company's incentives to bring the assets to market, or as put by Rebecca Eisenberg: the public domain may become 'a treacherous quicksand pit in which discoveries sink beyond reach of the private sector'.[485]

The literature on the relative merits of the Bayh-Dole regime compared to a regime where R&D outputs are committed to the public domain or otherwise made open access, is dense, but ambiguous and inconclusive.[486] It is therefore widely acknowledged that in the context of information production, legislators and policy makers must enter the world of "second best" solutions and imperfect institutional alternatives (or complements).[487] Furthermore, imperfections in a particular innovation institution do not necessarily argue for the legitimacy or primacy of an institutional alternative. To move from the identification of imperfections

483. Originally Bayh-Dole Act applied to SME's and non-profits only, but then under President Reagan it was extended to all companies, regardless of size. See Ronald Reagan, 'Memorandum on Government Patent Policy' (The American Presidency Project 18 February 1983) <http://www.presidency.ucsb.edu/ws/?pid=40945> accessed 13 October 2016.

484. Wendy Schacht, 'The Bayh-Dole Act: Selected Issues in Patent Policy and the Commercialization of Technology' (2012) Congressional Research Service <https://www.fas.org/sgp/crs/misc/RL32076.pdf> accessed 16 September 2016, 2 ("[p]rior to 1980, only 5% of government owned patents were ever used in the private sector although a portion of the intellectual property portfolio had potential for further development, application, and marketing. The Bayh-Dole Act was constructed, in part, to address the low utilization rate of these federal patents."); David C Mowery and Bhaven N Sampat, 'The Bayh-Dole Act of 1980 and University–Industry Technology Transfer: A Model for Other OECD Governments?' (2005) 30(1) J Tech Transfer 115. Also see the US Bayh-Dole Act, as codified in US law at 94 Stat. 3015, and in 35 U.S.C. § 200-212, and as implemented by 37 C.F.R. 401.

485. Rebecca S Eisenberg, 'Public Research and Private Development: Patents and Technology Transfer in Government- Sponsored Research' (1996) 82(8) Virginia L Rev 1663 ("Eisenberg, 'Public Research and Private Development'"), 1664.

486. Michael Sweeney, 'Correcting Bayh-Dole's Inefficiencies for the Taxpayer' (2012) 10(3) Nw J Tech & IP 295 ("Sweeney,'Correcting Bayh-Dole's Inefficiencies for the Taxpayer'"); Eisenberg, 'Public Research and Private Development'; Rebecca S Eisenberg and Arti K Rai, 'Bayh-Dole Reform and the Progress of Biomedicine' (2003) 662(1) Law and Contemporary Problems 289 ("Eisenberg and Rai, 'Bayh-Dole Reform'"); Samuel Loewenberg, 'The Bayh–Dole Act: A Model For Promoting Research Translation?' (2009) 3 Molecular Oncology 91.

487. Carroll, 'One Size Does Not Fit All', 1391 ("[t]hus, uniform patents and copyrights are second-order second best, or, in other words, a second-best solution nested within the second-best solution of intellectual property rights"); Komesar, *Imperfect Alternatives*.

in one institution to the conclusion that therefore a different institution should be preferred commits what Harold Demsetz has referred to as the "nirvana fallacy".[488] What is required is a comparison of the two different institutions against some base-line objective,[489] according to the framework developed by Neil Komesar.[490]

In the present chapter, the two institutions of exclusive IP (in the form of Bayh-Dole) and open access licensing (in the form of either royalty-free or FRAND) will be assessed in relation to how well they manage the resource of intellectual infrastructure against the base-line objective of ensuring technology transfer.[491] This is the purpose of Parts III and IV of this chapter. Before that analysis can begin, it is first necessary to elucidate the concept of intellectual infrastructure in detail, and to defend its uniqueness as an information asset.

B. Intellectual infrastructure

1. Background

a) Defining Intellectual Infrastructure

According to the work of Brett Frischmann and Peter Lee, when a resource is non-rival, generic, and derives most of its social value from downstream uses, it may be classified as infrastructural. This definition has both supply and demand side components. On the supply side, the asset must be able to support multiple simultaneous uses (often across different markets)- i.e. it must be 'non-rival'; and it must be 'general purpose' or generic (in the sense of having relative independence from end use).

In many ways, the requirement of 'genericness' maps to the level of abstraction according to which an information resource is defined. [492] Casually formulated, the more abstract an

488. Demsetz, 'Information and Efficiency'.
489. Frischmann and McKenna, 'Comparative Analysis', 4 ("[c]omparative institutional analysis presumes some objective and evaluates different institutions in terms of their ability to accomplish that objective. ")
490. Ibid.
491. It should be pointed out that in the case of intellectual infrastructure, the concept of 'technological transfer' has a very special meaning: not just the dissemination of the technology as an end-product, but also its productive use in the innovation system, serving to scaffold downstream innovation. See Frischmann and Waller, 'Revitalizing Essential Facilities', 13 ("infrastructure resources are intermediate goods that create social value when utilised productively downstream and that such use is the primary source of social benefits. In other words, while some infrastructure resources may be consumed directly to produce immediate benefits, most of the value derived from the resources results from productive use rather than consumption. ")
492. However, intellectual infrastructure often exhibits a 'fractal' character: it can be built up of indispensable components on lower levels of abstraction which also function as necessary inputs. Since access to each of the lower-level components functions as a bottle-neck to the higher-level generic infrastructure, they may also need to operate under an open access rule. The term 'fractal' is used here to refer to the 'recursive' nature of intellectual infrastructure, meaning that such assets may exist at different levels of abstraction. For discussion of this attribute of infrastructural assets see Frischmann, *Infrastructure*, 276 ("the infrastructure concept [seems] to have a fractal nature when applied

information asset is, the greater the potential number of downstream uses; while the closer the asset becomes to an implementation, its use gradually becomes identified with a single use.[493] If an idea or technology feeds in as an input into a wide range of downstream uses (whether within a single market or research space or multiple ones[494]) then it is most likely generic[495]. Due to its ability to feed into a range of possible uses, a resource's genericness may also give rise to high social value in the form of spillovers. However, as Frischmann observes[496]:

> although infrastructure may generate substantial social welfare ; rather it is the functional nature of the resource and the manner in which it generates social value that matters.

The genericness and high social value of an information resource are necessary but not sufficient to identify it as critical infrastructure;[497] it must also perform the function of infrastructure *in fact*. In economic terms, a candidate asset for an infrastructural asset must exhibit *derived demand*, [498] meaning that downstream users require the asset as an input for their own productive activities. This was a key component of the 'infrastructure screening test' developed in chapters 1 and 2. Examples of intellectual infrastructure include generic ideas, scientific discoveries, and technological innovations that form part of the cumulative cultural and informational 'backdrop' that feeds into society's socio-cultural and technological production systems.[499] Put like this, the concept of intellectual infrastructure seems to be a very rich idea. In fact, this conceptualisation of intellectual infrastructure links up with the literature on cultural evolution and theoretical biology[500], as well as economic arguments for

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to intellectual resources because you could identify infrastructure at various scales…")

493. Frischmann, *Infrastructure*.

494. Frischmann and Waller, 'Revitalizing Essential Facilities.'

495. It is, however, important to distinguish between widespread use of a single input in the same use-case compared to widespread use of a sinlge input in many different use cases. Both may be considered generic, but a lot will turn on the particular facts of the resource's use.

496. Frischmann, *Infrastructure*, 278.

497. In fact, highly specific inventions (such as may be disclosed in a patent) can have high social value due to the more generic teaching embedded inside, which feeds back into the public domain, see R. Polk Wagner, 'Information Wants To Be Free: Intellectual Property and the Mythologies of Control' (2003) 103 Columbia L Rev 103(1) ("Wagner, 'Information Wants To Be Free'"), 1005 ("[t]his information may not be embodied in any product or service, but instead might consist more generally of ways of viewing problems, adaptations of old or unrelated principles, a promising direction of research, or the identification of new uses for materials").

498. Sidak and Lipsky, 'Essential Facilities', 1215 ("[t]he demand for use of the facility is a derived demand based on the underlying demand for the end product").

499. Frischmann, *Infrastructure*, 260 ("[t]he cultural environment as infrastructure has an intergenerational dimension. Each generation is blessed beyond measure with the intellectual and cultural resources it receives from past generations; each generation experiences and changes the cultural environment and passes it on to future generations").

500. For example, see Kim Sterelny, *The Evolved Apprentice: How Evolution Made Humans Unique* (MIT Press 2012) ("Sterelny, *The Evolved Apprentice*") xii: ("…human cognitive competence is a collective achievement and a collective legacy; at any one moment in time, we depend on each other, and over time, we stand on the shoulders of not a few

the freedom of speech.[501] But the richness of this concept does not prevent it from being defined precisely enough so as to be useful for legal and economic analysis. Chapters 1 and 2 discussed in detail the legal and economic tests for assessing *de facto* and cooperatively-set technological standards as infrastructure. By and large, these tests are tuned to focus on the *function* of these resources within productive systems rather than simply checking boxes of infrastructural attributes. These tools provide lawyers and economists with the analytical traction required to define and apply 'infrastructure screening' tests in legally and economically meaningful ways.

Importantly, while clearly encompassing both de facto and de jure standards as intellectual infrastructure, the above understanding also embraces pioneering inventions or 'general purpose technologies'. General-purpose technologies[502] are technological innovations that are so fundamental that they can lead to 'discontinuities'[503], which completely reshape markets and sometimes economies. Steam engines[504], electricity[505], and computation[506] are examples of the latter. As developed in Section B(3) below, this category of intellectual infrastructure is a likely output of subsidised R&D.

Having established the scope of the intellectual infrastructure concept, it is necessary to explain in greater detail its relationship to open access licensing regimes, by briefly rehearsing and extending the arguments already developed in chapters 1 and 2.

b) Intellectual infrastructure and open access licensing

In an ideal world, all intellectual infrastructure would be publicly provided and available at zero cost[507], as in the case of much traditional infrastructure. Although this holds true for a subset of intellectual infrastructure (that which falls outside the IP system, see discussion at B(3) below), it is not possible in the real world, as it would require the Government to

giants but of myriads of ordinary agents who have made and passed on intact the informational resources on which human lives depend".)

501. Yochai Benkler, 'Free As the Air to Common Use: First Amendment Constraints on Enclosure of the Public Domain' (1999) 74 New York U L Rev 354 ("Benkler, 'Free As the Air to Common Use'").

502. Lipsey, Carlaw and Bekar, 'Economic Transformations'.

503. Or radical changes in the trajectory of technological or market evolution. Philip Anderson and Michael L Tushman, 'Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change' (1990) 35 Administrative Science Quarterly 604; Michael L Tushman and Philip Anderson, 'Technological Discontinuities and Organizational Environments' (1986) 31(3) Administrative Science Quarterly 439.

504. Nicholas Crafts, 'Steam as a General Purpose Technology: A Growth Accounting Perspective' (2004) 114(495) Econ J 338.

505. Petra Moser and Tom Nicholas, 'Was Electricity a General Purpose Technology?' (2004) 94(2) Amer Econ Rev 388.

506. Basu and Fernald, 'Information and Communications Technology'.

507. Arrow, 'Economic Welfare and the Allocation of Resources for Invention', 614-615: ("The cost of transmitting a given body of information is frequently very low. If it were zero, then optimal allocation would obviously call for unlimited distribution of the information without cost.")

harvest and synthesise an impossible amount of information. The market- and competition in particular- is required as a 'discovery procedure'.[508] For this reason, the market operates in liberal democracies- both with respect to certain types of traditional infrastructure and some information assets (in the form IP)- as a procedure for coming up with novel solutions. As discussed in Section III, the downside of this mechanism with respect to IP is that the scope of IP laws is a regulatory choice and therefore most likely to be full of type I and II errors. Because of this, society relies on the interaction of other institutions, such as competition law, with the IP system to ensure that information markets operate efficiently. Chapters 1 and 2 of this thesis argued that the role of competition law in opening up IP can be explained according to an 'infrastructural approach': ensuring the public availability of critical infrastructural IP where such availability is essential to sustain effective competition and innovation.

By keeping infrastructure open (via either royalty-free or FRAND licensing[509]), neither IP right holders[510], nor Government, nor other mechanisms of top-down decision-making[511] get to exclusively determine downstream productive uses via denial of access or arbitrary setting of access terms.[512] Instead, open access permits a 'bottom up' process, whereby individual decision-makers can self-select their downstream productive uses of the infrastructural asset, permitting the emergent complexity and unpredictability of innovation systems.[513] Tim Wu develops this argument with respect to intellectual property in general, where he argues for a 'polyarchal' rather than a 'hierarchal' approach to patents –suggesting that patent scopes should be narrowed or patent eligibility requirements raised, so as to allow a greater flourishing of innovation.[514] To this end, the work of Mark Lemley reminds us that it is a fallacy to assume that an individual right owner will always pursue the most productive uses of its information asset:[515] Economic theory states that *markets*, not individuals, generally make efficient decisions, where the cost of stupidity, greed or short-sightedness is elimination

508. See generally F. A. Hayek, 'Competition as a Discovery Procedure' (1968), republished in The Quarterly Journal of Austrian Economics Vol. 5, No. 3 (Fall 2002): 9–23
509. See the FRAND discussion in chapter 1.
510. Tim Wu, 'Intellectual Property, Innovation, and Decentralized Decisions' (2005) 92(1) Virginia L Rev 104, ("In general, broad rights or rights held by a limited number of parties promote a hierarchical decision architecture. Conversely, diffuse rights or non-assignment of rights leads to the market default: polyarchical decision making architectures, where any firm or individual may decide to undertake a new project.")
511. Such as *e.g.*, IP owners acting as gate-keepers to entire markets or research spaces.
512. Frischmann and Waller, 'Revitalizing Essential Facilities', 18 ("[o]pen access eliminates the need to rely on either the market or the government to "pick winners" or uses worthy of access. On one hand, the market picks winners according to the amount of appropriable value generated by outputs, and consequently output producers' willingness to pay for access to the infrastructure. On the other hand, to subsidise production of public goods or non-market goods downstream, the government needs to pick winners by assessing social demand for such goods based on the social value they create.")
513. David C Colander and Roland Kupers, *Complexity and the Art of Public Policy : Solving Society's Problems from the Bottom up* (Princeton University Press 2016); Tim Wu, 'Intellectual Property, Innovation, and Decision Architectures' (2005) University of Chicago Public Law & Legal Theory Working Paper No. 97.
514. Tim Wu, 'Intellectual Property, Innovation, and Decentralized Decisions' 101.
515. Lemley, 'The Regulatory Turn in IP'.

from the market. But a market requires demand and supply side substitutability in order to operate. As will be shown later in this section, these conditions are often absent in the case of intellectual infrastructure.

The preference for open access in relation to infrastructural resources also goes some way to explaining the dominant provisioning mechanism of traditional infrastructure. By being publicly provided, most traditional infrastructure is able to remain open access[516] without the need for assuring private appropriability of the value created. Even in the case of the liberalisation of Government-owned assets, a condition of letting market forces operate is often the implementation of open access rules by regulatory bodies.[517] In the case of intellectual infrastructure, the situation is more complex. Ownership over information is determined by the scope of intellectual property laws. The line between what may or may not be protected under intellectual property laws maps (to a vast extent) the line between genericness and specificity that also motivates the identification of infrastructure. By consequence, it also traces the contours of the regulatory choice over the preferred provisioning mechanism for categories of information resources: those information assets which fall under IP have been selected to be provided by the market, whereas information falling outside IP is left to the operation of other institutions, such as subsidies, prizes or indirect value appropriation mechanisms.[518] But despite this regulatory choice, the boundary between what society chooses to be propertised and what should remain in the public domain as intellectual infrastructure is messy and constantly litigated. Indeed, the boundary between what is generic and abstract and what is sufficiently specific to be protected has been at the core of a number of landmark IP cases, including the granting of patents over software,[519] gene sequences[520], and business models[521], as shown by the recent US Supreme Court case of *Alice v CLS Bank.*[522] In an Amicus Curia Brief to the Court in that case, Jack Lerner implicitly endorsed an infrastructural approach, which links the 'genericness' of the information asset to its infrastructural function:

516. As stated in chapter 1, 'open access' does *not* mean that infrastructural resources have to be zero cost: as with highway tolls, a fee can be charged; the crucial point is that it is publicly available and open indiscriminately to all comers on similar terms.
517. Mair, 'Taking Technological Infrastructure Seriously'.
518. Gallini and Scotchmer, 'Intellectual Property'; Mair, 'Intellectual Property', 59-62.
519. Bessen and Maskin, 'Sequential Innovation'.
520. Geertrui Van Overwalle (ed.) *Gene Patents and Collaborative Licensing Models: Patent Pools, Clearinghouses, Open Source Modls and Liability Regimes* (Cambridge University Press 2009).
521. Stefan Wagner, 'Business Method Patents in Europe and Their Strategic Use: Evidence From Franking Device Manufacturers' (2006) Munich School of Management, University of Munich Discussion Paper 2006-15 <https://epub.ub.uni-muenchen.de/1265/1/Wagner_bmp.pdf> accessed 14 October 2016.
522. See discussion in Jack Lerner, Brief of Public Knowledge: Alice Corporation Pty. Ltd. v. CLS Bank International and CLS Services Ltd. (2014) USC Legal Studies Research Papers Series No. 14-7 <http://ssrn.com/abstract=2405553> accessed 8 August 2016.

> Being the basic tools of innovation, abstract ideas must remain available to the public; to do otherwise would impede innovation more than promote it.

For the purposes of this chapter, information assets that are infrastructural but fall outside the IP regime are referred to as 'scientific infrastructure'. Intellectual infrastructure that falls within the IP system is referred to as 'technological infrastructure.' One useful way of viewing the relationship between IP and infrastructure is to imagine IP as a system with a number of 'safety valves' labelled 'infrastructure' attached. These valves serve to ensure that property rights are either: a.) not granted over intellectual infrastructure in the first place (such as limited by subject matter requirements for IP eligibility), or, b.) if they are granted, that they are managed in an open access manner (as enforced by competition law or other institutions). Of course, both of these valves are notoriously imperfect and are subject to both Type I and Type II errors.[523]

2. Scientific infrastructure

The 'safety valve' of subject matter requirements includes (in the field of patent law, for example) that the information resource does not fall into one of the excluded categories of subject matter. These categories exclude from being considered an 'invention', inter alia, the following: discoveries, scientific theories, mathematical methods, aesthetic creations, schemes, rules and methods for performing mental acts.[524] Most of these excluded subject matters can be qualified as 'scientific infrastructure', since they may also function as indispensable, non-rival inputs for the further development of both scientific and technological progress.[525] From an economic perspective, perhaps the key attribute of these subject matter exclusions is their 'genericness': despite being discoveries or breakthroughs in their own right (and thus surely worthy of incentivisation), they are fundamentally tools or inputs for the creation of more scientific knowledge. Irrespective of which philosopher of science one subscribes to, the creation of scientific knowledge is universally acknowledged to be a cumulative and self-feeding process: scientific theories or discoveries open new research pathways or eliminate old ones, which then produce new scientific theories or discoveries, and so on.[526] In the case of this 'scientific infrastructure', the 'social bargain' embodied in IP- trading private value

523. In particular, patent laws may be over-inclusive: granting property rights over poorly-defined or abstract inventions, as discussed in Part II, Section B(3).
524. See European Patent Convention, art 52. <https://www.epo.org/law-practice/legal-texts/html/epc/2016/e/ar52.html>.
525. Lee 'The Evolution of Intellectual Infrastructure', 42 ("[i]n trademark, copyright, and patent law, raw materials such as generic words, abstract ideas, and natural principles constitute "intellectual infrastructure " that is not eligible for individual ownership.")
526. See generally Karl Popper, *Conjectures and Refutations* (2nd edn, Routledge 1963) and Thomas S Kuhn, *The Structure of Scientific Revolutions* (Otto Neurath, 2nd edn, University of Chicago Press 1970).

appropriation for social spillovers- tips in the direction of openness over exclusivity: the social-value of openness and free exchange and reuse is intuitively regarded[527] as significantly greater than the counterfactual case of propertisation. In place of patents[528], the generation of scientific knowledge is generally incentivised by reputational effects within the university system[529], Government R&D subsidies, and prizes. [530] Similarly to patents, in the creative industries copyright law excludes the application of copyright to 'ideas', which should remain 'free as the air to common use',[531] as well as, in the case of software, ostensibly 'infrastructural' components of software programs such as application programming interfaces[532] (APIs), logic, or algorithms.[533]

In the case of scientific research itself, the existence of patents over scientific infrastructure underlies one of the most controversial debates in intellectual property today, with a number of commentators decrying the creation of knowledge 'anti-commons'[534] and patent thickets[535] which hamper scientific progress. In addition to patents over scientific infrastructure, publishers' 'pay walls' have also traditionally limited access to scientific publications and have consolidated concerns over knowledge anti-commons.[536] Perhaps in response to concerns

527. The author is not aware of any systematic study on this.

528. Though, there is continued debate out the scope of patentable subject matter when it comes to science, particularly biotechnology, see for example, Charlie Schmidt, 'Negotiating the RNAi Patent Thicket' (2007) 25 Nature Biotechnology 273.

529. Rochelle Cooper Dreyfuss, 'Double or Nothing: Technology Transfer Under the Bayh-Dole Act' (2013) NYU Law and Economics Research Paper No. 13 ("Dreyfuss, 'Double or Nothing'"), 54 ("[r]eputational rewards come from publishing early and sharing materials; the commitment to communitarianism ensures that good work is available to continually push the frontiers of knowledge forward.")

530. In many ways, the above description of the relationship between scientific infrastructure and the IP system is idealised. In practice, subject matter exclusions over scientific discoveries have not prevented the careful drafting of patent claims in relation to, for example, gene sequences, or other biotechnological discoveries and inventions. See European Parliament and Council Directive 98/44/EC of 6 July 1998 on the legal protection of biotechnological inventions and Patrick Van Eecke et al., 'Monitoring and Analysis of Technology Transfer and Intellectual Property Regimes and Their Use' (European Commission DG Research 2009).

531. Benkler, 'Free As the Air to Common Use'.

532. See *Google vs Oracle* case Oracle Am., Inc. v. Google, Inc., 750 F.3d 1339 (Fed. Cir. 2014) cert. denied 135 S. Ct. 2887 (2015); see also Joe Mullin, 'Google Beats Oracle – Android Makes "Fair Use" of Java APIs" (arsTechnica, 27 May 2016) <http://arstechnica.com/tech-policy/2016/05/google-wins-trial-against-oracle-as-jury-finds-android-is-fair-use/> accessed 13 October 2016. In the EU, interfaces are also exempted from the general ban on reverse engineering or decompilation of object code into source code, see Article 6 of the Software Directive.

533. 'The Software Directive' 2009/24/EC, at recital 11 ("[i]n accordance with this principle of copyright, to the extent that logic, algorithms and programming languages comprise ideas and principles, those ideas and principles are not protected under this Directive.")

534. Michael Heller, 'The Tragedy of the Anticommons: Property in the Transition Form Marx to Markets' (1998) 1111(3) Harv L Rev 621.

535. Carl Shapiro 'Navigating the Patent Thicket: Cross Licenses, Patent Pools and Standard-Setting' in Adam B. Jaffe, Josh Lerner and Scott Stern, *Innovation Policy and the Economy 1* (The MIT Press 1998) ("Shapiro, 'Navigating the Patent Thicket'").

536. Jorge L. Contreras 'Confronting the Crisis in Scientific Publishing: Latency, Licensing and Access' (2013) 53 Santa Clara Law Review 491 and Alex Mayyasi, 'Why is Science Behind a Paywall' (Gizmodo, 13 May 2013) <http://gizmodo.com/why-is-science-behind-a-paywall-504647165> accessed 14 October 2016.

about the growing access problems to scientific infrastructure, a very recent initiative by the European Union is now requiring all scientific publications that have received EU funding to be fully open access by 2020.[537]

3. Technological infrastructure

Technological infrastructure can arise from the market in at least three ways. First, as discussed in detail in chapters 1 and 2 of this thesis, a technological innovation or dominant design can achieve wide-spread adoption in a market due to the demand-side effect of network externalities.[538] Technological convergence and the requirements of interoperability can drive both supply and demand sides within a market to settle on a single solution to a particular technological requirement. These market forces can then transform the asset from being a specific product to an abstract 'standard'. For example, when the Windows operating system ('OS')[539] was first introduced in 1985 it was simply one among many operating systems, including UNIX and OS/2. However, its success in the marketplace among both consumers and suppliers (in particular, its tight coupling to the x-86 chip architecture[540]), led to its specific features being abstracted away into a 'standard': it exposed a richer API[541] to application developers, who then developed various 'killer' apps, leveraging the economics of two-sided markets to drive both consumer and supplier adoption. This led the Windows OS to become the *de facto* standard for PC operating systems, a position it still retains, (though increasingly tenuously[542]) to this day. Crucially, the supply-side components of genericness and non-rivalry were already inherent in the concept of an operating system[543], but it was the market success and network effects which drove it to its infrastructural status. The success of Windows also resulted in the demise of competing operating systems.[544]Indeed, the risks inherent in dynamic competition for 'generic' technological assets (and the stochastic process by which the market selects 'winners'[545]) has contributed to the emergence of the second

537. Nadia Khomami, 'All Scientific Papers To Be Free By 2020 Under EU Proposals' (*The Guardian*, 28 May 2016) <https://www.theguardian.com/science/2016/may/28/eu-ministers-2020-target-free-access-scientific-papers > accessed 14 October 2016.

538. Farrell and Klemperer, 'Coordination and Lock-in'; Arthur, 'Increasing Returns and the New World of Business'.

539. Although up until the release of Windows XP, MS Windows was actually a graphical 'shell' for the underlying MS-DOS OS.

540. Mair, 'Taking Technological Infrastructure Seriously'. Also see final chapter of this thesis for more detailed discussion of the x-86 architecture.

541. Application Programming Interface, or the set of functions and procedures that allows programmers to write software for a particular platform. A rudimentary was already available since the beginning of MS-DOS, but these were later greatly expanded in subsequent versions.

542. See the final chapter of this thesis for more detailed discussion on this point.

543. Barnett, 'The Host's Dilemma'.

544. This point could be debated, as in many ways Windows was unique in being a user-friendly home OS for private citizens. Its main competitor was actually its predecessor, MS-DOS, rather than UNIX, which retained its use for scientific, commercial and computation-intensive use-cases.

545. Arthur, 'Competing Technologies'.

way in which technological infrastructure can arise - the process of cooperative standard-setting. As described in chapter 1, the requirement of interoperability in technology markets combined with the high stakes and probabilities of losing standards wars, has created strong incentives for companies to cooperate on upstream infrastructural assets in order to compete in a shared downstream market of interoperable products.[546] Companies agree ex ante to define a standard, which is then implemented in specific products downstream.[547] Both these examples of *de facto* and cooperatively-set standards meet the definition of intellectual infrastructure, by being generic, non-rival information resources which feed into and sustain significant downstream value creation, as argued for in detail in chapters 1 and 2. However, unlike scientific infrastructure, these information assets are built up of components that usually fall squarely[548] within protectable IP subject matter, making them 'technological infrastructure' according to the definition of this thesis. While their economic functions may be generic, their constituent components are highly specific. For this reason the access regimes to both *de facto* and *de jure* standards have caused significant controversy and attracted antitrust intervention (including the *ex ante*[549] and *ex post*[550] application of competition law), and are only recently starting to find a semblance of organisation.[551]

The third way technological infrastructure can arise from the market derives from the nature of the IP system itself, particularly patents. The case of 'first inventor patents' or 'pioneering patents' refers to patents that are the first contribution to a technological area. Often these patents are necessarily broad because the technological area is still in its infancy and poorly defined. Famous historical examples of pioneering patents may include Watson's 1769 high-pressure steam patent[552], early solutions to technical problems of the sewing machine[553], and Edison's patent over incandescent lighting.[554] These examples of pioneer patents were all extensively litigated and are often cited as cases where the granting of over-broad patents

546. Mair, 'Intellectual Property'.
547. Jones, 'Standard-Essential Patents'.
548. This is generally the case because technologies included in standards are derived from the technological frontier, and so are often novel, inventive, and have industrial application (the criteria for patentability under the EPC, sections 54, 56 and 57).
549. Ex ante competition law regimes include the *Horizontal Guidelines and* Commission Regulation (EU) No 316/2014 of 21 March 2014 on the application of Article 101(3) of the Treaty on the Functioning of the European Union to categories of technology transfer agreements and *Communication from the Commission Guidelines on the Application of Article 101 of the Treaty on the Functioning of the European Union to Technology Transfer Agreements*, OJ C 89 28.4.2014
550. *i.e.,* the essential facilities doctrine or the 'infrastructural approach' developed in Mair, 'Taking Technological Infrastructure Seriously; Petrovcic, 'Patent Hold-Up'; Lemley and Shapiro, 'Simple Approach'; Geradin, 'Pricing Abuses'.
551. Unified into the 'Infrastructural Approach' suggested by chapter 1 of this thesis.
552. George Selgin and John L Turner, 'Strong Steam, Weak Patents, or the Myth of Watt's Innovation-Blocking Monopoly, Exploded' (2011) 54(4) J Law & Econ 841.
553. Mossoff, 'The Rise and Fall'.
554. Arthur A Bright Jr., *The Electric-Lamp Industry: Technological Change and Economic Development from 1800 to 1947* (MIT 1949) 88–91.

significantly retarded follow-on innovation,[555] making them prime candidates for technological infrastructure as well as 'general purpose technologies'. It is important to underline the essential difference between broad patents constituting technological infrastructure and the case of *de facto* standards discussed first in this section, as the two may be easily confused. *De facto* standards achieve their infrastructural status mainly due to effects on the demand-side, i.e. network effects and 'tipping'. In many cases, there is a certain amount of stochasticity in the market's selection of a 'winner' from a standards war[556], as often the true value of a *de facto* standard is the fact that there is a standard at all, rather than the specific features of any one.[557] In the case of pioneering patents constituting technological infrastructure, this is not the case at all: the patent usually embodies a radical innovation that is a significant contribution to the state of the art. If follow-on innovators demonstrate a relatively inelastic demand for the technological infrastructure, it is not due to 'lock-in' caused by switching costs (as is often the case in *de facto* standards), but by the fact the pioneering patent is a genuinely radical innovation which has no substitutes, and is often of broad scope. In markets of complex technologies, genuine radical innovations are often a synthesis of pre-existing component technologies[558], which may implicate dozens if not hundreds of essential patents in order to practice the pioneering invention, such as *e.g.,* wireless charging (implicating patents over wireless protocols, magnetic resonance and batteries)[559], or 3-D printing (implicating patents over *e.g.,* plastics, semiconductors and robotics).[560]

The issue of patent scope with respect to pioneering patents is a difficult one[561], as it goes to the heart of patent theory.[562] Some patent systems (for example, the German Patent Act and

555. For discussion of Edison's incandescent lighting patent see Wu 'Intellectual Property, Innovation, and Decentralized Decisions'.
556. Stan J Liebowitz and Stephen E. Margolis, 'Path Dependence, Lock-In, and History' (1995) 11(1) J L Econ & Org 205; Arthur, 'Competing Technologies'; Mair, 'Taking Technological Infrastructure Seriously'.
557. Consider an operating system as discussed in chapter 2. The value of an operating system inheres more in its downstream 'application ecosystem' rather than in the specific attributes of the OS itself which may interest only the specialist. Also see chapter 1 of this thesis for more detail on this point, as well as the Preface, which quotes a similar argument from the OPUS organisation.
558. Willam B Arthur, 'The Structure of Invention' (2007) 36(2) Research Policy 274, 285: ("[i]nvention is not an event signaled by some striking breakthrough…In the end the problem must be solved with pieces – components – that already exist (or pieces that can be created from ones that already exist). To invent something is to find it in what previously exists.")
559. LexInnova, 'Wireless Power: Patent landscape Analysis', WIPO (2015) <http://www.wipo.int/export/sites/www/patentscope/en/programs/patent_landscapes/documents/lexinnova_plr_wireless_power.pdf> accessed 13 October 2016.
560. '3D Printing: a Patent Overview Report' (UK Intellectual Property Office, 2013) <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/445232/3D_Printing_Report.pdf> accessed 13 October 2016.
561. Merges and Nelson, 'On the Complex Economics of Patent Scope'; John R Thomas, 'The Question Concerning Patent Law and Pioneer Inventions' (1995) 10 Berkeley Tech LJ 35.
562. Which in some ways attempts to channel incentives towards radical innovations or technological 'prospects', Edmund W Kitch, 'The Nature and Function of the Patent System' (1977) 20(2) J L & Econ 265 ("Kitch,'The Nature and Function of the Patent System'").

French patent law) [563] have specific rules regarding follow-on innovation to such patents, which include mandatory licensing in the form of 'dependency licenses'. [564] However, not all jurisdictions provide for such licenses, meaning that the issue of access to pioneer patents may have to be dealt with by the ex post operation of competition law as argued in chapters 1 and 2 of this thesis.[565] Part IV of this chapter develops an alternative approach to these options in the context of subsidised R&D by including ex ante rules/incentives within the structure of the subsidy grant.

As will be argued below, information outputs under a subsidised R&D regime are more likely than the IP-enhanced market to give rise to such general purpose technologies and intellectual infrastructure, leading to pioneering patents and generating specific problems relating to the mixed IP/subsidy provisioning system. Developing these arguments is the nub of Section B(4) below. Parts III and IV will then explain how the institutions of IP and subsidies may have a role to play in ensuring the openness of such technological infrastructural involving pioneering IP.

4. Technological infrastructure arising under a subsidised R&D regime

The three ways technological infrastructure can arise from the *unaided* market have been summarised above, but there is an additional way technological infrastructure can emerge, which is a variation of the third category of pioneering inventions: when the market mechanism of IP is 'enhanced' by an R&D subsidy. Much has already been written about the interaction of R&D subsidies and IP in the context of the Bayh-Dole regime.[566] However, insufficient attention has been given to the nature of the information assets that are likely to arise from this interaction. This is surprising because it is clear without much inspection that IP assets arising from subsidised R&D are a unique class of assets, distinguished from market-driven information assets along a number of axes. First, R&D subsidies operate in the a space where both the competitive market and the IP system fail to deliver the goods, such as under conditions where the desired output approximates a pure public good, or where R&D investments are prone to excessive risk or 'Knightian uncertainty'.[567] As discussed in Section A(2), the institution of R&D subsidies is often recruited to operate with the IP system in order to stimulate the emergence of high risk/uncertain[568] 'radical' innovations. R&D subsidies

563. See e.g. *Patentgesetz,* 16 December 1980 , <http://www.wipo.int/wipolex/en/text.jsp?file_id=401424> accessed 13 October 2016.
564. Kaseberg, *Intellectual Property*, 122. ("...one 'internal' IP solution provided under, for example, the German Patent Act and the French law on improvements on patented inventions is a compulsory license in the form of a dependency license.")
565. Ibid.
566. Mowery and Sampat, 'The Bayh-Dole Act of 1980'; Sweeney 'Correcting Bayh-Dole's Inefficiencies for the Taxpayer'; Eisenberg and Rai 'Bayh-Dole Reform'; Eisenberg 'Public Research and Private Development'.
567. Mazzucato, *The Entrepreneurial State* (2011).
568. Commission, 'Framework For State Aid For Research and Development and Innovation' (Communication)

would likely be unavailable for mere incremental innovations, as risk and uncertainty would be low, and the projected social value of incremental R&D projects would also be unlikely to attract a subsidy.[569] A well-working subsidy system generally prioritises projects with large 'external effects' (i.e. high social value in the form of spillovers, (see Section A(1)) and that yield outputs which are generic. As Nicolaides argues[570]:

> Knowledge of more general nature or with multiple applications tends to be neglected. Yet, it is probably this type of knowledge that is more valuable to society at large. It appears reasonable that society should subsidise to a larger extent knowledge with larger external effects.

In the above excerpt, Nicolaides suggests that generic information assets with high social value are worthy subsidy targets. Given the nature of both scientific and technological research trajectories, R&D outputs are only likely to be of a 'general' rather than a 'specific' nature in cases where a research or technical area is relatively or completely novel.[571] In cases where IP is also available over the R&D outputs, then the latter are likely to be both high risk/uncertain and generic. As discussed in 1.2(iii), such radical innovations would likely give rise to general purpose technologies implicating 'pioneer patents'. These attributes provide the supply-side conditions for the R&D outputs to be qualified as potential technological infrastructure. The demand-side conditions (i.e. that the information resource actually performs the role of scaffolding downstream productivity) also depends on whether the resource is substitutable. Under European competition law, a crucial component of the test for whether an asset is infrastructural to a market or market(s) is whether access to it is a *conditio sine qua non* for effective competition. According to Advocate-General Jacobs in *Bronner*:[572]

> I do not rule out the possibility that the cost of duplicating a facility might alone constitute an insuperable barrier to entry. That might be so particularly in cases in which the creation of the facility took place under non-competitive conditions, <u>for example, partly through public funding</u>. (added emphasis)

C(2014) 3282, 21-23.

569. Nicolaides, 'The Economics of Subsidies for R&D'.

570. Ibid.

571. See also Thomas Kuhn's 'normal' science versus 'revolutionary' science dichotomy, in *Kuhn, The Structure of Scientific Revolutions.*

572. *Bronner*, Opinion of AG Jacobs (emphasis added).

Although as far as the author is aware, the above situation has not been a feature of any recent competition law cases[573], it is reasonable to infer that the public subsidisation of an IP-protected, generic information resource would create a rebuttable presumption that the latter is non-duplicable by the private sector. This would mean that access to it is a *sine qua non* for follow-on innovation. Furthermore, on the demand-side it is not necessary under European competition law for the information resource to currently function as a necessary input to downstream companies in order to be qualified as infrastructural: 'it is sufficient that there is demand from potential purchasers and that a potential market for the input at stake can be identified'.[574] Given the above, and the analysis on pioneering patents in Section B(3), it is argued that the R&D outputs arising from the mixed IP/subsidy regime of Bayh-Dole are likely to be qualified as technological infrastructure.[575]

The above theoretical argument is also supported by some empirical data, which suggests that the role of public money in the innovation system is generally associated with reducing the risk and uncertainty of pioneering, radical innovation.[576] As argued by Mariana Mazzucato, empirical evidence demonstrates that[577]:

> …from the development of aviation, nuclear energy, computers, the internet, the biotechnology revolution, nanotechnology and even now in green technology, it is, and has been, the state not the private sector that has kick-started and developed the engine of growth, because of its willingness to take risk in areas where the private sector has been too risk-averse.

The US Defense Advanced Research Projects Agency' ('DARPA') explicitly endorses the mission statement of 'taking on risk, and high risk in pursuit of high payoff'[578] (as well as

573. State-sponsored monopolists or regulated monopolies (such as recipients of state aid or Services in the General Economic Interest, which are transitioning towards liberalisation) have traditionally been the main targets of the EFD in both the EU and US. See Frischmann and Waller, 'Revitalizing Essential Facilities' 8 ("The best cases for the essential facilities model typically involve the denial of access to infrastructure and networks, particularly in the context of regulated industries in transition"). It should be noted that in relation to SGEIs, the EU competition laws only apply in so far as 'the application of such rules does not obstruct the performance, in law or in fact, of the particular task assigned to them'. See *Joined Cases* C-115/97 Brentjes [1999] [ECR I-6025. In cases where an SGEI has been given an exclusive task, therefore, it is unlikely that the language quoted above in *Bronner* could be used in order to require compulsory licensing under the essential facilities doctrine.

574. Guidance on Article 82 EC [now 102 TFEU], para 79.

575. It is not suggested that Art102 TFEU would actually apply in such cases (State Aid rules would probably supercede), but just for the sake of analysis, such assets would likely meet the requirements under AG Jacob's reasoning in *Bronner*.

576. Mazzucato, *The Entrepreneurial State, 21-23*.

577. Ibid, 23.

578. DARPA, 'Our Research' <http://www.darpa.mil/our-research>.

often adopting an open access licensing approach, as will be discussed in Part III, Section B). In addition, a cursory look at the European Framework Programme 7 subsidised R&D projects also supports the hypothesis that such projects generally do have a pioneering flavour, with project titles ranging from 'musculoskeletal robot development'[579], to 'nanocomputing building blocks with acquired behaviour'.[580] Although one cannot discount the possibility that a certain amount of 'gaming' of the European subsidy programme is taking place (see discussion in Part IV), the novelty and inventiveness of such projects will also undergo an additional layer of scrutiny when patents over the outputs are filed.[581] As we are concerned here only with subsidised R&D that *does* result in patents, it is reasonable to infer that such patents will be in some sense 'pioneering' patents of broad scope. Such patents are therefore likely to belong to the class of technological infrastructure, in the sense of being required inputs for follow-on innovation in the subsidy target area.

As already mentioned, the Bayh-Dole regime as implemented in European R&D subsidy policy allocates all resulting IP to the subsidy recipient. The key question confronted by the remaining parts of this chapter is whether or not such a regime of exclusive rights allocation is the best resource management strategy for such assets. Section B(1) developed the argument that technological infrastructure and open access licensing are intrinsically linked due to social welfare considerations. However, this point needs further development in order to go through, as the economic arguments supporting exclusive rights as both an incentivisation mechanism and as a mechanism for efficient technology transfer are deeply entrenched in traditional information economics and innovation theory.[582]

It is the task of Part III to engage in a detailed analysis of the economics of IP, aiming to apply pressure to a number of key struts, as they apply generally and also in the specific case of technological infrastructure, including revealing the inherently regulatory nature of IP by using tools from game theory. Part IV will then unpack in greater detail the economics behind subsidies with respect to the same. Part V will then conclude.

III. THE INSTITUTION OF INTELLECTUAL PROPERTY

579. CORDIS, 'A Framework For Musculoskeletal Robot Development' (MYOROBOTICS –FP7-ICT-2011-7) <http://cordis.europa.eu/project/rcn/102206_en.html> accessed 14 October 2016.
580. CORDIS, 'FP7:FET Proactive Initiative: NANO-SCALE ICT DEVICES AND SYSTEMS', <http://cordis.europa.eu/fp7/ict/fet-proactive/nanoict_en.html> accessed 14 October 2016.
581. It is submitted that this second layer of screening of the inventiveness of subsidised information outputs would help control the private gaming of the subsidy system, at least with respect to subsidised projects yielding registrable intellectual property rights.
582. See e.g. Kitch, 'The Nature and Function of the Patent System' (1977); Epstein, 'What Is So Special about Intangible Property?'; Harold Demsetz, 'Toward a Theory of Property Rights' (1967) 57(2) Am Econ Rev 347.

The purpose of this Part is to assess exclusive intellectual property rights as an institutional arrangement for managing technological infrastructure. In order to do this, first the economic foundations of IP as a 'spillover' internalisation mechanism will be unpacked (Section A). Section B then focuses on IP as a mechanism for technology transfer, by looking into the commonly-held idea that exclusive rights and discrete propertisation drive dissemination of information assets via the vehicle of commercialisation. Section C then kicks off the critical approach, by putting pressure on the 'IP as property' model by deploying game theoretical tools.

A. Intellectual Property and Spillovers

From an economic perspective, the instrumental purpose of intellectual property is to increase the level of socially beneficial spillovers by creating a mechanism for innovators to privately appropriate a greater proportion of the value of their inventions and creations. In essence, spillovers and private appropriation (incentivisation) are two sides of the same coin. By granting innovators a time-limited[583] intellectual property right over their inventions and creations, innovators benefit from enforcing exclusivity over their information assets. Nevertheless, spillovers still persist under the latter: only, they tend manifest around the 'edges' of the IP right, for example, in the form of patent design-arounds, and in the 'signalling' effect of IP[584] – the market learns that something is possible if only because somebody else has done it.[585]

Spillovers may also be generated by the imperfections of the IP system. As will be discussed in Section C, IP is unlike real property, where possession itself can be leveraged to enforce exclusivity without always requiring public intervention.[586] The intangible and fugitive nature of IP means that IP holders rely on public intervention (in the form of the courts) in order for their rights to be activated at all.[587] Infringers can often get away with 'ripoffs' due to, for example: producing ripoffs in quantities which fall below the efficient threshold for IP owners to seek judicial remedies, legal carve-outs for 'fair use' and 'experimental use' doctrines[588], or simply by avoiding detection[589]. The fact that IP requires public intervention in order for the right to be activated is a key component of the critique of the 'property model'

583. In addition to all these types of spillovers, it should also be noted that once the IP right expires, of course, it then enters the public domain and is freely available as in information input to other innovators.
584. Clarisa Long, 'Patent Signals', (2002) 69 U Chicago L Rev 625.
585. Wagner, 'Information Wants To Be Free' (2003); Arrow 'Technical Information', 649: ("[t]he appearance of a product on the market automatically conveys information; if nothing else, the information that the product can be produced. The existence of the product is a signal that the product can be produced.")
586. Rubin,'The Illusion of Property'; Lemley, 'Response: Taking the Regulatory Nature of IP Seriously'.
587. Unless of course technical measures to ensure exclusivity are used in the case of digital goods, such as are permitted under Art 6 of the 'Information Society Directive' 2001/29/EC.
588. See Part II, Section B(1) 'Intellectual Infrastructure'.
589. Mark A Lemley, 'Ignoring Patents' (2008) 19 Mich St L Rev 19 ("Lemley, 'Ignoring Patents'").

of IP developed in Section C(1) below, which aims to situate IP as market regulation rather than property.

It is clear then that despite the instrumental purpose of IP to work as an 'appropriability mechanism', spillovers still persist- and remain, in many ways, a core motivation behind IP.[590] Rather than being at odds with the development of a rich and diverse public domain and 'information commons', some IP scholars[591] argue that a strong IP system actually helps to promote the latter. The argument runs that unless innovators are granted the kind of legal exclusivity provided for by IP, the default position would be to keep inventions and creations secret[592] (in so far as they are created or invented at all[593]) rather than to disclose them to the public (see also Section C(1) for a game theoretical analysis of these dynamics).[594] By ensuring that innovators can still appropriate value from their innovations notwithstanding public disclosure, the IP system helps to liberate information assets from the darkness of invention journals and laboratories and bring them out into the light of public inspection- where they can give rise to the spillovers identified above.

Despite the rough alignment between private appropriation and socially valuable spillovers described above, the institution of IP still embodies a significant tension between private value appropriation and social welfare. This tension is often characterised as society having to engage in a trade-off between 'static' and 'dynamic' efficiencies. The term 'static efficiency' refers to the single-period maximising pareto-efficient conditions for the pricing and quantity of the information embedded in the IP. The work of Kenneth Arrow in his classic 1962 paper, *Economic Welfare and the Allocation of Resources for Invention*[595], established (and proved mathematically) the modern consensus that the price that ensures efficient allocation is equal to marginal cost, which in the case of an information asset, is zero.[596] By inducing 'artificial scarcity' of knowledge assets, the IP system facilitates the violation of this first-order efficiency condition and replaces it with the 'second order' condition of maximising

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590. Lemley and Frischmann, 'Spillovers'.
591. Wagner, 'Information Wants to Be Free'.
592. Shubha Ghosh, 'How to Build a Commons: Is Intellectual Property Constrictive, Facilitating, or Irrelevant?' in Charlotte Hess and Elinor Ostrom (eds), *Understanding Knowledge as a Commons: From Theory to Practice*' (MIT Press 2007), 216-219; also see Wagner, 'Information Wants to Be Free' (on his "Type III information", which is not appropriable but which stimulates further indirect information production).
593. A traditional model of IP suggests that without the existence of intellectual property laws, certain categories of creations and inventions may not be invented or created at all.
594. But the usefulness of such disclosures is often not as high as one might like, see Lisa Larrimore Ouellette, 'Do Patents Disclose Useful Information?' (2012) 25(2) Harv J Law & Tech 545.
595. Kenneth J Arrow, 'Economic Welfare and the Allocation of Resources for Invention' in National Bureau for Economic Research, *The Rate and Direction of Inventive Activity: Economic and Social Factors* (Princeton University Press 1962).
596. Because the reproduction of information requires no resources, except indirectly (in the form of the materials used, if any, for information transfer). This is also one of the outcomes of the First Fundamental Theorem of Welfare Economics, which sets marginal cost to price.

'dynamic' efficiency' - the incentives to engage in technological innovation. A compelling, if heterodox[597], early justification for this static/dynamic efficiency trade-off derives from the work of Joseph Schumpeter, who suggested in his book *Capitalism, Socialism and Democracy*[598], that IP such as patents have a 'propelling' effect, despite the loss of static efficiency:

> the protection afforded by patents…is…on balance a propelling and not an inhibiting factor.

Schumpeter supported this claim by appealing to his novel vision of the economy as one in constant 'turmoil', continuously revolutionised from within by risk-taking entrepreneurs vying to assign each other to oblivion with the next technological innovation. Powering Schumpeter's radical vision of the entrepreneurial economy are supra-competitive profits in the form of monopoly rents, which pick up the bill for the heavy R&D investments required to drive innovation. The concomitant deadweight losses which society sometimes pays due to monopoly pricing is in exchange for the continued inventive and creative effort expended by the monopolist – who must keep on running, as it were, in order to stay still.[599] The inventive and creative effort is argued to shake out in spillovers that enter the economy both micro-economically (in the form of process and product enhancements) and macro-economically (in the form of economic growth.)

Appeals to theories of dynamic competition such as those developed by Schumpeter above are regularly used to justify concentrations of power within markets characterised by high innovative activity.[600] While these arguments often have some purchase in relation to some high-technology products, they encounter difficulty when deployed in support of exclusive rights over products with infrastructural attributes. In the case of most resource types, including IP-protected resources, this 'dynamic competition' model can function well since private decisions may be driven towards optimal social outcomes due to actual supply side substitution (or the threat of the same) and elastic demand. The common conception that IP generally leads to monopoly or supra-competitive pricing is false in many cases due to the dynamic disciplining effect of firm entry.[601] If the asset owner is greedy or stupid, other suppliers can push them from the market and buyers can switch suppliers, or choose not to purchase the asset at all.[602] Under such conditions, top down decision-making with regard to

597. Because this model went against traditional economic model that high market concentrations were not good for the economy.
598. Schumpeter, *Capitalism, Socialism, and Democracy*.
599. Also referred to as the 'Red Queen Effect'. Daron Acemoglu, Gino Gancia and Fabrizio Zilibotti, 'Competing Engines of Growth: Innovation and Standardization', (2012) 147(2) J Econ Theory 570.
600. Ibid; Economides, 'Antitrust Issues In Network Industries'; Priest, 'Rethinking Antitrust Law'.
601. See useful summary in Langlois, 'Technological Standards'.
602. Lemley, 'The Regulatory Turn in IP', 109-110 ("[b]ut market decision-making is efficient largely because when

resources is in a sense 'democratised' into emergent 'market decisions'. However, in the case of technological infrastructure, these trade-offs start to sharpen. In such cases, not only is the resource non-substitutable (or non-duplicable[603]) but the demand manifested by downstream companies becomes inelastic:[604] if downstream markets and competition are to exist at all, access to the resource is required; IP becomes a barrier to entry that cannot be justified by dynamic social welfare concerns.[605]

Technological infrastructure in the form of *de facto* standards, cooperatively-set standards, and pioneering inventions are unique in how they affect the marketplace because they exist, in many ways, *outside* of the market. In the language of spillovers: technological infrastructure is a locus of considerable potential downstream value creation and spillovers due to its scaffolding role, but this also makes it a target for anticompetitive behaviour which attempts to internalise those spillovers. Where there is value creation, there is also the opportunity for value appropriation. Since spillovers and private value appropriation are two sides of the same coin as argued in the beginning of this section, it is often the target of strategic behaviour to capture it with private rights, as argued in the following Section B on technological transfer, and in Section C(3) on 'property traps'.

As will be discussed further below, while the existence of IP is often conflated with the economic justifications for real property and efficient markets (and therefore, with the idea that private incentives track optimal social goals), their use may lead to situations of 'IP failure'[606] in relation to infrastructural assets. While competition law casts a shadow over technological infrastructure emerging as both *de facto* and cooperatively-set standards (as discussed in chapters 1 and 2), pioneering inventions which emerge via subsidised R&D presents an opportunity to apply another approach, by creating incentives for open access within the structure of the subsidy grant itself. Ex ante regulation is generally to be preferred over ex post enforcement because it allows private companies the opportunity to self-organise and pre-empts the social costs associated with type 1 and 2 enforcement errors.[607]

As further developed in Section C and Part IV of this chapter, it is suggested that the subsidy system can operate to ensure open access over technological infrastructure, by restructuring incentives ex ante via modifications to the subsidy grant policy. Before that argument

stupid, greedy, or shortsighted people in the private sector make poor decisions, they are overthrown by people who make correct decisions. For private decision-making to produce efficient decisions, there must be a competitive market.")

603. See discussion in chapter 1.2(iii)

604. This is of course a factual issue and must be shown to hold true case by case.

605. 'Objective justifications' is a possible defense in such cases, but requires demonstration that exclusivity and denial of access increases social welfare compared to an open access scenario. Microsoft case. See discussion in chapter 2.

606. *i.e.,* not market failures but IP failures, in terms of achieving its social goals – which is to stimulate innovation

607. Easterbrook, 'Limits of Antitrust'.

is developed, it is important to assess the prevalent economic theories surrounding the technology transfer function of IP in more detail.

B. Technology Transfer Function of IP

In the context of the US Bayh-Dole Act and its European transplants, it is the use of IP as an efficient technology transfer mechanism (both for licensing and improvement), which is the overriding justification for the private allocation of outputs arising out of subsidised R&D.[608] In the US context, the motivation behind the private allocation of sponsored R&D results (as opposed to liberating them to the public domain or retaining Government ownership) has been described as follows:

> If the results of federally-sponsored research were to be rescued from oblivion and successfully developed into commercial products, they would have to be patented and offered up for private appropriation.

In the European R&D subsidy programmes- such as Framework Programme 7 and Horizon 2020- the private allocation of IP also embeds the assumption that 'the technology will be transferred and immediately used by the entity that can create most value out of it.'[609]

A central strut of this approach as applied to IP makes the claim that where knowledge assets are brought within the property system, decisions over resource allocation are decentralised and distributed among the market participants. This combination of 'decentralisation' and property rights enables innovators to harness the information signals from the price system into their investment decisions about where to direct their resources.[610] According to Paul Goldstein[611], unless information products are brought under a property regime, innovators would be left 'blind' to market forces, by being 'depriv[ed] of the signals of consumer preference that trigger and direct their investments'[612], and will be unable to efficiently allocate their resources. This point goes to the utility of IP in ensuring the directional efficiency of R&D efforts. This position is also often buttressed by the observation of some IP scholars that the exclusive nature of these IP rights helps to parcel out the information resources in efficient

608. Dreyfuss, 'Double or Nothing', 53 ("[t]he expectation was that industry would adapt the advances, find applications, create new businesses and jobs, enhance productivity, and improve social welfare.")
609. Mario Cisneros, 'EU State Aid Policy: A Model to Assess Intellectual Property Rights and Knowledge Dissemination in R&D Cooperation' (European Commission 2014) 12 <http://ec.europa.eu/competition/consultations/2013_state_aid_rdi/cisneros_mario_en.pdf> accessed 4 August 2016.
610. Friedrich A Hayek, 'The Use of Knowledge in Society' (1945) 35(4) Am Econ Rev 519.
611. As quoted in William Fisher, 'Theories of Intellectual Property' in Stephen Munzer (ed), *New Essays in the Legal and Political Theory of Property* (Cambridge University Press 2001) 183.
612. See ibid, 183("[t]o stop short of these ends would deprive producers of the signals of consumer preference that trigger and direct their investments".)

'bundles', which aids in the process of technology transfer – ensuring that the resources are allocated to their most productive uses without incurring excessive transaction costs.[613]

Prominent defenders of this model of IP as property include Edmund Kitch[614], Richard Epstein[615] and Harold Demsetz.[616] While recognising the incentive effect of IP, these scholars, in their different ways, tend to emphasise the function of IP as a technology transfer mechanism. According to Kitch[617], a patent operates much like a 'prospect' in mineral mining, where the resource owner retains exclusive control and is able to manage and direct the applications of, and access to, the resource. This sole control over the resource allows society to avoid wasteful duplicative R&D investments[618], as well as helping to organise follow-on innovation investments. By owning exclusive rights over an information resource, the IP owner gets to act as 'gate keeper' over the resource and society gets to avoid a 'tragedy of the commons' of resource underinvestment.[619] Epstein adds to this argument by stressing the primacy of exclusivity in facilitating 'the cooperation between any two or more parties by allowing for the division of property rights and coordination of labor on whatever terms and conditions they see fit'.[620] In short, for Epstein, part of the power of the exclusive nature of IP is (perhaps paradoxically) in permitting the resource owners' choice when not to be exclusive: in furnishing the tools to encourage cooperative behaviour.[621] For Epstein, the problems associated with the emergence of scientific and technology 'anticommons' are caused by too little rather than too much propertisation, as property rights and their technological transfer function go hand in hand.[622] Harold Demsetz adds an extra gloss to this approach by situating the propertisation of knowledge resources within an overall theory of property evolution, and arguing that the propertisation of information assets helps to reduce social cost and increases

613. F. Scott Kieff, 'Property Rights and Property Rules for Commercializing Inventions' (2001) 85 Minn L Rev 697.
614. Kitch, 'The Nature and Function of the Patent System'. Michael Abramowicz, 'The Danger of Underdeveloped Patent Prospects' (2007) 92 Cornell L Rev 1065.
615. Epstein, 'What Is So Special about Intangible Property?'.
616. Demsetz 'Information and Efficiency'; Demsetz, 'Toward a Theory of Property Rights'; Harold Demsetz, 'Barriers to Entry' (1982) 72(1) Amer Econ Rev 47.
617. Kitch, 'The Nature and Function of the Patent System'.
618. But it may also lead to wasteful 'patent races', see the seminal article Christopher Harris and John Vickers, 'Patent Races and the Persistence of Monopoly' (1985) 33(4) J Indus Econ 461.
619. Although often not applicable to knowledge goods because of their non-rival nature, Kitch has resurrected the argument in his prospect theory by arguing that lack of exclusive control over the resource would lead to underuse of the asset. Lemley, 'Economics of Improvement' ("Kitch makes an analogous argument: that the private incentive to improve and market an invention will be less than the social value of such efforts unless the patent owner is given exclusive control over all such improvements and marketing efforts.") This idea has been empirically challenged in Merges, 'On the Complex Economics of Patent Scope' (1990)
620. Epstein, 'What Is So Special about Intangible Property?'
621. Ibid.
622. Ibid, 49 ("The second limitation that attaches to the basic system of property rights deals with the ability to use contractual devices for the purposes of exchange or cooperation. Exchange and cooperation normally increase the size of the pie and thus are welcome."); Richard A Epstein, 'Why There Is Too Little, Not Too Much, Private Property' (2011) 53 Arizona L Rev 51.

social value, by making such resources 'tradable' in the Coasean sense.[623] In Demsetz's 1969 paper *Information and Efficiency: Another View Point*[624] (drafted as a response to Arrow's classic 1962 paper[625]), Demsetz argues that as positive spillovers increase, there is pressure on the property system to expand to privatise information goods so as to internalise the spillovers. Since the pattern of spillovers changes in relation to technological developments, it is often argued by neo-Demsetzians[626] that as today's information economy expands, more propertisation is needed of the information space.[627] One powerful interpretation of the actual mechanism at play relies on the idea that information products without clearly defined rights engender high transaction costs and thus inefficiency, leading to social cost. This social cost is signalled in both the political system (perhaps by lobbying[628]) and via the Courts (in disputes over misappropriation) to lead to the evolution of property rights in hither-to under-propertised areas.[629] The greater internalisation of the social benefits of information goods by innovators facilitated by the IP system is argued to realign private benefits with social benefits and therefore leads to more innovation, better and more efficient technology transfer, and greater spillovers. The latter effect is due to the fact that spillovers are often an increasing geometric function of R&D investment, rather than an arithmetic one.[630] This account of the evolutionary development of IP will be discussed and critiqued in greater detail in Section C.

All the above reasoning is underwritten by the intuition that IP facilitates technology transfer via the vehicle of commercialisation. The Bayh-Dole regime as adapted by the EU subsidy regime attempts to recruit this technology transfer component of IP by allocating exclusive rights to the subsidy recipient. However, as argued in Section A above, although IP-driven technological transfer may work well for a large number of IP-protected information assets, the arguments cannot be imported whole-sale into all categories of information goods, as IP-protected technological infrastructure presents special difficulties. In particular, the IP-driven technology transfer as commercialisation argument presents a model that is essentially top-down: the access decisions are made on the supply side rather than the demand side. The deficiencies of this approach and the arguments for open access were already discussed

623. Brett M Frischmann and Alain Marciano, 'Understanding the Problem of Social Cost' (2014) Cardozo Legal Studies Research Paper No 435 <http://doi.org/10.2139/ssrn.2445819> accessed 14 October 2016.
624. Demsetz, 'Information and Efficiency'.
625. Kenneth J Arrow, 'Economic Welfare and the Allocation of Resources for Invention'.
626. *E.g.,* Kieff, 'Property Rights and Property Rules'.
627. Ibid.
628. Robert P Merges, 'From Medieval Guilds to Open Source Software: Informal Norms, Appropriability Institutions, and Innovation' (2005) Social Science Research Network <http://www.ssrn.com/abstract=661543> accessed 14 October 2016.
629. According James E Krier, 'Evolutionary Theory and the Origin of Property Rights' (2009) 95 Cornell L Rev 139, 142 ("Krier, 'Evolutionary Theory'") ("Demsetz's idea of the actual progress is something like they result from 'gradual changes in social mores and in common law precedents,' themselves to some degree the product of 'legal and moral experiments'-'hit-and-miss procedures' that select in favour of cost-minimizing approaches").
630. Mair, 'Taking Technological Infrastructure Seriously'.

in Part II, Section B and will not be rehearsed again here. But it should be underlined that the Bayh-Dole approach to IP allocation may still retain some force even with respect to technological infrastructure if it is conclusively shown that IP released under open access terms is somehow underutilised compared to those released under an exclusive IP regime. It is submitted that although this position may have been justified in 1980s, when the Bayh-Dole Act came into force (and perhaps even for the subsequent two decades), there are now a range of modern technology transfer mechanisms which exist that have been shown to function admirably for the dissemination of open access resources. For example, with respect to open source software, there are a number of online repositories where developers can both post, download and modify source code, such as Github[631] and Source Forge.[632] These online repositories enable downstream users to search and browse existing repositories, including by category type, programming language, or industry. Far from needing to be 'rescued from oblivion' by exclusive IP rights, these open access software products are universally available, easily searchable, and expanding every day.[633]

The model of making open source software available in a single repository has been so successful that it has also become the model for the dissemination of some key publicly-subsidised software products as well as scientific results, at least in the US. The US 'Defense Advanced Research Projects Agency' ('DARPA') created its 'DARPA Open Catalog' in 2014[634], which is a portal for the release of both open source software and peer-reviewed publications (as well as experimental results) that emerge from sponsored R&D. [635] Historically, DARPA has also been a source of radical innovations released on open access terms, such as the early foundations of the Internet and interactive voice recognition software.[636] Recent open source projects released on DARPA's Open Catalog include powerful facial recognition software[637], as well as tools for improving security, and managing and analysing large data sets.[638] As already argued in Part II, Section B, all these R&D outputs tend to have a strong pioneering character, which makes them candidates for being qualified as technological infrastructure. By making the IP over these radical innovations open access, DARPA can be seen attempting to amplify the social impact of its publicly-subsidised R&D. DARPA's approach has recently also been followed up by NASA's parallel open access repositories.[639]

631. See GitHub <https://github.com/>.
632. See SourceForge <https://sourceforge.net/>.
633. James Boyle 'Open Source Innovation, Patent Injunctions, and the Public Interest' (2012) 388 Duke L & Tech Rev 30; Merges, 'From Medieval Guilds to Open Source Software'.
634. PHYS ORG, 'DARPA Open Catalog Makes Agency-Sponsored Software and Publications Available To All' (5 February 2014) <http://phys.org/news/2014-02-darpa-agency-sponsored-software.html>
635. DARPA, 'Open Catalog' <http://opencatalog.darpa.mil/>. Rather than holding the repositories, open catalog lists the projects and provides links to *e.g.*, github.
636. Johnny Ryan, *A History of the Internet and the Digital Future* (Reaktion Books 2010).
637. http://www.itl.nist.gov/iad/humanid/feret/feret_master.html.
638. See eg. 'XData', DARPA, 'Open Catalog' <http://www.darpa.mil/program/xdata>
639. NASA, 'NASA-Funded Research Results' <https://www.nasa.gov/open/researchaccess> accessed 14 October

Despite DARPA's and NASA's initiatives in ensuring the open access of key sponsored technological infrastructure, the economic arguments for open access over IP as a technology transfer mechanism are still far from mainstream. Nevertheless, open access approaches to infrastructural technologies continue to grow in the private sector, with a number of leading companies such as Twitter[640], Google[641], Tesla[642], Toyota[643] 'pledging' various key patents to be licensed for free without threat of litigation.[644] For example, Elon Musk's electric car start-up, Tesla Motors Inc (which, incidentally, has been a recipient of a reported 4.9 Billion USD[645] in R&D subsidies and other public sector financial aid) recently kicked-off its 'All Our Patents are Belong to You' [646]initiative. This patent 'non assertion pledge' essentially grants competitors a royalty-free patent license to its core technology patents, despite the company still being in a non-profitable phase of its development.[647] The economic logic behind Tesla's open access pledge seems to be the idea that (much like open source software[648]) competitors' use of its infrastructural technology will help with consumer acceptance, expand the market generally, and drive follow-on innovation from which the economy as a whole (and Tesla) will benefit,[649] by driving microeconomic and macroeconomic spillovers.

The above examples of open source software, DARPA's and NASA's open repositories, and Tesla's open patents pledge all apply pressure to the notion that exclusive IP rights are an essential component of technological transfer, at least with respect to infrastructural technologies. It is the purpose of the next section to continue this critique of exclusive IP rights by taking on the central idea driving the efficiency-based justifications for IP: that IP behaves like real property. It begins by deploying game theoretical tools to analyse the 'property' arguments as applied to IP in the work of scholars like Epstein, Goldstein and

2016.

640. Adam Messinger, 'Introducing the Innovator's Patent Agreement' (*Twitter*, 17 April 2012) <https://blog.twitter.com/2012/introducing-the-innovator-s-patent-agreement> accessed 14 October 2016.

641. Google , 'Open Patent Non-Assertion Pledge' <https://www.google.com/patents/opnpledge/pledge/>.

642.Elon Musk, 'All Our Patent Are Belong To You' (*TESLA*, 12 June 2014) ("Musk, 'All Our Patent Are Belong To You'")<https://www.tesla.com/blog/all-our-patent-are-belong-you> accessed 14 October 2016.

643. Charlie Osborne, 'Toyota Pushes Hydrogen Fuel Cell Cars With Open Patent Portfoli' (*ZDNet*, 6 January 2015) <http://www.zdnet.com/article/toyota-pushes-hydrogen-fuel-cell-cars-with-open-patent-portfolio/> accessed 14 October 2016.

644. Jorge L Contreras, 'Patent Pledges' (2015) 47(3) Ariz St L J 543.

645. Jerry Hirsch, 'Elon Musk's Growing Empire is Fuled By $4.9 Billion in Government Subsidies' (*Los Angeles Times*, 30 May 2015) <http://www.latimes.com/business/la-fi-hy-musk-subsidies -20150531-story.html> accessed 14 October 2016.

646. Elon Musk, 'All Our Patent Are Belong To You'.

647. According to Musk, Tesla will not be profitable until 2020. Dana Hull and John Lippert, 'Musk Says Tesla's China Sales Fell, No Profit Until 2020' (*Bloomberg*, 14 January 2015) <http://www.bloomberg.com/news/articles/2015-01-14/musk-says-tesla-s-china-sales-fell-no-profit-until-2020> accessed 14 October 2016.

648. Musk, 'All Our Patent Are Belong To You'.

649. Ibid, ("[t]echnology leadership is not defined by patents, which history has repeatedly shown to be small protection indeed against a determined competitor, but rather by the ability of a company to attract and motivate the world's most talented engineers. We believe that applying the open source philosophy to our patents will strengthen rather than diminish Tesla's position in this regard").

Demsetz and as discussed in Sections A and B above. It is divided into three sub-sections, including a discussion of game theory and the evolution of property; game theory and the special case of IP; and the emergent strategic dynamics of the latter in the form of 'property traps' over technological infrastructure. It will conclude that the core nature of IP is more closely allied to market 'regulation' rather than a natural right, and that this finding erodes the efficiency assumptions underwriting much IP scholarship favouring exclusive rights, particularly as they relate to technological infrastructure. This insight then feeds into Part IV, which considers the role of R&D subsidies in guiding optimal outcomes under a subsidised R&D regime, which allocates exclusive rights to the subsidy recipient.

C. Exploring Intellectual Property as Property

Having now unpacked both the spillovers justification for IP as well its function as a technological transfer mechanism, the below sub-sections aim to apply pressure to an assumption which underwrites both these arguments: that IP behaves like property.[650] By drawing on the recent work of Shubha Ghosh and Mark Lemley, as well as some useful tools from game theory, it will be argued that IP is really a form of market regulation. By understanding IP as regulation rather than property, it can be viewed as an imposition on the market rather than as something that emerges organically from it. This is not simply a point about nomenclature: it also means that the assumptions related to efficiency and optimality that generally accompany market and property-based arguments do not apply with the ease that property right theorists often suggest. Rather, as with all regulation, the shoe is on the other foot: the efficiency of IP should be proven as compared to the unaided market. Sections A and B above have already placed pressure on the efficiency of exclusive IP as a management regime in relation to technological infrastructure with respect to both its spillover and technology transfer functions. The sub-sections below provide further ballast to these arguments by taking on the core economic foundation of Demsetz's evolutionary argument, as briefly developed in sub-section B above. The argument begins with a game theoretical account of property evolution, then discusses the particular problems this account has with intellectual property. It then moves onto examine the unique difficulties the property approach encounters with respect to technological infrastructure, such as property traps.

1. Game theory and the evolution of property

The previous sub-sections developed a brief sketch of the quasi-naturalistic theory of IP evolution of Harold Demsetz. This theory has been extremely influential as a powerful economic justification and description of the instrumental role of IP as a spillover internalisation mechanism. The nub of Demsetz's argument is that 'private property rights…

650. Rubin, 'The Illusion of Property'.

emerge to enable the internalisation of externalities as the value of resources increases and technologies and markets emerge to make internalisation less costly (more beneficial).'[651] Although often treated in the literature as being a robust 'evolutionary' explanation of the emergence of the institution of property[652], Demsetz's origin story is incomplete as it must presuppose the existence of the State to enforce property rights. A more powerful approach would be to start from the baseline of the interaction between individual agents over how to manage access to a resource, and attempt to derive the notion of property directly from there. Indeed, part of the power of philosophical arguments for private property as a 'natural right' is the latter's ability to be derived from the pre-State 'state of nature'.[653] In relation to real property, this project has been recently attempted in a compelling way by a number of publications in the field of evolutionary game theory, in particular by the independent work of Herb Gintis[654] and Brian Skyrms.[655]

These theorists, both of whom integrate evolutionary game theory with findings from behavioural economics regarding the 'endowment effect'[656], conceptualise property rights as emerging from an iterated N-person Hawk-Dove (HD) game. The HD game refers to two strategies that individuals can adopt when they contest over a resource: to back down (Dove) or defend aggressively (Hawk). If we assume that one of the players is the 'owner' of the resource, then it can either opt to defend against an ownership contest, or relinquish it to the intruder. The intruder can either choose to back down against a defensive owner or engage in battle. If both back down, then the two share the resource (i.e. Dove/Dove). If both opt to act aggressively (Hawk/Hawk), then they risk injury or death, or prohibitive costs. The numerical payoffs in the matrix at Figure 1 below aim to capture the *relative* outcomes of agents adopting particular strategies. Under normal conditions of a symmetric HD game, there are two pure-strategy equilibria.[657] The Nash equilibria, referred to as the 'private property equilibrium' (3,1) and 'anti-private property equilibrium'[658] (1,3) are as underlined in the payoff matrix below.

651. Frischmann, 'Evaluating the Demsetzian Trend'.
652. Krier, 'Evolutionary Theory', 39: ('Harold Demsetz's *Toward a Theory of Property Rights,* despite its many well-known shortcomings, has been the "point of departure for virtually all efforts to explain changes in property rights " since its publication some forty years ago.')
653. Jeremy Waldron, *The Right to Private Property* (OUP 1990).
654. Herbert Gintis, 'The Evolution of Private Property' (2007) 64(1) J Econ Behavior & Org 1.
655. Brian Skyrms, *Evolution of the Social Contract* (CUP 1996) pp 76-79; Brian Skyrms, *The Stag Hunt and the Evolution of Social Structure* (CUP 2004); Brian Skyrms, *Social Dynamics* (OUP 2014).
656. Daniel Kahneman, Jack L Knetsch and Richard H Thaler, 'Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias' (1991) 5(1) J Econ Perspectives 193.
657. There is also a 'mixed strategy' equilibrium, but it will not be covered here.
658. This equilibrium has however seldom been observed in a state of nature. However it has been formally shown that 'the anti-private property equilibrium again has a lower average payoff that the private property equilibrium, so it will be disadvantaged in a competitive struggle for existence'. See Gintis, 'The Evolution of Private Property'.

	Hawk	Dove
Hawk	-1, -1	3, 1
Dove	1, 3	2, 2

Figure 1: Hawk Dove game as a model of private property evolution

If one assumes the endowment effect as an exogenous factor[659], then the symmetry in the payoff matrix is broken and owners are more likely to commit resources to defending a resource than intruders are in contesting it, provided the value of the resource is lower than the costs of fighting for it[660], or (V(resource)<<C(contest)). This means that the 'private property equilibrium' would constitute a dominant strategy and would tend to dominate a population given the symmetry-breaking exogenous factor of the endowment effect. A general two-prong strategy of 'deference to possessors' and 'protecting what one possesses' would likely emerge from the game (referred to as the Bourgeois strategy) as an evolutionarily stable strategy (ESS).[661] However, as the value increases or the costs decrease, then it is increasingly likely that individuals will choose to duke it out over high-value resources: the coercive power of the State is required to raise the intruders' costs in these cases in order to prevent the emergence of Hobbes's state of nature – the n-person Hawk-Hawk equilibrium, or 'a war of all against all'.[662] Demsetz's evolutionary theory of property would suggest that the State's decisions to recognise and enforce property rights occurs when a.) the State receives signals of social cost (number of battles/disputes over resources), and b.) the costs of instituting a property regime are less than the benefits (such as also in the case of some rivalrous common resources not captured by the HD game[663]).

The above game-theoretical analysis is a plausible way of explaining the emergence of State-enforced property rights in evolutionary terms. However, it does have some significant limitations when applied to IP, which also applies pressure to Demsetz' evolutionary account in relation to information resources as discussed below.

2. Game theory and IP

The model sketched above only seems to apply to tangible property since it assumes that possession is roughly equal to ownership and that the resource is rivalrous and excludable.

659. *i.e.,* an extra factor which affects strategy choose outside of the payoff profiles. Gintis, 'The Evolution of Private Property' 6, ("Similarly, the value of the ownership is taken as exogenous")
660. Here the cost is symmetrical for both the resource owner and invader
661. Krier, 'Evolutionary Theory'; Skyrms, *Social Dynamics,* 140.
662. Gintis, 'The Evolution of Private Property', 18 ("[t]he true value of modern private property, if the argument in this paper is valid, is fostering the accumulation property even when $\pi_g > (1 + \beta)\pi_b(1 - c)$. It is in this sense only that Thomas Hobbes may have been correct in asserting that life in an unregulated state of nature is "solitary, poor, nasty, brutish, and short.")
663. Hardin, 'The Tragedy of the Commons', 1243–48.

In the case of intangible knowledge goods, these assumptions do not hold. In particular, in a 'state of nature' knowledge goods cannot be possessed[664], nor are they rivalrous nor excludable.[665] Instead, once a knowledge good is made public, private ownership is expensive to individually enforce (adopt Hawk strategy) as enforcement must also comprise 'monitoring costs' in addition to the costs involved in trying to prevent ripoffs[666], whatever these may be. In an unregulated state of nature (pre-IP law), these factors increase the costs of the resource owner defending its ownership, meaning that the inequality of V>>C which underlay the HD game may change signs to V(resource)<< C(contest). The change in this inequality leads to a well-understood 'game-switch' in game theory, resulting in the transformation of the HD game structure into a 'prisoner's dilemma' ('PD') or 'public goods game'. This game is generally thought to apply to knowledge goods, and is often used as the justification for IP in the form of the 'free rider argument'.[667] If one modifies the stakes from protecting a resource to creating a resource ('innovate') and intruding on a resource to ripping it off ('imitate'), then we get the PD payoff matrix (fig. 2), where the strategy of 'imitate' always dominates innovating, since companies who choose to imitate the outputs of innovators get access to the resource at zero cost without having to undergo the sunk costs of R&D:

	Innovate	**Imitate**
Innovate	2, 2	.5, 3
Imitate	3, .5	1, 1

Figure 2: prisoner's dilemma model of IP

The structure of this game has been of vital and continued interest to economists and property theorists as its only Nash equilibrium (Imitate/Imitate) is one where private interests lead to a pareto-inferior result (1,1), violating the notion of the 'invisible hand' – where private interests align with the pareto-optimal result (2,2).[668] As a consequence, PD games are generally argued to require public intervention to modify the payoff structure to resemble something closer to an 'invisible hand' game: the Government introduces IP law to modify the costs of imitation so that V<<C, either returning the game back to an HD game, or creating an 'invisible hand' game[669], where 'innovate' becomes the dominate strategy. This result is

664. Except perhaps by secrecy. This option is discussed later in this sub-section.
665. These attributes derive from the knowledge's status as a 'public good'
666. It is important to underline the fact that for this example these costs only include costs associated with trying to enforce ownership over knowledge assets in a 'state of nature', so does not include the costs involved in mobilisation of state apparatus, such as *e.g.*, initiating legal proceedings etc.
667. Epstein, 'What Is So Special About Intangible Property?'; Krier, 'Evolutionary Theory'; Kieff, 'Property Rights and Property Rules'; Tansey *et al.*, 'Patent Agression'.
668. McAdams, 'Beyond the Prisoner's Dilemma'.
669. Samuel Bowles, *Microeconomics : Behavior, Institutions, and Evolution* (Russell Sage Foundation 2004).

often used as an economic motivation to justify the institution of intellectual property. This intuition is echoed by Demsetz, where he asks us to:[670]

> Consider the problems of copyright and patents. If a new idea is freely appropriable by all, if there exist communal rights to new ideas, incentives for developing such ideas will be lacking. The benefits derivable from these ideas will not be concentrated on their originators…

Essentially, Demsetz is arguing that the 'imitate/imitate' equilibrium will dominate in a world where innovators are not given the right to appropriate directly from their innovations, such as in a world with poorly-enforced IP laws or in a pre-IP 'state of nature'.

However, the PD model of knowledge resources as sketched above, while a useful tool and often used as a justification for IP[671], is also a gross simplification of the actual game played. The quoted paragraph from Demsetz in the excerpt above and the outcome of the PD game, seem to suggest that before the advent of IP law, knowledge goods were simply not produced. Clearly, this result is false. Knowledge goods *were* produced, but they were produced in contexts where the knowledge was tightly controlled and managed. These often took the form of private arrangements, outwardly resembling modern trade secret law, although often much more draconian, such as in the glass-blowing guilds of medieval Venice.[672] The 2-strategy PD payoff matrix can therefore be modified to include a third strategy of 'keeping secret', as the available options are not dichotomous but actually trichotomous. Following on from the work of Ghosh[673], once this extra option is included (and the relative payoffs suitably modified) it becomes clear that rather than being a 2-strategy PD game, the pre-regulated 'state of nature' of knowledge assets was rather more like an 'assurance game' or 'Stag Hunt'. [674] Below (fig. 3), the essence of this game is captured by constructing a pay-off matrix where two players have the choice of either keeping the knowledge asset secret or disclosing it.

670. Demsetz, 'Information and Efficiency', 359.
671. Adam D. Moore, 'Intellectual Property and the Prisoner's Dilemma: A Game Theory Justification of Copyrights, Patents, and Trade Secrets' (August 17, 2016). Available at SSRN: https://ssrn.com/abstract=2825252
672. See generally, Merges, 'From Medieval Guilds to Open Source Software'.
673. Ghosh, 'Patent Law and the Assurance Game'
674. Ibid; Skyrms, *The Stag Hunt*.

	Innovate (disclose)	Keep secret
Innovate (disclose)	5, 5	3, 4
Keep secret	4, 3	3.5, 3.5

Figure 3: assurance game as a model of IP

In this game there are two equilibria, one 'payoff' dominant (Innovate/Innovate) and one 'risk dominant' (Keep secret/Keep secret). If the players begin the game by mutually selecting identical equilibrium strategies then neither has any incentive to change strategy. Although both players would of course be better off if they both selected the payoff dominant strategy of Innovate (disclose), this strategy is risky since if the other player chooses to keep secret, then the Innovate player's payoff would be less than if it also chose to keep secret. Under uncertainty, therefore, players are likely to settle on the pareto-inferior Keep secret/Keep secret equilibrium. The role of intellectual property law has been argued to function as a regulation for driving agents' behaviour towards the socially optimal but risky NE of Innovate/Innovate, with the assurance that their disclosures will be protected. Another way of putting this is that IP laws provide the players with the *assurance* that disclosures will be protected such that players can trust each other not to free ride on each other's innovations, but that unlike the PD game, *secrecy*, not imitation is the dominant choice in an uncertain world.

It has been argued by some scholars that this conceptualisation of the role of IP is a more accurate portrayal than the prisoner's dilemma, at least with respect to patents.[675] The 'assurance game' structure of IP law has been elaborated in detail in the work of Shubha Ghosh, who along with recent work by Mark Lemley[676], argues for a reconceptualization of IP away from the traditional 'property' model and towards a model where it has a role as 'market regulation'.[677] But although this concept of IP may provide a richer and deeper analysis than the normal PD game, it still doesn't escape the criticism mentioned at the beginning of this section, which argued that the regulatory nature of IP introduces all kinds of errors and inefficiencies into its economic foundations. By moving away from IP as a property 'right' functioning as a cornerstone of free markets, it is seen instead to be an intervention into the operation of these markets in pursuit of a regulatory goal. It puts defenders of IP into a position faced by all other proponents of regulations, in having to assess: [678]

675. Ghosh, 'Patent Law and the Assurance Game'.
676.Lemley, 'Response: Taking the Regulatory Nature of IP Seriously'; Lemley, 'IP and Other Regulations'; Ghosh, 'Patent Law and the Assurance Game'.
677. Ghosh 'Patent Law and the Assurance Game', 327 ("[u]nder the terms of the assurance game , the purpose of law is not to punish copying, but to create a set of rules within which participants will do the right thing because of the assurance that others will reciprocate. The assurance of reciprocity is the basis for the well-regulated marketplace") ; Shubha Ghosh, 'Patents and the Regulatory State: Rethinking the Patent Bargain Metaphor after Eldred', (2004) 19(4) Berkeley Tech LJ 1315.
678. Lemley, 'Response: Taking the Regulatory Nature of IP Seriously'.

> whether an IP rule is worth the cost depends, as it does with any other regulation, on whether the benefits we get from that rule (presumably increased or higher- quality innovation or creativity) are worth the costs.

Here it is important to pause to absorb the essential differences between conceptualising real property as a Hawk-Dove game and IP as an assurance game. It is clear that in the case of the HD game with respect to tangible resources, it is possible to construct a 'naturalistic' evolutionary scenario where (given the endowment effect) private property emerges endogenously from the market as a privately and socially efficient solution to the problem of conflict over resources, or 'social cost', which can be signalled to the legislature and courts and taken into account to drive propertisation decisions. Even the exogenous institution of State-enforced property rights can be seen to help internalise these costs (or 'externalities' in the language of Demsetz') by serving to regulate 'edge cases' of high value resources, which might otherwise be worth fighting for, giving rise to social cost.[679] In the case of knowledge goods in the assurance game (or indeed the PD game), there is no equivalent of a 'social cost' signal driving the dynamics of intellectual propertisation. This is because the social cost of not having an IP regime or an insufficient one is not signalled to the legislature by observable increases in 'battles', or competitive exploitation[680] as in the case of real property, but comes about, presumably, by less disclosures and innovation. Crucially, the *absence* of something does not produce a signal, but is in fact only a hypothetical or counterfactual 'social cost'.

This simple comparison between real property operating under a HD game and IP operating under an assurance game (or even a PD game) has an important consequence for evolutionary theories of IP: that the IP regime could not evolve naturalistically from the interplay between private actors, but is always an exogenous imposition on the market. This means that unlike real property, the dynamics of IP expansion cannot easily be explained by social cost internalisation and efficiency but should look for other likely explanations.[681] In practice it would be extremely difficult to distinguish between IP laws which are legitimate responses to (a counterfactual assessment) of social cost and IP laws which result from special interest, or "public choice". This means that the evolutionary aspects of 'Demsetz's descriptive thesis [might actually] best describe public choice dynamics' rather than the dynamics of evolution towards a more 'innovation enhancing' IP system in response to social cost signals.[682] Denuded

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679. Gintis, 'The Evolution of Private Property'.
680. Also referred to as negative externalities. These social costs may also arise through *e.g.,* 'tragedy of the commons' situations'.
681. See discussion infra
682. Frischmann, 'Evaluating the Demsetzian Trend in Copyright Law', 4 ("[t]hat is, Demsetz's descriptive thesis best describes public choice dynamics, at least in the field of intellectual property. As the value of intellectual resources increases and new technologies and markets emerge, the pressure of special interests to create and extend private

of its ‘organic’ or evolutionary justifications, the IP system can be viewed as an institution imposed on the market rather than growing out of it. The key point is that the economic forces driving the dynamics of IP expansion and development cannot be derived from efficiency considerations as Demsetz argues, but may instead be the product of minoritarian bias and the growing influence of private concerns.[683]

Of course, like many regulations, IP also has upsides: in particular, where IP-protected resources exist in competitive markets (whether static or dynamic) it has the attribute of being able to stimulate bottom-up, self-directed innovation.[684] However, its downsides include the fact that its conceptualisation as ‘property’ as opposed to market regulation means that it tends to treat all resources alike even if they have very different characteristics and effects on the market. This ‘one size fits all’ criticism of IP is not new[685], but it is submitted that its consequences have not yet been completely worked through for the case of intellectual infrastructure. Specifically, as already argued in Section A, the high spillover potential of technological infrastructure attracts companies to try to appropriate this value by filing, claiming and asserting patents over it. This can lead to highly complex strategic situations where companies find themselves forced to adopt aggressive IP strategies just to retain the freedom to operate and access to technological infrastructure. Jonathan Barnett has referred to such sub-optimal strategic situations as ‘property traps’. Below, this additional strategic aspect of IP with respect to technological infrastructure will be examined, before turning to Part IV, which attempts to show how the subsidy system can help mitigate these outcomes in the context of these assets arising from subsidised R&D.

3. Property traps

The above two sub-sections focussed on applying pressure to the arguments that IP behaves like property, by demonstrating fallacies in Demsetz’s evolutionary approach to the propertisation of the information space. Instead of the traditional model of IP as a subset of property (as an institution which evolves organically from the market in response to social cost) it was argued that IP behaves a lot more like market regulation. As an *intervention* in free markets, as opposed to a pre-condition for them, IP is prone to all the usual errors and

property rights likewise increases.”). Of course, nobody can deny that IP is the product of historical evolution, as IP laws have precursors stretching back to renaissance Italy, see Patentgesetz von Venedig, <http://www.wolfgang-pfaller.de/venedig.htm>.

683. Some scholars see the development of modern IP laws in seventeenth century England in the form of the Statute of Monopolies and the Statute of Anne as a turning point in the transition from feudalism to capitalism by providing private sector greater control over resources. This thesis endorses this view, but stresses the point that excessive private ownership of resources can also lead towards inefficiencies and negative wealth distribution effects as much as excessive public ownership.

684. Mair, ‘Taking Technological Infrastructure Seriously’; Mair, ‘Intellectual Property’.

685. Carroll, ‘One Size Does Not Fit All’.

inefficiencies which plague market impositions. This sub-section highlights the problem of 'property traps', as they apply particularly to technological infrastructure.

The term 'property trap' describes the scenario where the strategic environment 'traps' companies into having to adopt an exclusive rights strategy to technological infrastructure, even when an open access approach would be both privately and socially optimal.[686] Property traps have been observed empirically[687] as associating particularly with technological infrastructure due to strong incentives for private appropriation of the enormous spillovers they produce.[688] Stated simply, a property trap may arise as a strategy of accumulating and asserting IP over technological infrastructure (hereafter: 'strong property' strategy) because it is the best response to an environment where at least one company is adopting this strategy. To pursue an open access strategy (patent non-assertion, hereafter 'open access' strategy) in such an environment would lead to the worse outcome for both the technological infrastructure owner(s) and its follow-on innovator(s) since they would be blocked from using their own assets as well unable to strategically respond to companies using the strong property strategy.

From a game theoretical perspective, the 'strong IP' strategy constitutes the risk-dominant Nash equilibrium because the players have little[689] incentive to deviate from it in an environment of high infringement risk and the concomitant risk of litigation and legal costs.[690] This would mean that companies who adopt a strong property approach would have a higher relative payoff when playing against open access strategy adopters. Interestingly, this result also means that strong property players dominate open access players even though the 'strong property' approach may be more costly (in terms of IP acquisition, monitoring and enforcement costs).

The structure of this game is identical to the assurance game identified in the preceding section, since although the 'payoff' dominant strategy of open access/open access maximises both private and social interests, the nature of the high-risk strategic environment drives players towards the risk-dominant equilibrium of strong property/strong property. Interestingly, the nature of the strong property strategy also has some dynamic feedback effects: when

686. Jonathan M Barnett, 'Property as Process: How Innovation Markets Select Innovation Regimes' (2009) 119 Yale LJ 384 ("Barnett,' Property as Process'"), 384 ("…[the] "property trap" effect where, under high coordination costs, the regime selection mechanism is prone to fail: litigation risk and associated transaction cost burdens drive innovators to over-consume state-provided property rights").
687. Gavin Clarkson and David DeKorte, 'The Problem of Patent Thickets in Convergent Technologies' (2006) 1093 Annals of the New York Academy of Sciences 180; von Graevenitz, Wagner and Harhoff 'Incidence and Growth of Patent Thickets'; Mossoff, 'The Rise and Fall'.
688. For example, in regard to cooperatively-set standards, see Timothy S Simcoe, 'Private and Public Approaches To Patent Hold-Up in Industry Standard Setting' (2012) 57 Antitrust Bulletin 59, 64 ("patents declared to SSOs were four to seven times more likely to be litigated than a typical patent with the same age and technology class.")
689. Assuming coordination costs for negotiating a cooperative solution are too high.
690. Barnett, 'Property as Process'.

companies adopt the strong property strategy, the logic of the interaction drives increased patenting behaviour and patent acquisition in order to play the strategy, further propertising the technological area and intensifying the strategic risk, entrenching the strategy and the sub-optimal equilibrium. Below (fig. 4) the payoff matrix for this game is shown, including the two underlined Nash equilibria.

	Open access	Strong property
Open access	4,4	1, 3
Strong property	3,1	2, 2

Figure 4: IP management regime choice and the assurance game model.

It is important to note that the assurance game payoff matrix embeds the concept of 'path dependence': if the game begins by companies adopting a 'strong property' starting point, then companies will have no incentive to swap strategies to open access. However, if the companies begin by assuming a starting strategy of open access then the companies likewise have no incentive to switch strategies. Therefore, if companies find themselves playing a strong property strategy, then the underlying dynamics make the 'strong property' NE an 'efficiency' or 'property' trap.

In order for one player to switch strategies from a Strong Property approach to an Open Access it is clear that she must first go through a 'payoff trough', which means that a strategy switch is very unlikely. As a result, open access strategies are highly unlikely to emerge from the market by market forces alone, or at least not without a concerted effort by a number of players to solve what is essentially a coordination problem.[691] In the case of cooperative standards, chapter 1 of this thesis has explained the instrumental role of competition law enforced FRAND commitments to solve an intimately related problem.[692] The behaviour of companies like Tesla, and the other companies mentioned in Section B which adopted 'patent pledges' is another way companies attempt to 'truncate' the strong property strategy, by creating initial conditions of 'open access' such that the payoff dominant NE can get a foothold in the market.[693] Part IV of this chapter will argue that having incentives for open access licensing built into the structure of subsidy grants will also help to move private strategic behaviour in a technological area towards the payoff dominant open access/open access equilibrium with respect to infrastructure arising via subsidised R&D.

691. Mair, 'Taking Technological Infrastructure Seriously'; McAdams, 'Beyond the Prisoner's Dilemma'.

692. In that chapter, the problem of ex post openness of a standard was described as a prisoner's dilemma rather than an assurance game. Both points of view are justifiable, and the solutions are similar: an intervention to change the payoff structure to reach a cooperative solution.

693. Also referred to as 'indirect truncation' in Barnett, 'Property as Process'.

Now to sum up. The fact that technological infrastructure functions as a nexus of downstream value creation and spillovers makes it attractive to private companies seeking to appropriate and internalise value. However, companies still have the choice of selecting a payoff dominant open access strategy or a risk dominant strong IP strategy. One of the prevailing strategies in high technology markets is the strong IP strategy, which has tended to self-reinforce in some markets as a 'property trap' due to path dependence and high risk. The easiest way for companies to drive strategic behaviour towards the open access equilibrium via private ordering is to trigger this dominant strategy at the outset, as evidenced by Tesla's open patent pledge and the growing prevalence of patent pledges by technology companies. Public solutions to arriving at an open access solution include the ex post operation of competition law, which casts a 'shadow' over the private ordering behaviour of companies, nudging them towards cooperative solutions.[694] A third possible solution explored in Part IV below is to include incentives ex ante in the structure of subsidy grants to drive private companies to adopt open access solutions with respect to technological infrastructure arising out of subsidised R&D.

IV. R&D SUBSIDIES AND TECHNOLOGICAL INFRASTRUCTURE

The nub of this part of the chapter is to demonstrate how the EU subsidy system under Horizon 2020 can be modified in an economically robust way to help ensure the openness of technological infrastructure arising under subsidised R&D projects. Part II examined why R&D outputs arising from subsidies are likely to have infrastructural attributes. Part III then explored in detail why a resource management approach of exclusive intellectual property rights is a poor way of ensuring efficient use of these unique resources. The game theoretical components of the above analysis also demonstrated how external institutions to IP may be necessary to help nudge companies towards the payoff dominant open access equilibrium in the management of technological infrastructure. Below, the role of the EU subsidy grant system will be examined as one such institution, by looking in detail at key components and economic motivations behind this innovation institution, as well as its complex interaction with IP.

As discussed in previous sections of this chapter, public R&D subsidies are often directed at high risk R&D projects with high potential social value and spillovers. Since subsidies are very much a 'visible hand' in the market place, the real world application of subsidies may (much like IP) lead to a subversion of their intended purpose, or at least to unexpected effects. The imperfections of the institution of R&D subsidies have been studied in detail, and a sizable

694. Mair, 'Taking Technological Infrastructure Seriously'.

economic literature has arisen exploring the many dimensions of 'subsidy failure', including, shirking, crowding out, and distortionary directional R&D incentives. [695]

Despite the existence of this critical literature, subsidies continue to attract significant resources from public coffers. This is true even, or especially, for the 'free-market-oriented' United States, where one third of all R&D is funded by government or the non-profit sector.[696] Many commentators in the European Union have regarded the US's innovative success with envy, and have ascribed at least some of the US's economic success to its public policy around R&D subsidies.[697] Recent EU policy initiatives which aim to transplant the US approach to the EU (whether explicitly or implicitly) include a new legislative agenda on the public procurement of R&D services, and a refreshed- and well-heeled[698]- R&D subsidy program, Horizon 2020. A key element in all these initiatives is the allocation of any IP arising out of the R&D to the private party subsidy recipient, a policy which closely tracks the similar US Bayh Dole approach. Part IV, Section D below will closely examine and critique this policy using the insights harvested from the discussion of IP in Parts II and III, in particular the game theory approach which conceptualises the socially-optimal outcome (open access/open access) as an assurance game requiring 'encouragement'.

Before engaging that analysis, some basics. Section A will outline the key economic arguments for R&D subsidies as an alternative, or complement to the institution of IP. This analysis will focus on the importance of subsidies in correcting the 'blind spots' of an IP regime, where the 'invisible hand may be invisible because it's not there'. Section B will then briefly summarise the main areas of 'subsidy failure', including information problems and private sector gaming. Section C will then narrow its focus on the specifics of the H2020 grant system, before Section D develops the relationship between open access rules and the subsidy grant. Part V then concludes.

A. Economic Justifications for Subsidies

As with IP, one of the core concepts underlying the theoretical understanding of R&D subsidies is 'spillovers'. After the pioneering 1890 work of Alfred Marshall[699], which first

695. David and Hall, 'The Heart of Darkness'; Nicolaides, 'The Economics of Subsidies for R&D'.
696. Kapczynski, 'The Cost of Price'.
697. 'Pre-commercial Procurement of Innovation: A Missing Link in the European Innovation Cycle' (March 2006) ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/pcp/precommercial-procurement-of-innovation_en.pdf accessed 14 October 2016.
698. The budget of the H2020 program is nearly 80billion Euros. Commission, 'Factsheet: Horizon 2020 Budget' (25 November 2013) <http://ec.europa.eu/research/horizon2020/pdf/press/fact_sheet_on_horizon2020_budget.pdf> accessed 14 October 2016.
699. As discussed in Adam Jaffe, 'Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program' (1996) Brandeis University and National Bureau of Economic Research <http://www.atp.nist.gov/eao/gcr708.htm> accessed 14 October 2016.

identified and discussed the concept 'knowledge spillovers', Arthur-Cecil Pigou has been credited with one of the earliest robust economic analyses of their effects. In his book *The Economics of Welfare*[700], Pigou puts his finger on the issue of R&D spillovers, stating that often R&D outputs are:[701]

> of such a nature that they can neither be patented nor kept secret, and, therefore, the whole of the extra reward, which they at first bring to their inventor, is very quickly transferred from him to the general public…

While recognising the importance of patent laws to align social and private investment optima where R&D outputs are eligible for such protection[702], Pigou's primary solution to the problem of spillovers was one of direct government intervention in the form of 'bounties' (or "extraordinary encouragements"; now called 'subsidies').[703] The economic purpose of such subsidies was considered to be aimed at 'shift[ing] the recipient-firm's marginal cost to the right (pushing its innovation effort theoretically up to a level that closes the gap between the private level and the "socially optimal level" of R&D".'[704] Pigou's understanding of the relationship between the role of IP and R&D subsidies appears to be one of complementarity: where knowledge outputs can be brought within an appropriability regime such as IP or patents, then this may serve to 'bring marginal private net product and marginal social net product more closely together';[705] however, where knowledge outputs fall outside a private appropriability regime, then social welfare will be increased if society applies a subsidy. For Pigou, it seems to go without saying that the two institutions of IP and subsidies operate in different (if not mutually exclusive) spaces: subsidies apply where IP fails; and where IP successfully operates, subsidies would seem to be unnecessary. This perspective of the relationship between IP and subsidies will be further unpacked and developed in Part IV Section D.

700. Arthur Pigou, *The Economics of Welfare* (4th edn, Palgrave Macmillan and Co. 1932).
701. Ibid, 139.
702. Ibid, ("[t]he patent laws aim, in effect, at bringing marginal private net product and marginal social net product more closely together. By offering the prospect of reward for certain types of invention they do not, indeed, appreciably stimulate inventive activity, which is, for the most part, spontaneous, but they do direct it into channels of general usefulness").
703. Ibid, 166 ("[i]t would still be possible, however, to defend a system of bounties to industries in general, the funds for which should be collected by some kind of lump-sum taxation, by arguing that the sum total of effort and waiting devoted to industry could be increased with advantage to economic welfare.")
704. David, Hall & Toole, 'Is public R&D a complement or substitute for private R&D? A review of the econometric evidence' (2000) Research Policy 29 497–529
705. Ibid.

Although almost a century old, Pigou's economic justification for subsidies is still one of the most widely-cited and robust in the literature.[706] The argument has since acquired a number of layers of added sophistication, including a more nuanced theoretical and empirical elaboration.[707] Under a static analysis, subsidies qualify as a simple 'wealth transfer' from society to producers: tax money is given to producers to invest in R&D, which raises their amount of R&D investment. This is justified by the argument that somewhere in the R&D process lurks a 'multiplier effect': i.e. that the amount of social welfare lost in the wealth transfer results in a net social welfare payoff down the line, which exceeds the cost. The key to this argument again rests in the concept of 'spillovers', which are assumed to be an *increasing* function of R&D investment.[708] Econometric analyses roughly support this contention, as discussed in Part II of this chapter.[709]

The intuitive explanation for the multiplier effect of R&D investment (and thus the economic justification for subsidies) is that the knowledge outputs which 'spill over' are used *productively*,[710] such as by giving rise to outputs which trigger (or operate as inputs into) follow-on innovation. But it must be noted that the high spillovers used to justify the application of subsidies in the first place are purely conjectural: the social demand is not signalled because the R&D has not yet been performed, and thus they derive from hypothetical cases constructed by (counterfactual) economic models.[711] Of course, using counterfactual economic models to direct public policy does not necessarily weaken the resulting policy where no other information is available, however, it does underline an important distinction between the 'bottom up' system of IP (which responds to actual social demand), and the 'top down' system of R&D subsidies (which follows centralised agenda-setting) with respect to the directionality of R&D.[712]

Although it seems reasonable that society should privilege the funding of R&D with higher spillovers,[713] it is very difficult for the subsidy provider to know this information in advance.

706. Lemley and Frischmann, 'Spillovers' 106 ("With the notable exception of Pigou, economists don't much care about pecuniary externalities, reasoning that wealth transfers "within" the market— that is, externalities mediated by the price mechanism—result in offsetting private costs and benefits.")

707. Mainly these elaborations focus on different ways of controlling the negative and riskier aspects of subsidies which give rise to unjustified social cost

708. One such mulitplier effect of 'network externalities' is discussed in detail in Mair, 'Taking Technological Infrastructure Seriously'.

709. Griliches, 'The Search for R&D Spillovers'.

710. *i.e.,* as inputs to further downstream innovation.

711. According to the Framework for state aid for research and development and innovation, recital 67 ("counterfactual analysis: the change of behaviour has to be identified by comparing what the expected outcome and level of intended activity would be with and without aid. The difference between the two scenarios shows the impact of the aid measure and its incentive effect").

712. This is the root cause of the 'information problems' of R&D subsidies identified in Part III Section A(3) of this chapter.

713. Nicolaides, 'Economics of Subsidies for R&D', 7. It appears reasonable that society should subsidise to a larger

In the EU subsidy program H2020, this problem is addressed by using a proxy best described as 'proximity to market', as will be discussed in the next sub-sections.

One of the most controversial aspects of R&D subsidies concerns the risk of 'crowding out' private investment.[714] Crowding out occurs when the subsidy system faultily targets an R&D area where private incentives are already sufficient for investments to go ahead, leading to a substitution of public funding for private funding, and wasted public expenditure. This may happen, for example, where the IP system and the nature of the knowledge outputs targeted are sufficient in themselves to ensure private appropriability, as discussed in more detail in Section B below. Crudely formulated, there is an inverse relationship between the efficacy of the IP system in stimulating the targeted R&D and the necessity for public R&D subsidies. However, there are nevertheless a number of cases where despite the efficacy of the IP system in stimulating R&D, a subsidy system may still be desired to operate alongside it, such as in cases of high risk/uncertainty or where the IP system would lead to too much internalisation of desirable spillovers. Briefly summarised, these cases of desirable mixed subsidy/IP may include the following cases: (i) where high appropriability via an IP regime translates into lower social spillovers due to monopoly pricing or access problems (*e.g.,* Watson's steam engine patent and the explosive advance in steam engine use and innovation after its expiry[715]). This can occur in situations where the R&D output is a technological infrastructure or a general-purpose technology; (ii) it is also possible that eminently patentable inventions with high social value (notwithstanding the patent monopoly) may fail to go ahead due to private sector risk aversion, as discussed in Part II, Sections A and B.[716] In such cases, R&D subsidies may play an important role, where the private sector (including venture capital) markets are sub-optimally risk-averse; (iii) in addition, it should not be forgotten that just because IP protection is available, companies may nevertheless choose *not* to avail themselves of it in order to actively encourage spillovers via opting out of the exclusive rights regime[717] and attempting to create an open access equilibrium in the assurance game. The subsidy system may also play an important role in incentivising such behaviour, as will be discussed in detail in subsequent sub-sections; (iv) finally, the IP system has in in-built (and intended) bias towards commercialisable creations and inventions at the expense of more generic R&D outputs. Subsidies may help to correct this bias by also rewarding creations and inventions that fall

extent knowledge with larger external effects.

714. According to the Communication From The Commission Framework For State Aid For Research And Development And Innovation, C(2014) 3282, recital 62 ("R&D&I aid can only be found compatible with the internal market if it has an incentive effect. An incentive effect occurs where the aid changes the behaviour of an undertaking in such a way that it engages in additional activities, which it would not carry out or it would carry out in a restricted or different manner without the aid. The aid must however not subsidise the costs of an activity that an undertaking would anyhow incur and must not compensate for the normal business risk of an economic activity")

715. See the target argument of George Selgin and John L Turner, 'Strong Steam, Weak Patents'

716. Link and Scott, *Public Goods, Public Gains.*

717. Barnett, ' Property as Process '; Barnett, 'The Host's Dilemma'.

outside the scope of desirable IP targets. Given the above points, it should be reasonably clear that the institution of R&D subsidies is not always a substitute for IP, but can, under certain conditions, operate fruitfully in tandem with it.

B. Subsidy Failure

As is clear from the above analysis, the award of R&D subsidies to private companies hinges on the subsidy provider's assessment of the social value of the R&D. The problem with this approach is that it lacks the decentralisation of the private sector, where the invisible hand of the price system is able to convey information to companies investing in R&D. This approach suffers from the information problems that beset all non-market interventions: it is extremely difficult for non-market institutions to sufficiently integrate information signals about social demand and spillovers, without actually being a market entity. In particular, the subsidy system is vulnerable to private sector gaming: where applicants for subsidies 'puff up' the potential social value of their R&D projects in order to receive funding. Instead of assessing projects by proven social demand as in the case of the private sector, the 'visible hand' of the subsidy provider is responsible for defining the R&D domains of high social value[718], and a number of panels and 'experts' have the duty of screening proposals from the private sector to assess whether they qualify for funding within each domain. Superficially, this award process is not unlike that performed by examiners at the patent office, except subsidy reviewers are less highly trained, the award dispute system less highly developed, and the examination reports are not publicly available. Furthermore, unlike the subsidy review process, the patent system has an inherent mechanism for dealing with the risk of false negatives: all patent applications, whether successful or not, are published to the public domain within eighteen months. This means that even if a patent application is falsely assessed as unpatentable by an examiner, the essentials of its 'teaching' are nevertheless disclosed to the public, who can then make of it what it will. By contrast, failed subsidy applications are not put into the public domain, meaning that spillovers from false negatives do not enter society.

However, even given a perfectly objective and stream-lined proposal review process, centralised decision-making over R&D subsidies will still likely give rise to significant errors.[719] But putting aside the issue of false negatives, which are notoriously difficult to study in either institution[720], subsidy programs have attracted a burgeoning literature on

718. In the US SBIR system (https://sbir.nih.gov/review/selection-process), this is referred to as 'program priorities'. In the EU H2020, it is divided into 3 pillars (excellent science, industrial leadership, societal challenges), with a number of specialised sub-programmes.

719. It is also difficult to know the relative number of false positive and false negatives in this system. In patent system false negatives less of a problem (in terms of social welfare) since the information goes to public domain anyway via publication of patent applications.

720. Mark A Lemley, 'Rational Ignorance at the Patent Office' (2001) 95(4) Nw U L Rev 1.

the problem of false positives, otherwise known as the crowding out of private investment, as already briefly discussed in Section A above. Crowding out is a concern from a social welfare perspective because it involves a wealth transfer from the tax payer to the producer, but without a multiplier effect: the R&D itself might still have a multiplier effect, but it is not causally related; instead it is more like a 'windfall.' Where IP is also available to the producer- and allocated by default, under the EU 'Bayh Dole' regime- then social welfare also takes a hit in the form of the dead weight loss of (potentially) monopoly pricing. The issue of crowding out and the related one of 'double subsidisation' (discussed further in Section C below) have triggered a raft of scholarship on subsidy design, some of which may have influenced the EU H2020 program, as will be discussed below, where the mechanism of 'proximity to market' is perhaps one solution to minimise the social cost of poorly-targeted R&D subsidies.

C. EU H2020 and Proximity to Market

As mentioned in Section A, the EU H2020 subsidy program (in line with EU State Aid rules) utilises a 'proximity to market' criterion as a rough proxy for the 'spillovers' to private appropriability ratio.[721] Essentially, the more basic and generic the R&D is, the greater is its potential for spillovers, and the higher the subsidy intensity it attracts from the granting agency. Although it is not presented in these terms, it is submitted that the H2020 system of determining subsidy intensity (i.e. the percentage of total costs eligible to receive public funding) embeds a strong recognition of the infrastructural attributes of generic R&D. The more generic the R&D output is (and thus the greater the value of spillovers) the greater the available subsidy intensity it attracts (e.g. 100% for basic research). Likewise, the closer the R&D project is to the market and the less generic it is, the less the available subsidy intensity (50% for Industrial research for a large enterprise), as shown below (fig. 5).[722]

Aid for R&D projects	Small enterprise	Medium-sized Enterprise	Large enterprise
Fundamental research	100 %	100 %	100 %
Industrial research	70 %	60 %	50 %

Figure 5: Subsidy intensity and market proximity.

The proximity to market rule also helps to avoid 'crowding out' and 'double subsidisation': the public liability decreases in tandem with the subsidy intensity, which decreases as the possibility for private appropriability goes up. Since the tax payer has already subsidised the

721. See Annex II (maximum Aid Intensities) of *The Commission Framework For State Aid For Research And Development And Innovation.*
722. Table derived from information at Ibid.

R&D investment, the fact the subsidy beneficiary may also have the opportunity to charge the tax payer monopoly prices for accessing the R&D output (via the IP system) means there is the chance the producer gets to offset its innovation costs twice. This risk may be less where the object of the subsidy is to overcome excess risk-aversion and inertia in the market, although this caveat is very hard to accurately assess.[723] Turning subsidy intensity down and according subsidy recipients IP rights over R&D outputs may well be one way of limiting direct public cost, but as Part III argued, it does not necessarily lead to greater technology transfer. Indeed, exclusive rights over technological infrastructure resulting from sponsored R&D may lead to the inefficient management of knowledge resources.

So far, the analysis has only focused on the economic reasons behind why subsidy intensity is turned down where it starts to enter the domain where IP operates. Little has been said on why subsidy intensity is turned up when IP fails to be effective, such as where the R&D output gets further away from the market. In explaining the latter, it will be shown that 'proximity to market' is a bad criterion for deciding subsidy intensity. By examining closely the economics behind spillovers, IP and subsidies developed so far in this chapter, it is argued that the key point should be the extent to which the R&D output can be used as a productive input to further knowledge creation, *i.e.*, its potential as an economic 'multiplier' – an asset which sustains downstream value creation. This analysis involves a switch in focus from the supply-side to the demand-side, and will begin by looking deeper into the deceptively obvious fact that basic scientific research should attract a subsidy intensity of 100%.

D. Infrastructural knowledge and open access

1. Basic research

More than eighty per cent of US basic R&D is funded by the government and non-profits.[724] This figure seems very high, (particularly given the free-market rhetoric of the US) until one asks the question: who else would fund it? Basic scientific research generally falls squarely outside the IP regime.[725] Scientific theories, including mathematical theorems, and algorithms are expressly excluded from patentability under most patent laws. Likewise under copyright law, 'ideas' are not protectable, only 'expressions'. In both these IP regimes, legislators have circumscribed, if perhaps messily in some cases[726], the types of intellectual creations which should remain in the public domain and 'part of the storehouse of all men'.[727] Although never

723. Putting a monetary value on risk or uncertainty is always a matter of guess work
724. Kapczynski, 'The Cost of Price'.
725. See discussion in Part II, Section B(2).
726. The boundaries of IP protection are constantly litigated.
727. As quoted in Lee, 'The Evolution of Intellectual Infrastructure'.

explained in the legislation itself[728], there seems to be a general repugnance in both case law and academic commentary to the idea that fundamental truths, principles, and discoveries in nature could be owned. According to Suzanne Scotchmer, the reason why basic R&D is publicly sponsored rather than privately sponsored is "that the benefits of basic research are hard to appropriate by private parties",[729] but there seems to be more to it than that: if scientific theories and principles were susceptible to IP (or otherwise substantially privately[730] funded), research outputs would likely be strongly biased towards outputs with 'observable and appropriable returns'[731] rather than generic, fundamental research with unobservable immediate application.

And here is the nub. It is not the case that the output of basic research has high spillovers because of its low appropriability (i.e. because of the absence of an appropriability regime such as IP); rather, the social returns on any direct appropriability mechanism for basic scientific outputs would be likely dwarfed by its social costs[732]. This is because scientific research outputs are not so much discrete outputs as *constituents* and inputs for the framework for doing further scientific research. It constitutes the framework both for further scientific research and, *inter alia*, technological evolution.[733] In short, it has the function of intellectual infrastructure. In this sense, the value of basic research to society is the social value it supports downstream, in its productive use for further knowledge creation, as well as in its role as an input into technological progress. Since the main value of science is in its status as a *productive* resource[734], economic theory and the social bargain favour an open access regime to research outputs, which guarantee the widest dissemination possible. In addition, open access eliminates directional incentives with respect to the resource, and permits all-comers to determine their own uses rather than the price system (under an IP market system).[735]

To sum up, the reason why basic research is subsidised 100% in most public subsidy systems is plausibly due to its extremely high social value as an *infrastructural* resource, relative paucity and undesirability of available private appropriability mechanisms, and strong open access preference (in order to ensure its functioning as infrastructure). As will be discussed below, certain knowledge assets in technology may also share many of these attributes. Indeed, it will be submitted that the key attribute of basic research that singles it out for unique treatment is its infrastructural character rather than anything special about scientific knowledge, and

728. See discussion of intellectual infrastructure Part II, Section B(1).
729. As quoted in Frischmann, *Infrastructure*, 308, fn 181.
730. Meaning for a profit, NGO and nonprofits do not count here.
731. Ibid, Frischmann, *Infrastructure.*
732. E.g. monitoring costs, enforcement costs and also social cost of lost innovation
733. The relationship between basic science and technoloy is however a complex one, see Donald Stokes *Pasteur's Quadrant: basic science and technological innovation* (Brookings Institute Press, 1997)
734. Not necessarily in an economic sense, but as in the sense of scaffolding *further* research.
735. Kapczynski, 'The Cost of Price'.

that this attribute is shared by other types of resources, such as the case of technological infrastructure, as described in Parts II and III of this chapter, and further developed below.

2. Technological infrastructure and subsidies

It is the purpose of this sub-section to integrate the insights from Parts II and III, and the arguments presented so far in Part IV. It attempts to defend the position that technological infrastructure shares many commonalities with basic research, which suggest that public policy should be oriented to encourage open licensing regimes, especially when such resources are eligible for the private allocation of exclusive IP protection.

The economic and legal literature on high technology innovation and markets has long identified important commonalities between basic science and certain types of technological resources.[736] These commonalties have ranged from the identification that progress in both domains is fundamentally 'cumulative' in character, to the application of philosophy of science perspectives (in particular, that of Thomas Kuhn) to aid the understanding of technological progress.[737] One essential insight in this respect is the way in which 'dominant' designs within an industry can scaffold significant follow-on innovation, feeding back on the design and making it a 'standard', or infrastructural to an entire market, such as in the case of de facto standards and general purpose technologies. It is well recognised in intellectual property and competition law scholarship that 'infrastructural assets' such as these pose unique problems to the innovation system.[738] Standardisation bodies, antitrust authorities, and private companies have all adopted various formal and informal tools to deal with this problem. The core of the point is that, like basic science R&D outputs, the vast amount of social value of technological infrastructure is generated downstream of the asset, in its productive uses. Since the purpose of public R&D subsidies is to generate social value with the minimum cost to society's scarce resources, subsidy programs are designed to proactively 'dial up' subsidy intensity where spillovers are high and appropriability mechanisms are inadequate. In the case of technological infrastructure, however, the 'proximity to market' criterion means that companies which intend to generate infrastructural assets might be forced to rely on an underperforming IP institution as the means of resource management (see Part III).

It is submitted that instead of looking to the existence of a private appropriability mechanism when judging 'proximity to market' and thus subsidy intensity, a preferred approach would be to place more weight on how to open the resulting R&D outputs in practice. As argued in Part II, such subsidised R&D outputs are highly likely to have attributes of technological

736. Discussions of Kuhn's revolutionary science vs normal science and the similarity to that of working within a dominant design and working towards a new one. See Arthur, 'The Nature of Technology'

737. See generally Philip Anderson and Michael L Tushman, 'Technological Discontinuities and Dominant Designs'

738. Frischmann and Waller, 'Revitalizing Essential Facilities'; Wagner, 'Information Wants to Be Free'; Rubin, 'The Illusion of Property'; Barnett, 'Property as Process'

infrastructure, even when they are close to market (and subject to the lower subsidy intensity). By allocating IP to subsidy recipients in such a context, the management of such resources risks degenerating into the 'strong IP' sub-optimal equilibrium identified in Part III as well as relying on the 'top down' (and not necessarily efficient) decisions of the resource owner, who would be undisciplined by market forces. One powerful way of avoiding this outcome would be for the H2020 subsidy program to explicitly 'dial up' subsidy intensity even for 'close to market' R&D outputs, provided the outputs are licensed on an open access basis, such as royalty-free or FRAND terms.[739] As shown in Part III, in the subsection on technology transfer, there are a range of modern technology transfer mechanisms which do not rely on exclusive rights in order to get the generated resource to market. In the case of software, an open access approach might require the outputs to be licensed under open source terms. In the case of other technological outputs, perhaps FRAND conditions would suffice. A cursory empirical study by the author of FP7 software projects found no statistically significant difference between subsidy intensities of FP7 software projects licensed on open source terms compared to closed source.[740] By making a distinction in the available subsidy intensity grant between exclusive and open access R&D outputs with respect to technological infrastructure, the EU subsidy system could also aid private companies in reaching the payoff dominant open access equilibrium, leading to avoidance of social cost and greater spillovers.[741] Since the overarching economic goal of subsidies is to tap into the economics of the multiplier effect and increased social value, such an approach is also consistent with the underlying policy of the H2020 system.

As Paul Romer has said, "to speed up growth, it is not enough to increase spending on research and development. Instead, an economy must increase the total quantity of inputs that go into the process."[742] Although Romer's point may hold for all types of inputs, it is surely particularly true with respect to infrastructural assets. By liberating the outputs of sponsored R&D, particularly in software products (which are easily transferred), the EU could follow

739. Where the licensing regime is FRAND, then the subsidy intensity may however be less than royalty-free since FRAND may still create barriers to access.

740. Data was requested from DG Research. Data was processed by the author to only include software deliverables. Software deliverables with language suggesting 'open source' or 'open licensng' was then separated from non-open source or non 'open' software deliverables, to create two sets of FP7 software projects. The means between the two groups' subsidy intensities was then compared using statistical tools and found not to be statistically significant.

741. Furthermore, such distinction would not fall foul of EU State Aid law since although such sponsorship would most likely fall into the category of 'development' rather than basic research, the State Aid Guidelines would consider the open source licensing of R&D outputs to be 'non-economic' and thus would fall outside the application of the usual State Aid rules. See Commission Communication on the framework for State aid for research and development and innovation [2014] OJ C198/01 at rectial 19 ("The Commission considers that the following activities are generally of a non-economic character: (a)… wide dissemination of research results on a non-exclusive and non-discriminatory basis, for example through teaching, open-access databases, open publications or open software.") (*bold* added)

742. Paul M. Romer 'Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers' (2001) Innovation Policy and the Economy, Vol 1

the lead of DARPA and NASA in fostering a vibrant bottom-up eco-system of self-directed innovators.

V. CONCLUSION

In conclusion, this chapter has attempted to shed light on an arguably under- acknowledged source of technological infrastructure in the economy: sponsored R&D. It is argued that sponsored R&D in technological areas is likely to have a pioneering flavour due to the market failures of uncertainty and risk. When pioneering inventions are linked with an assessment of high social spillovers (such as would attract subsidy grants), then the R&D outputs that result are argued to map fairly robustly to the class of 'technological infrastructure'. Under the default regime of Bayh-Dole (and its EU transplants, such as the IP clauses of the H2020 framework), the task of technological transfer is left to the subsidy recipient who has exclusive rights over the R&D outputs. By using tools from game theory, it is suggested that an exclusive rights regime over technological infrastructure is unlikely to give rise to socially optimal results. The nature of the game played by innovators in high technology is described to be a 'stag hunt' or 'assurance game'. It is shown how such a game is sensitive to government policies which incentivise open access over exclusive control. One simple policy that may help achieve this end is explored, in the shape of dialing up subsidy intensity in response to the ex ante open licensing commitments of subsidy recipients, either on royalty-free or FRAND terms. Adopting simple policy prescriptions such as this may help guide the invisible hand of private resource allocation decisions towards social optima by serving to institutionalise the infrastructural approach of 'if infrastructure, then open access'. This approach helps liberate key technological infrastructural assets to the bottom-up process of innovation-niche exploration, without the top-down control of either Government agenda-setting or IP right holders.