**Resolving the Patents Paradox in the Era of Covid19 and Climate Change:**

**Towards a Patents Taxonomy**

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**Abstract**

This paper revisits the patents debate and considers the role of intellectual property rights and their impact on society in the context of inventions designed to protect global common pool resources (CPRs) such as public health and the environment. A review of the theoretical and empirical literature suggests that there has never been a clear consensus amongst researchers on the benefits of the patent system and intellectual property rights. As Robinson notes, “The patent system introduces some of the greatest of the complexities in the capitalist rules of the game and leads to many anomalies.” We explore these anomalies by specifying a taxonomy of patents for different classes of inventions, including inventions to protect CPRs. This class includes vaccines and inventions that reduce externalities, such as, CFC gases and greenhouse gas emissions. In these instances, the effectiveness of innovations depends critically on rapid global diffusion. Our theoretical analysis utilises Ostrom’s *CPR dilemma* to analyse the complexities surrounding innovation and CPRs. We find that the effectiveness of innovations to protect CPRs depends on industrial characteristics and wider regulatory environment. Empirical evidence is brought to bear on these conclusions via 2 case studies that each embodies a natural experiment; one on vaccines pre- and post-TRIPS and one on environmental technologies to reduce CFC gases and CO2 emissions with and without an agreed UN Protocol. The insights gained are explored in our policy section. Our analysis suggests the need for a more nuanced approach to patent policy that is embedded in the wider context of innovation systems and takes account of the anomalies raised by CPRs. For CPR innovation subject to positive network externalities we advocate that policy should prioritise diffusion over private incentives for R&D and use alternative policies to patents to stimulate investment in R&D.

**JEL Codes:** O3 Innovation, R&D, Technological Change, Intellectual Property Rights; I1 Health;

I18 Public Health; Q5 Environmental Economics; Q55 Technological Innovation; Q58 Government Policy

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*“This leads to what we may call the paradox of patents. A patent is a device to prevent the diffusion of new methods before the original investor has recovered profit adequate to induce the requisite investment. The justification of the patent system is that by slowing down the diffusion of technical progress it ensures that there will be more progress to diffuse. … Since it is rooted in a contradiction, there can be no such thing as an ideally beneficial patent system, and it is bound to produce negative results in particular instances, impeding progress unnecessarily, even if its general effect is favourable on balance.* Robinson (1956).

**1. Introduction**

The system of intellectual property rights introduced under the TRIPS Agreement is now over a quarter of a century old. While early patent laws can be traced back to the 15th Century, the consolidation of national laws under a single international system marked a milestone in the history of intellectual property rights (IPR) - a remarkable achievement not least because agreement on policy was reached without a consensus in the academic literature on the benefits of patents (Machlup and Penrose, 1950). This paper revisits the patents debate and considers the role of IPRs and their impact on society in the context of inventions designed to protect common pool resources (CPRs) such as public health and the environment. In particular, we seek to address the question of whether the patent system is fit for purpose to meet 21st Century challenges. Within that context, a central question is whether the one-size fits all approach to patents under TRIPS allows sufficient flexibility to avoid social costs (Kapp, 1963) and meet global challenges for all classes of invention from vacuum cleaners to vaccines.

While the recent history of patent law over the past 25 years is a fairly settled one from a legislative point of view, the longer run picture tells a different story with various countries adopting, abolishing and then readopting patent laws. IPRs have also been applied differently with some laws specifying assessment of applications on a case-by-case review of potential costs and benefits, to the current system where assessment is made primarily on the basis of originality and property rights (Biagioli, 2019). This ‘patent schizophrenia’ reflects the lack of consensus in the academic literature on the costs and benefits of patents. Investing in R&D is a risky activity and the returns are uncertain. In the absence of policy interventions there is likely to be underinvestment for a variety of reasons. At the same time, most of the benefits to society come not from the R&D or the invention itself, but from its widespread diffusion. A central question at the core of the patents controversy is whether patents can generate sufficient private sector investment in R&D to outweigh the costs of preventing or slowing down diffusion for a considerable time period – normally 20 years. As Robinson (1956, p. 86) noted, “[t]he patent system introduces some of the greatest of the complexities in the capitalist rules of the game and leads to many anomalies.” Today, Covid19 and the climate crisis have accentuated those anomalies and put them under the spotlight of intense public scrutiny.

In this paper we revisit the patents debate in light of the current one-size-fits-all policy system and consider the case for a more granular approach that goes beyond assessment based on originality and infringement of IPRs. We argue that it is important to explore, rather than ignore anomalies, and to consider a variety of cases characterised by: (i) different industry structures/contexts including economies of scale and pecuniary externalities; (ii) variation in the extent and nature of network externalities; and (iii) the wider regulatory environment within the context of regional, national and global innovation systems. To that end we set out a taxonomy of patents/inventions according to their impact on CPRs, as these have been at the forefront of public policy debates in the current era of Covid19 and climate change.

CPRs are non-excludable and subtractable making them subject to the tragedy of the commons hallmarked by a conflict between individual (private) and collective (public) interests. Inventions and patents for CPRs include vaccines and technologies that reduce externalities, such as greenhouse gas emissions. Our taxonomy sheds light on factors influencing the ability of innovations to protect CPRs and the relationship between the *efficacy* of inventions and the speed and extent of diffusion. A central question in this regard is to determine whether and under what conditions the *efficacy* of CPR-protecting innovations is affected by the speed and extent of diffusion.

The remainder of the paper is organised as follows. Section 2 revisits the patents controversy and provides a review of the literature setting out some of the key issues occasioned by Covid19 and climate change. Section 3 provides a conceptual framework for our analysis setting out a taxonomy of cases to inform the design of policies to promote innovation and diffusion. Within this taxonomy we focus on the complex case of inventions to protect CPRs, such as vaccines and low/zero-carbon technologies using the concept of the CPR dilemma. Section 4 presents our empirical analysis using case studies as natural experiments (Lee, 1989). Here we compare the development, diffusion and efficacy of vaccines for polio, which took place prior to TRIPS and without the use of patents, with the development of vaccines for Covid19 post TRIPS. We also consider an intermediate case of HIV/AIDS drugs and the use of compulsory licensing. In relation to climate change we consider the challenges posed by CFC gases and policies to eliminate their use under the UN Montréal Protocol, and current policies to encourage the diffusion of low/zero emissions vehicles. These are contrasting cases, one governed by a universally ratified UN Protocol to eliminate CFC gases by setting a common standard supported by funding for technology transfer and patent costs, the other with a more flexible policy: the Nationally Determined Contributions of the Paris Agreement. Section 5 discusses the policy implications of our theoretical and empirical analysis for the system of IPR and the diffusion of innovations to protect CPRs. Section 6 concludes by considering the broader implications of our findings for international governance of IPR and CPRs.

**2. Patents Pre and Post-TRIPS: A Review of the Literature**

*2.1 Patent system prior to TRIPS – limited evidence of effectiveness in promoting innovation*

Understanding how the aspects of the patent system that are ill-equipped to deal with complex global challenges can be improved upon, requires an appreciation of the contested origins of the contemporary patent system prior to TRIPS and the scale of the challenge now facing CPRs. The origins of the contemporary patent system can be traced to a compromise between protectionist and free trade interests (Machlup, 1958). This resolution was not only controversial but also left unresolved questions over its ability to meet society's demand for technological progress and the extent of the social loss involved in “the temporary prevention of the use of the most efficient process by most if not all other producers” (Machlup and Penrose, 1950:24).

The extent of the social loss is already apparent in CPRs where much of the technology for sustainable development already exists (Clugston, 2021); what is missing is an appropriate mechanism to support its rapid diffusion. Widely available vaccines have been key to combating the spread of viruses such as polio (Blume, 2005). But vaccine research networks have become privatised and fragmented, while vaccines for a wide range of diseases are now in short supply (WHO 2020). Electric vehicles offer a solution for stemming the rise of harmful emissions. Although their sales have soared over the last decade, by 2019 only five countries (Norway (13%), Iceland (4.4%), Netherlands (2.7%), Sweden (2.0%) and China (1.6%)), had a share that exceeded 1.5 per cent (IEA, 2020: 44).

*A Lack of Consensus*

While there has long been academic consensus on the centrality of invention to economic development and growth, the evolution of the patent system shows far less consensus on the role of patents in promoting innovation and diffusion. The main deficiency in the patent system was its attempt to achieve a purpose that cannot be achieved by parcelling up streams of creative thought into a series of distinct appropriable claims (Polanyi, 1944; Robinson, 1956; Dosi et al, 2006). Objections to the patent system disputed the view that without the patent system there would be insufficient levels of inventions and that patents represented the most efficient form of promoting invention (Machlup and Penrose, 1950). Historical evidence supports these objections. For much of the 1800s the case for patents seemed lost in several European countries (Machlup, 1958). Evidence from exhibits at world fairs in 1851 and 1876 indicate high levels of quality innovations in countries such as Switzerland and Denmark with no patent laws and prizes for exhibits from the Netherlands where patents were abolished in 1869 (Moser, 2013, Schiff, 1971).

Against these objections, the superiority of the patent system rested on its ability to protect the difficult and relatively scarce activity of inventing, while placing codified knowledge in the public domain (Machlup, 1958; Polanyi, 1944). In this regard, patents came to offer a standard remedy for the market failure problem facing the developers of costly but promising technologies, since it offers a mechanism to appropriate some of the gains of later innovations (Arthur, 1989). Crucially this rests on the assumption that it is invention rather than innovation which the patent system is designed to protect. But because knowledge is for the most part a public good, addressing market failure by creating appropriability in this way also depends on ensuring artificial scarcity to amend for non-rivalry and non-excludability in use (Dosi et al, 2006). Thus, while appropriability and artificial scarcity serve to limit diffusion, the costs of this to society are particularly severe in the case of CPRs, since much of the inventions in these areas occur far upstream from either marketable products or production processes such that they grant the holder control over access to understanding (Nelson, 2006).

In practice the conditions for appropriability are rarely perfect and vary substantially across sectors and countries (Levin et al, 1997; Torrisi et al, 2016). Tight appropriability tends to be the exception rather than the rule and such complementary assets as manufacturing and distribution capabilities are central to maintaining competitive advantage (Teece, 1986). This in turn has meant that many patents are either not used or are used as a strategic tool to block other patents (Torrisi et al, 2016). This can be problematic where many different organisations hold patents required to manufacture a standardised product (Contreras, 2012). In these cases, a license must be negotiated with each patent holder to meet the standard. At the extreme this leads to a patent thicket where the costs of negotiating licences becomes so high as to make production uneconomical (Contreras, 2012).

The effect of national pharmaceutical patent legislation on domestic innovation shows a close association between patent protection and other measures of economic development including the level of R&D activity, the overall market environment, and international integration (Ginarte and Park, 1997). Qian’s (2007) study on 26 countries for the period 1978-2002 indicates that national patent protection is not sufficient to stimulate innovation but finds evidence of accelerated innovation in countries with higher levels of economic development, educational attainment and economic freedom.

*Patent Stacking and the Problem of the Anti-Commons*

CPRs are subject to the tragedy of the commons (Hardin, 1968). The stacking of patents in technologies in these areas leads to the problem of the anti-commons. This is the mirror opposite of the tragedy of the commons, where instead of a CPR suffering from overuse, a privatised resource suffers from underuse (Heller and Eisenberg (1998). Looking at the case of biomedical research, Heller and Eisenberg (1998) show how the patent system created too many concurrent fragments and incentivised the stacking of licenses producing an anti-commons. These practices impede progress and diffusion by creating too many concurrent fragments of IPRs in potential future products and too many upstream patent owners stacking licenses on top of the future discoveries of downstream users. The high bargaining costs created by fragmented and overlapping IPRs deter researchers from pursuing innovative research in these areas. For CPRs, too much appropriability could work against diffusion.

*Fragmentation in Vaccine Production*

There is increasing evidence that the fragmentation associated with the anti-commons problem is at the root of the challenges facing the faster roll out of vaccines and other technologies. Vaccines are not attractive to the pharmaceutical industry and account for a small proportion of turnover and high development costs (Blume, 2005). Many pharma companies abandoned vaccination production in the 1960s and 1970s, while public health institutions now make a negligible contribution to research in this area. One of the most serious consequences of this has been recurring vaccine shortages. The WHO (2020) reports that 56 out of 132 reporting countries (42%) reported national stockouts of one or more vaccines and 34 countries reported stockouts of two or more including oral polio and yellow fever vaccines.

One of the reasons for this is that the knowledge generation in vaccinological networks has been privatised and is protected by patents (Blume, 2005). Vaccine markets are now more concentrated with four firms (GSK, Pfizer, Merck, and Sanofi) controlling 90% of global market value and five produce 60 percent of global volume (SII, GSK, Sanofi, BBIL and Haffkine) (WHO, 2020: 4). Within these firms the production of vaccines has become fragmented and is increasingly outsourced to the contract development and manufacturing (CDMO) industry (Bown and Bollyky, 2021). The CDMO industry is largely concentrated in advanced economies. This has meant that the capabilities for vaccine production are increasingly concentrated within a small number of firms and advanced nations, while the development of new vaccines faces significant barriers in terms of the stacking of licenses.

*2.2 The Patent System, TRIPS and Low-Income Economies*

The social loss from restricting knowledge is especially severe in low-income economies. The application of patents has become more complex, extending IPRs to trade agreements involving a variety of products from agricultural products to advanced technologies and pharmaceuticals (Love, 2001; Shadlen et al 2020; Campi and Nuvolari, 2015). Yet the benefits of this for low-income economies are far from clear. Efforts to model the welfare impacts of tighter IP regimes on innovation in developed economies and imitation in less developed economies indicate that the initial acceleration of innovation in developed economies would be insufficient to compensate less developed economies for its subsequent decline (Helpman, 1993).

Since the Uruguay round of the World Trade Organisation (WTO) negotiations (1986-94), all

WTO members became party to the TRIPs Agreement. These agreements integrated intellectual property protection with global trade rules and globalised pharmaceutical patenting (Shadlen et al, 2020). This allowed pharmaceutical companies to globalise the protections they enjoyed in the US in response to emerging competition from nascent pharmaceutical producers such as India and China (Pistor, 2019). Although the WTO Doha Declaration reinstated the right of states to use compulsory licensing in times of public health emergencies, these agreements still offered significant loopholes. The patent system could still be used to forestall the development of generic drugs by privatising the results of drug trials or allowing exceptions knowing that developing countries lacked the production capacity and import options to make use of the Doha Declaration (Sparkle, 2020). A lack of production capabilities remains a key obstacle for developing economies in accessing more advanced vaccines (Smith et al, 2011).

*Mapping and Diffusing Capabilities*

The above discussion reflects the fact that in resolving grand challenges that require a rapid diffusion of technologies, the fine tuning of IPR regimes and incentives is likely to have only second order effects since the rates of success in fishing for opportunities depend to a large extent on firm-specific capabilities (Dosi et al, 2006). Part of the reason for this is that much of the innovation that is beneficial to society can occur outside of the patent system in societies where the patent system is not strong, and innovation is not captured in official patent data (Moser, 2013). In lower income economies such activities are often incorrectly labelled as imitation, when in fact they are crucial to the development of adsorptive capacity (Helpman, 1993). Secondly, firm specific capabilities especially in many CPRs tends to be unequally distributed. In mapping vaccine production capabilities, Bown and Bollyky (2021) show that the capabilities for vaccine manufacturing are mostly located in the US and Europe, with small presence in Japan and China.

*Can the Patent System be reformed to improve diffusion?*

In highlighting the anomalies of the patent system, the above discussion indicates that if society’s objective is to stimulate innovation for solving unresolved grand challenges through open-source technologies (e.g. Ahn et al, 2019), controversies about the nature and scarcity of inventions are arguably outside the point (e.g. Machlup, 1958). Protecting global CPRs requires rapid diffusion of knowledge that is consistent with the idea of a global knowledge society whereby the more people that use a technology “at the same time the more it tends to grow and to benefit each of its users” (Polanyi, 1944: 65). Our central argument here is that in the case of network externalities where diffusion is dependent on more people using a technology, offshoots of the patent system such as compulsory licencing (CL), patent pools and pledges must be assessed in terms of their potential to induce the transfer of technologies and production capabilities to low-income countries.

One of the main policy tools available to governments to deal with anomalies in the patent system is compulsory licensing. CLs have been used extensively in developed economies across such sectors as software, biotechnology, and pharmaceuticals (Love, 2001). Yet, despite the scale of the health crisis facing many economies, the use of CL by low and middle-income countries has been sporadic (Son, 2019). Hence CL often fails to quicken the diffusion of inventions in the countries where it is most needed. There are a variety of reasons underpinning this, stemming from a reluctance of poorer countries to engage in expensive litigation to the lack of a TRIPS compliant patenting registration system (Love, 2001). Son (2019) finds that countries with more developed patent systems are more likely to use compulsory licensing. The rationale underpinning this is that a compulsory license requires a functioning patent system.

Innovations that address some of the anomalies in the patent system regarding CPRs, especially the problem of stacking and the anti-commons, include patent pools and pledges. In a patent pool, patent owners license essential technology to a single agent, who in turn offers a license for the entire pool for a royalty fee, with revenues distributed among participants using a predefined formula (Contreras, 2012). In theory, this addresses the problems of stacking and appropriability, but only if all patent holders participate. Pledges differ from patent pools and cross licensing by conferring benefits on 3rd parties regardless of contribution to the commons and without formal contract. This represents a form of open innovation where the boundary of knowledge and resource exchange is expanded from individuals to a group, introducing a level of tension between altruism and commercial viability (Ahn et al, 2019). A study examining the Eco-Patent Commons, an innovative not-for-profit initiative with the objective of pledging green technology patents royalty free to accelerate their adoption by Contreras et al (2018), shows that the patents contributed did not attract a lot of interest even before contribution and pledging to the commons did not promote diffusion. Their findings highlight that patent disclosure alone is not sufficient for uptake without a dedicated coordination system to provide dedicated administrative support and managerial resources to promote the commons.

**3. A Patents Taxonomy for Global CPRs**

In this section we build on the existing literature to specify a taxonomy of patents based on CPR and industry characteristics and the wider policy/regulatory environment.

*3.1 Global Common Pool Resources and Patents*

We start by considering theoretical issues regarding technological progress and innovations designed to protect global CPRs. Even when there are known technological remedies for global CPR problems, the potential protection of CPRs may not be realised. Technological change and invention have created many innovations that have the potential to protect CPRs but there are significant challenges in effecting timely diffusion. For example, hybrid electric vehicles (HEV) have been in commercial production since 1997 and emit approximately half the GHG of comparable vehicles powered purely by internal combustion engines (ICE). Swift adoption and diffusion would have significantly reduced carbon emissions, yet some 25 years after their market debut, the global share of HEV vehicles was only around 10 per cent (comprising 5% Full HEVs and 5% Mild HEVs) in 2021.[[1]](#footnote-2) Consumers and economies remain locked-in to pure ICE vehicles. Similarly, vaccines to protect against Covid19 have been approved since December 2020 but despite considerable efforts, diffusion has been slow. Initially, COVAX in partnership with WHO and GAVI, set a target of 20% coverage by the end of 2021, that was subsequently increased to 40% with an additional target of 70% of the adult population in all countries by mid-2022. However, even the most modest targets for vaccine rollout have not been met with consequent negative effects on public health. Watson et al (2022, p. 1298) estimate that had the COVAX 20% and 40% targets been achieved, around 680,000 deaths would have been avoided in low- and low-middle-income countries. These examples suggest that we need greater understanding of why, in the presence of potential solutions to solve CPR problems, it remains difficult to implement them in a timely manner.

A key to unravelling this conundrum lies in understanding what Ostrom *et al* (1994) termed the *CPR dilemma*. The *CPR dilemma* is a situation characterised by the coexistence of two conditions: (i) suboptimal outcomes; and (ii) coordinated outcomes that are Pareto superior and feasible (Ostrom *et al,* 1994, p.16). This raises the question of what institutional arrangements enable attainment of optimal outcomes and whether these emerge from interactions between players or whether they require top-down regulation, or a combination of both.

Resolving the CPR dilemma requires identifying the nature of the problem, technological solutions *and* understanding the institutional arrangements that could enable society to reach efficient outcomes. We use Ostrom’s framework of the CPR dilemma to shed light on the institutional arrangements that can help resolve global CPR problems in the case of innovation diffusion.

To untangle these issues, we adopt the approach suggested by Bagioli (2019) who advocated an industry-specific approach that assesses the pros and cons of patents in specific industry contexts. We extend the idea of a more nuanced approach and combine analysis of industry characteristics with analysis of CPRs using the concept of the CPR dilemma, to derive a taxonomy of patents for innovations designed to protect global CPRs. In the following discussion we show how patents and industry characteristics may combine to exacerbate CPR dilemmas. To illustrate our theoretical arguments, we consider them in the context of the vehicles and vaccine sectors. These sectors form the basis of our case studies in section 4.

*3.2 CPR Dilemmas: Vaccines and Electric Vehicles*

The diffusion of vaccines can be analysed as a CPR dilemma combined with positive network externalities. Prior to the successful invention of Covid19 vaccines, governments made Advanced Purchase Agreements (APAs) that helped fund R&D *and* contracted pharmaceutical companies to supply an agreed number of doses in the event of vaccine approval by public health agencies. National governments faced two strategic choices: (i) to make bi-lateral Advanced Purchase Agreements (APA) with pharmaceutical companies; and/or (ii) to participate in multilateral purchase schemes, such as COVAX, designed to diffuse vaccines more equally and rapidly across countries (McAdams et al, 2020; Duke Global Health Innovation Center, 2020, John Hopkins Corona Virus Resources Centre, 2020). These two options can be viewed as individual and cooperative strategies where the cooperative strategy facilitated via COVAX has the advantage of: (i) encouraging rapid and widespread diffusion; (ii) preventing vaccine hoarding; and (iii) avoiding a situation where rich countries pre-order many times their required number of vaccines, thereby limiting supply to poorer countries.

An additional twist in the case of anti-viral vaccines is that vaccine diffusion is subject to network externalities. Rapid diffusion yields a positive network externality, while slower diffusion produces negative network effects: the lower the proportion of the population that is vaccinated the lower the benefit to vaccinated individuals and the greater the chance of virus mutations. In short, the speed of diffusion affects the efficacy of the invention.

In contrast to the cooperative strategy offered via COVAX, countries could choose to go it alone and strike bi-lateral APAs with pharmaceutical companies. The CPR dilemma predicts that in the absence of commitment to the cooperative strategy by all players, unenlightened self-interested behaviour by national governments results in an outcome that is inefficient compared to the coordinated outcome of more rapid diffusion across countries. Moreover, under the non-cooperative strategy, lower levels of vaccination allow the virus to circulate in the unvaccinated population and to mutate leading to ‘vaccine escape’ and negative network externalities that undermine vaccine efficacy. It is evident that anti-viral vaccines are subject to complex CPR problems which require robust institutional arrangements to resolve. The fact that slow diffusion undermines vaccine efficacy suggests a clear theoretical rationale for an *automatic* patent waiver for anti-viral vaccines during a pandemic.

It is tempting to think that this is a special case that arises in the case of vaccines and pandemics but does not have wider applications. However, similar CPR dilemmas arise in the case of hybrid (HEV) and battery electric vehicles (BEV). The vehicles sector is subject to significant economies of scale making it hard for new technologies to break through. Three problems combine to prevent the diffusion of HEVs and BEVs which together comprise the electric vehicle market (EV). First, economies of scale in vehicle production make it harder for new technologies to compete with existing ICE technologies that are producing at minimum efficient scale (MES). In essence, there is a coordination problem that requires consumers and/or producers to switch together to reach MES and compete with conventional ICE vehicles on cost/price. Second, production is subject to nested economies of scale problems in the supply chain. The main cost of EVs is the cost of the battery packs, and battery production is also subject to significant economies of scale (Mauler et al, 2001). Finally, in the case of BEVs (as opposed to HEVs) there is lock-in to conventional vehicles caused by well-established networks of fuel stations and the absence of comprehensive networks of EV charging points. This network externality reduces the benefit of owning a BEV and creates ‘range anxiety’ that limits demand. Patents exacerbate these three problems since they raise costs in the supply chain and in the vehicles market. Moreover, because patents slow diffusion of BEVs and charging points they reduce network externalities and the use value of BEVs. EVs also illustrate the problem of patent stacking and the anti-commons discussed in section 2, as patents play an extensive role throughout the vehicles supply chain. Theoretically, there is a case for voluntary institutional arrangements to waive patent fees in the case of EVs (as per Toyota’s voluntary waiver in 2019), while in the case of BEVs subject to network externalities there is a case for a formal patent waiver to resolve the CPR dilemma.

In Table 1 we combine our forgoing analysis of the CPR dilemma and industry characteristics to specify a taxonomy which categorises innovations according to their impact on global CPRs. The taxonomy defines 4 levels of impact arising from the interaction of a set of CPR characteristics and a set of industry characteristics. Different categories have different implications for patents policy, technology transfer and regulatory policies.

Category 1 deals with innovations that potentially have a negative impact on CPRs. In this case the speed of diffusion has no impact on the efficacy of the innovation and slower diffusion reduces the detrimental effect on CPRs. An example of such an innovation is fracking which may contaminate groundwater and releases methane gas that can remain a highly potent atmospheric pollutant for up to 20 years. In a study of hydraulic fracturing technology, Cahoy et al (2013) have argued that patents have prevented the experimentation necessary to understand fracking’s global impact on CPRs. They advocate relaxation of patent law to allow third party testing to determine the environmental and public health effects.

Category 2 covers the case of innovations that have neutral or insignificant impact on CPRs. In this case economies of scale in production and patent stacking have negative effects on diffusion but there is no specific impact on CPRs.

**Table 1 Innovations, Patents and CPRs: Towards a Taxonomy**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Innovations categorised by potential impact on global CPRs relative to *status quo*** | **Factors determining Impact on CPRs** | **Characteristics Affecting Diffusion** | **Example Technology** | **Policy implications** |
| *Is the nature of CPR problem time critical?* | *Impact of speed of diffusion on CPRs and on the efficacy of technology*  | *Coordination needed to resolve conflict between individual and collective interests (CPR Dilemma)* | *Economies of scale in production and geographic concentration of production* | *Economies of scale in supply chain and stacking of patents* | *Extent of Tacit knowledge vs Codified Knowledge*  |  | *Patent Policy* | *Technology Transfer Policies*  | *Regulation* |
| **1. Innovation has significant negative impact on global CPRs** | Yes | Slower or no diffusion protects CPRs | Coordination desirable to limit or restrict use of technology | Economies of scale slow diffusion reducing potential negative impact on CPRs | Stacking of patents will have positive effect on CPRs | No need to transfer tacit knowledge | Fracking | Patents beneficial as they slow diffusion with positive effects on CPRs, but may also prevent testing and obscure impact on CPRs | Not beneficial for society as this technology has negative impact on CPRs | Regulation needed to restrict diffusion or ban use |
| **2. Innovation has neutral or insignificant impact on global CPRs** | N/A | None | No | Economies of scale slow diffusion but with neutral impact on CPRs | Stacking of patents will slow further knowledge development | Tacit Knowledge sharing helps diffusion but no significant effect on CPRs | Turntable, food mixer  | Patents slow diffusion but with no or insignificant impact on CPRs | Not needed to protect or enhance CPRs | Not needed to protect or enhance CPRs |
| **3. Innovation has significant positive impact on global CPRs** | Yes | Slower Diffusion reduces potential positive impact on CPRs  | Timely coordination needed to promote technology sharing and/or coordinate shifts in demand | Economies of scale slow diffusion and have negative impact on CPRs | Stacking of patents has negative effect on CPRs e.g. patents on batteries increase price with knock on effects in vehicles industry | Sharing of tacit knowledge throughout supply chain needed to speed diffusion | Non-Ozone depleting CFC gases, Hybrid Electric Vehicles (HEV) | Patents slow diffusion and undermine potential protection of CPRs; institutional solutions needed e.g. multilateral fund to cover fees, patent waiver or pledge, including in supply chain | Transfer of Tacit Knowledge needed especially to low- income countries | Time limits, incentives, and other public policies needed to speed transition to superior CPR-protecting technologies |
| **4. Innovation has significant positive impact on global CPRs including via Network Externalities** | Yes, with critical tipping points | Slower diffusion diminishes CPRs and may reduce the efficacy of the invention e.g. virus mutates in unvaccinated population creating resistant strains; or lack of charging points reduces use-value of Battery Electric Vehicles (BEV) | Yes, urgent coordination required  | Economies of scale and geographic concentration of production inhibit or prevent diffusion over time and space | Stacking of patents will slow diffusion and knowledge transfer | Sharing of tacit knowledge at more than one stage of production needed to speed diffusion  | Covid19 Vaccines, Battery Electric Vehicles (BEV) | Patents slow diffusion *and* undermine efficacy of inventions; immediate waivers needed to support product diffusion, may also need waivers & other actions to unstack supply chain patents | Transfer of tacit knowledge needed, especially to low-income countries | Time limits and/or public policies needed to support expansion of production capacity and networks e.g. of electric vehicle charging points or public heath infrastructure to administer vaccines. |

Category 3 considers the case of innovations that have the potential to protect CPRs, for example, CFC replacement gases that are less damaging to the ozone layer, or HEVs that reduce carbon emissions compared to petrol and diesel ICE vehicles. In this category, the speed of diffusion is positively related to the beneficial effects on CPRs. Industry characteristics affecting the speed of diffusion include economies of scale in final production and economies of scale in the supply chain. High fixed costs of production in industries such as vehicles implies that production based on newer, cleaner technologies has higher unit production costs compared to existing technologies that are already at minimum efficient scale. As a result, it can be harder for more efficient technologies to overcome barriers to entry. Scale effects may also reside in the supply chain. Batteries are the main cost component of HEVs and EVs and battery pack production is also subject to significant economies of scale, slowing diffusion. Coordination both on the supply side or the demand side that expands production can speed up diffusion by putting new technologies on an equal cost footing with incumbent technology. For example, policies that shift consumer demand away from ICE vehicles to EVs can lower the unit cost of EVs.

In terms of patents, vehicle manufacturers have used voluntary patent sharing and waivers to resolve the CPR dilemma. In 2015 Tesla pledged to share its EV patents (provided the users agreed to share theirs) on the grounds that the real competition was not with other EV producers/technologies but with existing ICE technologies that dominate the market. In April 2019 Toyota made 24,000 EV-related patents freely available to its competitors, waiving the right to royalty fees and offering to provide related R&D services (tacit knowledge) on a fee basis. Toyota cited environmental concerns in its press announcement, but as discussed above the hallmark of the CPR dilemma is that both individual actors (firms) *and* society benefit from coordinated actions. The benefit to Toyota from encouraging the development of the EV market is greater economies of scale in production, including in the battery supply chain which reduce unit costs whilst also giving a fillip to the growth of BEV charging networks.

This last point leads us to category 4: innovations that have positive effects on global CPRs and also generate positive network externalities. A significant factor holding back consumer demand for BEV is ‘range anxiety’ associated with thin and patchy charging point networks. An expanding BEV market encourages the growth of charging networks and increases the use-value of BEVs. Similarly, rapid diffusion of vaccines increases their efficacy and the benefit to users, while slower diffusion undermines their effectiveness. This 4th category incorporating network externalities is therefore a special case where patents that slow diffusion of an innovation also undermine its effectiveness, its use value to consumers and its potential positive impact on CPRs.

**4. Case Study Evidence from Two Natural Experiments**

Drawing on the above insights we examine pairs of case studies of innovations that protect CPRs and the factors shaping their successful diffusion. Each pair has been selected to embody a natural experiment.

*4.1 Natural Experiment 1: Vaccines pre-TRIPS (Polio) and post-TRIPS (Covid19)*

An important case of technology diffusion prior to TRIPS for an innovation characterised by significant positive impacts on CPRs with network externalities is provided by the roll out of Jonas Salk’s unpatented polio vaccine. The case illustrates the importance of cooperative type buy in by state health authorities and building capacity via the exchange of scientific knowledge. The case is especially relevant since it involved a vaccine technology that had become suboptimal as epidemiological profiles changed (Blume, 2005). The case has relevance to COVID-19 since although many countries have been successful in eradicating polio by the 1970s, the disease remained prevalent in many developing countries during the 1980s (Ochmann and Roser, 2017). Central to dealing with emerging variants has been the ability to adapt vaccine production and administration in affected areas (Goldblum et al, 1994).

Following a large outbreak of polio in the 1950s the Israeli government scaled up industrial production of Salk’s polio vaccine. Israel, then a developing country, lacked capabilities in this area of vaccine production. In 1955 Natan Goldblum, director of the Israeli government virology department, was sent to Salk’s laboratory in Pennsylvania to study Salk’s methods (Blum et al, 2010). Israel emerged in 1957 as the third country in the world after the US and Denmark to produce a polio vaccine.

Israel's efforts to produce a polio vaccine are remarkable for two reasons. First, they led to a rapid drop in case numbers that replicated those achieved in high income economies such as the US (Figure 1). The number of polio cases in Israel dropped from an annual average of 650 in the years 1952 to 1956 to 57 in 1957 and 38 in 1960 (Blum et al, 2010: 2074). While the large drop in 1957 was like other countries in the region without capacity, and the potency and coverage of the vaccine, even in 1958, may have still been weak, by 1959 the impact of the vaccine on incidence was clear (Davies et al, 1960). Indeed, subsequent outbreaks were largely confined to the non-vaccinated and largely non-Jewish migrant populations and having in-country capacity helped innovate vaccination delivery for these populations (Figure 1).

Secondly, and more crucially in terms of the diffusion of knowledge, the production of the patent free vaccine stimulated an increase in research and diffusion of tacit knowledge on poliomyelitis during the periods surrounding outbreaks (Figure 2). Israel saw an increase in publications and citations indicating knowledge diffusion (Figure 3). The results of this included the production of an oral vaccine to treat an epidemic in 1961 which primarily affected the non-Jewish unvaccinated population and Goldblum’s own career which saw him publish more than 50 papers on poliomyelitis and engage in international collaboration on infectious diseases (Goldbum, 1994; Blum et al, 2010). There is similar evidence of knowledge diffusion from other countries that adopted Salk’s vaccine. Investment in Salk’s vaccine by the Dutch and Danish health authorities led to innovations that addressed local production bottlenecks, the production of an enhanced vaccine, and public investment in vaccine research that would not otherwise have been carried out by private companies (Blume, 2005).

**Figure 1: Polio Case Rate per 100,000 population: Israel (Jewish and Non-Jewish populations) vs United States (1951-70)**

Source: US data is from US Public Health Reports (1967: 419). Israeli data from Swartz (2008)

**Figure 2: Total Publication (LHS) and Citation (RHS) Data for Poliomyelitis (1940-2020)**

Notes: The results are based on citations search of the Web of Science database for scientific publications on poliomyelitis.

**Figure 3: Publication and Citations on Israel (IL) and Poliomyelitis as % of Total**

**(1952-2001)**

Notes: Results are based on citations search of the Web of Science Core Collection database for scientific publications on topic of poliomyelitis and Israel for the years 1952-2001

Source: Web of Science Core Collection

Potential counterfactual cases of developing countries in the region who did not benefit from technology transfers include Lebanon and Egypt. From 1966-1970 averaged reported cases increased to a yearly average of 270 in Lebanon and 1,665 cases for Egypt (Swartz, 2008: 75). Lebanon achieved polio free status in 1994, but experienced subsequent outbreaks of wild polio virus (Alawieh et al, 2017). Egypt did not eradicate the virus until the mid-1990s following the implementation of global vaccination strategies and establishment of WHO reference laboratories as part of the Global Polio Eradication Initiative (Aylward et al, 1997). The latter represents a type of cooperative strategy without technological capacity building. The evidence here indicates that this type of cooperative strategy is less optimal and slower than one with full technological capacity building.

*Vaccine Development and Diffusion for Covid19 post-TRIPS*

The announcement by the WHO in March 2020 that Covid19 infections constituted a pandemic triggered a race against time to create a vaccine. University scientists and pharmaceutical companies worked in a regulatory environment that supported fast-tracking of clinical trials with significant public funding both in the form of direct R&D subsidies and advanced purchase agreements (APAs). Governments of many advanced and middle-income countries struck individual APAs with pharmaceutical companies on the basis that if the vaccine was successful they would receive the contracted number of doses ahead of other buyers, but if the vaccine failed to attain approval, the companies would keep the money from the APA contract

(John Hopkins Centre, 2021). This combination of policies: fast tracking of clinical trials; R&D subsidies; and guaranteed markets for successful companies significantly reduced risk and encouraged investment in vaccine development. The development of Covid19 vaccines in less than 1 year was a remarkable collaborative achievement.

The picture regarding diffusion is less rosy. The case of South Africa’s fight against Covid19 illustrates how, even in developing countries with vaccine manufacturing capacity, patents on Covid19 vaccines had a negative impact on their efforts to produce vaccines and respond to the pandemic. At the onset of the pandemic, South Africa was, together with Morocco, Tunisia, Egypt and Senegal, one of the few African countries with Covid vaccine manufacturing capacity (WHO Africa, 2022). Despite this, South Africa has become one of the countries with the highest number of Covid cases and deaths on the African continent and the world, as can be seen in figures 4(a) and 4(b) (The Economist, 2021; Roser et al. 2022). One of the reasons is the delay in vaccination.

**Figure 4(a) Cumulative confirmed Covid cases in Africa by 14 August 2022**



Source: <https://ourworldindata.org/coronavirus/country/south-africa>

**Figure 4(b): Cumulative confirmed Covid deaths in Africa by 14 August 2022**



Source: <https://ourworldindata.org/coronavirus/country/south-africa>

In October 2020, South Africa called for the WTO to waive intellectual property rights on Covid vaccines, tests and treatments for (at least) three years - a proposal that was opposed by the pharmaceutical industry and many high-income countries (Huber 2022). In June 2021, the WHO and a South African consortium comprising two pharmaceutical companies and the Africa Centres for Disease Control and Prevention established Africa’s first Covid19 mRNA vaccine technology transfer hub in South Africa (WHO 2021). This was part of a pilot project aimed at providing low- and middle-income countries with the know-how required to produce Covid19 vaccines (Roelf and Steenhuysen 2022). South African biotechnology startup *Afrigen Biologics and Vaccines* sought to replicate *Moderna*’s mRNA vaccine, following Moderna’s commitment not to enforce their Covid19 vaccine patents during the pandemic. *Afrigen* asked *Moderna* to share its vaccine technology, but Moderna refused. Despite this, researchers at *Afrigen* managed to reverse engineer their vaccine and plan to get vaccine approval in 2024 (Langreth and Decker, 2020; Roelf and Steenhuysen 2022; Walker 2022). The process of making a Covid vaccine would have taken only a year with the help of Moderna (Davies, 2022).

The nature of the APAs has resulted in middle and high-income countries securing most available vaccine doses, while low-income countries have struggled to gain access. By May 2021, one month before the establishment of the WHO’s mRNA vaccine technology transfer hub, less than 1% of the South African population had been fully vaccinated against Covid19 (Mendez, 2021). This share has since increased to 32%, but is still significantly lower than that in Europe (66%) and the US (67%) (Roser et al. 2022).

As predicted by the CPR dilemma, vaccine supply has been cornered by bilateral country deals at the expense of multilateral deals designed to provide more equitable access. One of the biggest contrasts with the Polio case is the fact that privatisation of knowledge under TRIPS makes it much harder to diffuse production, so that a patent waiver without the necessary support for open innovation and technology transfer would mean that the ability to diffuse vaccine production is severely limited. In June 2022 a limited patent waiver was agreed by the WTO but it is not the broad waiver proposed in October 2020 by South Africa and India covering Covid19 vaccines, tests and treatments and the agreed text has been criticised as “a watered-down waiver of one small clause of the TRIPS agreement relating to exports of vaccines. It also contains new barriers that are not in the original TRIPS agreement text.” (Oxfam, 2022)

*4.2 Compulsory licensing under TRIPS and access to HIV/AIDS drugs*

A third regulatory environment that can be considered concerns compulsory licensing (CL). CL recognises the CRP dilemma by allowing the use of a patented invention without the patent owners consent in order to improve access to essential inventions, for example, pharmaceutical drugs (e.g. Stavropoulou and Valletti, 2015). CL was introduced in 1995 as part of the TRIPS Agreement. A CL is not the same as a patent waiver as some compensation is paid to the license owner and CLs are restricted to domestic consumption. Moreover, countries seeking a waiver must demonstrate that they have tried to strike a licence deal with the patent holder but have been unsuccessful. Hence, CL takes some time to initiate.

The diffusion of HIV treatments using CLs offer a case study of technology diffusion post TRIPS for an innovation characterised by significant positive impacts on CPRs with potential network externalities. In developing countries CLs have been used with the aim of improving access to HIV/AIDS drugs (Song, 2019). Today, 38 million people globally live with HIV, and most of them (28 million) have access to antiretroviral drugs (UNAIDS, 2021). In 1999, almost as many people lived with HIV (33 million), but the majority had no access to treatment (Berman, 1999). Empirical evidence shows that CL has played a crucial role in improving access to HIV/AIDS drugs in developing countries by reducing their prices (e.g., Urias and Ramani, 2020). Using a sample of 34 low and middle-income countries between 1995 and 1999, Borrell and Wasta (2002:5) found that switching all HIV/AIDS drugs from a patent to a no patent regime would have increased access by at least 30%.[[2]](#footnote-3)

But CL is not a silver bullet. CLs have proved to be a slow way of achieving coverage and diffusing knowledge of such treatments as Antiretroviral Therapies (ART). By 2005 ART coverage for patients living with HIV had reached 50 percent in the Euro Area (a proxy for developed countries) but stood at 3.6 percent in Sub Saharan Africa (Figure 5). By the mid-1990s, around the same time as the introduction of CLs, significant advancements had already been made in combination therapies including the FDA approval of ARTs. In some instances, the medicines patent pools for promising HIV treatments such as Dolutegravir have proved effective in achieving diffusion. Dolutegravir was licensed in 2014 and by the time it was added to WHO’s list of essential medicines to be made available at low cost in 2017, “several patent pool sub-licensees had filed for approval of generic versions” (Burrone et al, 2019: 576).

**Figure 5: Incidence of HIV vs Antiretroviral Therapy Coverage (ART) in Developed and Sub-Saharan Africa (SSA) Countries (2000-2020)**

Notes: Incidence of HIV is measured per 1000 population. ART coverage is expressed as a % of people living with HIV. The Euro Area is used as a proxy for coverage in Developed countries.

Source: World Development Indicators

As discussed by Moser (2013), when using the CL, countries do not have the knowledge transfer from the scientist and skilled workers who developed and implemented the original innovation. Figure 6 illustrates the slow diffusion of such knowledge from high to low-income economies. Although breakthroughs in ART resulted in a jump in publications on the topic, it was not unit the mid-2000s that there was a growth in research on ART relating to their application in Africa. In addition, facilitating timely, equitable and affordable access to health products requires also overcoming constraints in the supply chain of inputs and the diffusion of knowledge to increase manufacturing capacity in multiple countries to harness technology and innovation for the common good.

**Figure 6: Scientific Publications on ART (1990-2021)**

Notes: Results are based on citations search of the Web of Science database for scientific publications on Antiretroviral Therapies generally and those relating specifically to Africa

Source: Web of Science Core Collection

### *3 Natural Experiment 2: Environmental technologies for CFC Gases Under the Montréal Protocol and Low/Zero Emission Vehicles under TRIPS and the Paris Agreement*

In our second natural experiment case study we compare the diffusion of two environmental advancements: the reduction and near elimination of CFC gases and the diffusion of low/zero emission vehicles to replace pure ICE vehicles.

#### 4.3.1 IPR and CFC Gases: the Montréal Protocol

The Montréal Protocol (MP) introduced in 1987 is the only Environmental Protocol ratified by all 198 UN Member states and is widely regarded as the most successful. The agreement required developed countries to cut CFC gas consumption by 50 per cent between the baseline reference year (1986) and June 1999. In the event, the 50 per cent target was met by 1991/2, around 8 years ahead of schedule – see Figure 7. The success of the MP is due to a number of factors: (i) binding deadlines to phase out the most polluting CFCs; (ii) a robust system for measuring controlled CFC consumption by country; (iii) a multilateral fund that included flexible instruments and incentives to encourage cooperative research and diffusion of replacements for controlled CFC gases; and (iv) explicit recognition of the differences between developed and developing countries (De Sombre, 2000: 49), who were given longer to adjust and financial and technical support. Initially, key players in the industry were sceptical about committing to the Protocol’s cooperative regulatory framework however, alternatives were diffused within 5 years and controlled CFC emissions in developed countries were more than halved before falling to zero as shown in Figure 7.

Under the MP over US$3.9 billion was invested in a *Multilateral Fund for the Implementation of the Montréal Protocol* established in 1991 to provide technological assistance supported by strong links between the science base and industry. The Multilateral Fund covered the cost of patents and licensing fees for new technologies and products to replace CFC gases, thus speeding diffusion (UNEP, 2016) by effectively removing IPR-based obstacles.

 **Figure 7 Consumption of Controlled Substances under the 1987 Montréal Protocol**

Source: UNEP Ozone Secretariat (2021).



A central take-away point from this case study is that while prior to regulation key players in the industry resisted regulation, for example, Du Pont (Moore 1990), the MP successfully delivered many targets within 5 years by effectively removing the brake on diffusion emanating from patent fees, and by encouraging knowledge sharing and technology transfer via Articles 9 and 10 of the Protocol. After 1995/6 most remaining CFC production was in developing countries who were given a longer time frame as well as technology and knowledge transfer support to help them eliminate CFC gases. The work of the MP is ongoing as some of the replacements for controlled CFC gases emit GHGs and regulation is evolving to find solutions that protect the Ozone layer and reduce GHG emissions. Nevertheless, the MP provides useful guidance on policies to protect CPRs.

*4.3.2 Low/Zero Emission Vehicles in the absence of a binding UN Protocol*

## *The Case of Electric Vehicles*

The diffusion of BEV and PHEV presents rather differently – see Figure 8 which shows that in 2019 only Norway had a share in excess of 5%. This is due to a number of factors including: (1) their higher cost, partly associated with scale effects; (2) their shorter driving range; (3) the required charging time; (4) the need for charging infrastructure; and (5) the failure to internalise the negative effects of internal combustion vehicles through policy interventions (Barton and Schütte, 2017: 150-151).

# **Figure 8: Market share (%) of electric vehicles (BEV and PHEV) in selected developed and China (2010-2019)**

 Source: Data adapted from IEA(2020: 250)

Figure 9 provides data on the shares of EVs for 55 countries in 2022 (January-July). The aggregate global share of all 4 types of EV (including FHEVs and MHEVs) now stands at 23 per cent, a significant improvement on the figure of 10% in 2019, but there is wide cross-country variation, from Malaysia at less than 1 per cent to Norway at over 83 per cent. Norway heads the graph because it has set the tightest timeline (2025 – just 3 years away) for the phase out of petrol and diesel ICEs. In fact, all of the nations in the top-ten in Figure 9 have set *clear and near* dates for achieving 100% sales of EVs, confirming the power of a binding deadline. However, a key difference between the MP which set an internationally agreed timeline for the phase out of controlled CFC gases and the case of electric vehicles is that there is no internationally agreed protocol. As a result, countries have progressed at very different rates even within the broad groupings of developed and developing countries. For example, it is noticeable that the US is languishing in the bottom third of the table notwithstanding the regulatory lead taken by the state of California on emissions standards. A further difference between the CFC/MP case and the EV case is that the phase out of petrol and diesel cars and the diffusion of EVs has been unsupported by a multi-billion, multilateral fund to transfer technology and pay patent licencing fees, to help bridge the gap across countries.

This leads us to the question of patents. As discussed in section 3, Tesla announced a patent pledge in 2015, while in 2019 Toyota (the leader in terms of BEV and HEV R&D over the past 30 years via a MITI-led programme) agreed to waive the licence fee on 24,000 EV-related patents. Tesla’s patent pledge is a hub and spoke arrangement (Tesla benefits from the right to use the patents of any company using its patents), while Toyota’s royalty waiver, supported by a fee-based technical assistance programme is a unilateral patent waiver. At the time of the waiver some 50 companies were paying royalty fees to Toyota (FT, 2019) which raises the question of why Toyota would give up this revenue stream. Our analysis in section 3 indicates that Toyota stands to gain in at least 2 ways. Firstly, via a reduction in battery prices as economies of scale are realised in the supply chain, reducing costs and making it easier for EVs to compete with ICE vehicles (pecuniary economies of scale). And secondly, by the expansion of charging networks as EV sales increase (network externalities). Of course, Toyota may also

**Figure 9 Market Shares of New BEV, PHEV, Full-HEV and Mild-HEV Vehicles, 2022**

Source: Data from EV Volumes

benefit in terms of corporate social responsibility by meeting its stated objective: “to further promote the widespread use of electrified vehicles.” (Toyota, 2019).

Figure 10 shows the price of lithium-ion batteries used in EVs and its relationship to market size. As can be seen, there has been a significant price fall associated with the rise in sales consistent with pecuniary economies of scale in the supply chain. At the same time there have been significant increases in the extent of EV charging networks consistent with positive gains in network externalities, though networks are still underdeveloped in all countries.

**Figure10 Representative Price and Market Size of Lithium-ion Battery Cells**

Source: Ziegler and Trancik (2021b)

To explore the effect of the Toyota patent waiver we also look at the sales of non-Toyota EVs compared to Toyota EVs before and after the waiver and test for structural breaks in each group as well as conducting difference in difference analysis. Figure 11 shows that there is a clear change in trend for non-Toyota global sales of EVs from April 2020 onwards. To test for a structural break, we ran a regression of non-Toyota sales against a time trend and the US price of gasoline and then ran a CUSUM test. The results confirmed a significant structural break in April 2020 one year after the Toyota waiver, which roughly coincides with the time taken to expand production plants in the vehicles industry. Carrying out the same test for Toyota global sales revealed no significant structural break. Figure 11 shows a very modest upward trend for Toyota sales post April 2020.

**Figure 11 Global Sales of EV vehicles (HEV, PHEV, BEV, FCEV) by Toyota and by All Manufacturers *less* Toyota sales**

Data source: EV Volumes

Prior to April 2020 Toyota and the rest of the market followed approximately parallel trends satisfying one of the necessary preliminary conditions for difference-in-difference analysis. To conduct this analysis we treat ‘global suppliers of EVs excluding Toyota’ as the Treatment Group, as they stand to benefit directly from the patent waiver, and Toyota as the Control Group. We carried out difference-in-difference (DiD) analysis for the Treatment Group and the Control Group, pre and post the April 2019 patent waiver. Because of production lags we also conducted the DiD analysis pre-and post April 2020: the main results were unchanged. We estimate the following equation:

$$S\_{idt }= α+ β\_{1} W\_{d}+ β\_{2}D\_{t}+ B\_{3}\left(W\_{d}\*D\_{t}\right)+ β\_{4}G\_{idt}+ ε\_{idt} $$

where S is global EV sales, W is a dummy variable that takes the value of 1 for the Non-Toyota Manufacturers who may potentially benefit from the waiver, D is a time dummy that takes the value of 1 post-waiver and G is the $ price of gasoline in the US as a control variable for the cost of fuel. The US price has been chosen as it is relatively unaffected by taxes.

Tables 2 and 3 present the results from our DiD analysis and regression and provide statistical evidence to support the hypothesis that the Treatment Group benefited from the patent waiver.

**Table 2 Difference in Difference Analysis: Average Sales Pre & Post Waiver**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Toyota(Control) | All Manufacturers Except Toyota | Counterfactual | DifferencePre-waiver | Difference Post-waiver |
| Pre-waiver | 132095 | 307308 | 307308 | 175212 |  |
| Post-waiver | 188466 | 781601 | 363678 |  | 593134 |
|  |  |  |  |  |  |
| Difference in Difference |  |  |  |  |   417922 |

**Table 3 Difference in Difference Estimation Dependent Variable: Monthly Sales (by Group) January 2018-July 2022**

|  |  |  |  |
| --- | --- | --- | --- |
|  | *Coefficients* | $$Adjusted R^{2}$$ | *F-Statistic* |
| *Constant* | -356483.5(-4.35)\*\*\* |  |  |
| *W* | 175212.3(2.90)\*\*\* |  |  |
| *D* | 16363.74(0.749) |  |  |
| *W\*D* | 417922.2(5.83)\*\*\* |  |  |
| *G* | 177608.6(6.99)\*\*\* |  |  |
|  |  | 0.78 | 86.8\*\*\* |
| *Number of observations* | 110 |  |  |

\*\*\* denotes significance at the 1% level. t-ratios in parenthesis.

The results should be treated as providing only indicative support for a positive waiver effect rather than clear confirmation for the following reasons. Firstly, within the Treatment Group we do not know which companies used Toyota’s patents and/or technical support as this information is not available, though we do know that 50 companies were paying Toyota patent fees pre-waiver (FT, 2019). Those companies using Toyota’s patents and expertise would receive direct benefits, while those not doing so would only benefit from indirect effects (cheaper battery prices and richer EV charging networks). Indirect effects may underlie the gentle rise in Toyota sales post April 2020. Secondly, we may not have controlled for variables that affect the treatment group, but not Toyota. Whilst many regulatory changes affect Toyota and the Treatment Group equally we have not controlled for differences in the geographic markets of Toyota and the Treatment Group, though with international trade and Toyota’s global reach this may not be a critical factor. Nevertheless, Figure 11 does show that global sales by non-Toyota manufacturers increased significantly post waiver while Toyota sales showed only a very modest increase, as expected from our analysis in section 3. Indeed, most of the growth of the non-Toyota EV market has occurred post waiver. While further research is needed there is tentative evidence to support the case for an internationally agreed waiver for EVs as set out in our discussion of category 4 in Table 1.

**5. Towards a Taxonomy: Policy Implications and the Case of CPRs**

Technological progress has long been central to improving living standards. Yet technology is increasingly becoming a source of inequality of opportunity. Our analysis highlights key issues affecting diffusion for technologies related to CPRs. Underpinning this inequality is a lack of appropriate diffusion mechanisms consistent with the complex architecture where the diffusion of knowledge-based capabilities and policy regulation are central to innovation (Orsatti et al, 2020; Horback, 2008; Porter and van der Linde, 1995). This was forcefully illustrated in how the rapid development of vaccines represented a triumph for publicly funded research but the lack of coordination to manage IP, technology transfer, financing and allocation led to excess deaths and losses in economic output (Lancet Commission, 2022). Our contribution is to set out a taxonomy that could be incorporated into decisions on the granting and waiving of patents where certain conditions relating to global CPRs and industry characteristics (e.g. network externalities) are met. In these cases, a patent waiver would be triggered to tip the balance in favour of diffusion, open innovation, technology transfer and global coordination.

To improve preparedness for future pandemics and climate change, the taxonomy highlights several ways to overcome the typical coordination problems faced by individual states. Drawing on our taxonomy (Table 1), we suggest that for Category 4 innovations that protect global CPRs with significant network externalities, there is a case for waiving patents (either voluntarily or, if necessary, via international coordination) or creating a patents commons, unless it can be demonstrated that there is no infringement on the public interest and that a certain level of diffusion can be achieved in a timely manner. In the case of category 3 innovations, where there are potentially significant positive impacts on CPRs, policy needs to focus on effectively resourcing patent waivers so that a timely diffusion of tacit knowledge is achieved. The Montréal Protocol provides a useful template for illustrating the value of timeliness and public resourcing in overcoming coordination problems. The taxonomy also considers the case of category 1 innovations, which have negative externalities for CPRs. While the patent system slows down the diffusion of these technologies, it also prevents a full assessment of their costs on CPRs.

Could more be done to quicken the rollout of vaccines and green technologies, especially in low-income countries? Our analysis highlights several obstacles related to the patent system that prevent firms, especially in low-income countries from going out and fishing in the sea of opportunities (e.g. Dosi et al, 2006). At the time of writing, no low-income economy has sought to CL the production of a COVID vaccine, illustrating our argument that for patent policy, a CL system is not sufficient for faster diffusion. Similarly, waiting on firms to voluntarily waive their patents, such as that undertaken by Toyota, implies costly delays in terms of CPRs and is illustrative of the type of biases in human decision making that policy design needs to overcome (Klenert et al, 2020). Our natural experiments contrasting the pre and post TRIPS regulatory environment suggest that CLs and voluntary patent waivers are slower and less effective in achieving diffusion.

Policy prescriptions for lowering the barriers to innovation in low-income economies in the area of CPRs tend to focus on addressing learning poverty at the grassroots level (e.g. the World Bank’s Accelerator programme) or global immunity programmes. The success of GAVI and COVAX has also highlighted a lack of progress in building capacity for more complex vaccines under the Expanded Programme on Immunization, causing developing economies to lag behind wealthier economies in the early years of license (Smith et al, 2011). For policy to improve these opportunities, investment in R&D capacity alone will not be sufficient but also requires a focus on complementary assets and infrastructure (Teece, 1986). While it has long been recognised that there is significant potential for resourcing public sector vaccine agencies in both developed and developing countries, it has generally been accepted that most vaccines of interest will be developed in advanced economies by private companies, possibly in partnership with research-based organisations and with some public funding (Hausdorff, 1996).

If developing economies are reluctant to engage in CL or lack the capabilities for vaccine production, should policy makers take a different approach to protecting CPRs? Previous efforts to diffuse and promote innovation in the development of vaccines prior to TRIPS offers an important counterfactual, in particular illustrating the importance of the relationship between speed of diffusion and efficacy of innovation. Recovery from the current pandemic will require sustained high rates of vaccination and innovation to deal with variants. Salk’s unpatented polio vaccine in the 1950s led to innovations in local vaccination practices and ability to circumvent the problem of local production bottlenecks (Blume, 2005). This seems particularly important in the current environment given the problem of shortages in vaccine production capacity (WHO, 2020), and specific supply chain issues in supplying key inputs for vaccine production such as lipid nanoparticles, which have their own specialized supply chains (Bown and Bollyky, 2021).

A second alternative could focus on improving the system of patent pools and pledges for environmental technologies by asking how the IPR system can be adapted and resourced to ensure a better success rate? Here our findings indicate that while companies in some sectors may have incentives related to economies of scale and network effects to make their patents available and provide supporting resources, there can be a significant lag between this and the uptake/diffusion of technologies. A key advantage of a *patent commons* for diffusing technologies is their ability to confer benefits on third parties regardless of contribution to the commons and the absence of formal contracts. What they lack is tracking and dedicated administrative and managerial resources designed to promote their usage (Contreas et al, 2018). To effectively diffuse green technologies, these initiatives will require investment in administrative and technical support to give similar publicity and appropriability advantages to the patent system. A second area of improvement concerns the overall design of incentives. Clugston (2021) argues that, based on the failure of royalty free eco-patent commons to garner sufficient interest, key to improving the design of these programmes is to ensure that they maximise the value of IP assets for both contributors and users. Given the scale of the climate challenge and the need to diffuse green technology rapidly, the fee structure for these programmes would need to be largely borne by developed economies in order to encourage participation from low-income countries (Clugston, 2021). The success of the Montréal Protocol provides a useful blueprint for how public subsidies might be used to achieve this.

**6. Discussion and Concluding Comments**

In the case of global CPRs, the patent system does not function very well. It is disappointing that more than a century after the patent system became the cornerstone of protection for inventors, little has been done to correct the anomalies and distortions that it has created for the diffusion of certain technologies. Global coordination issues have stalled the use of green technologies such as electric vehicles, while compulsory licensing remains underused by developing economies. Our taxonomy indicates that the patent system must be seen in the wider context of the innovation system including the industrial, regulatory and institutional environment. We need a more granular approach and one that recognises that for technologies to protect global CPRs, that also have positive network externalities, patents are counterproductive because slowing down diffusion undermines their efficacy.

We propose a taxonomy of patents that may be used to assess when the resolution of the patents paradox should fall on the side of diffusion, rather than R&D incentives. We theorise that in the case of global CPRs, where the innovation generates significant positive network externalities and is time critical or has tipping points, the interests of society are best served by prioritising diffusion. We bring empirical evidence to bear on this proposition by considering a natural experiment of two case studies of pandemics: one without patents/IPR (polio) and one with patents (Covid19). We also find that in the case of Hybrid and EV technology that diffusion has been very slow - imposing significant costs on society in the form of cumulative CO2 emissions.

A key policy message from our empirical analysis in the case of vaccines for global pandemics is that IPR should be immediately waived as soon as a Pandemic is announced and that knowledge and technology transfer should be supported by policy measures to strengthen innovation systems across the globe. In the case of green technologies, our findings indicate that diffusion could be speeded up by non-patent regulations e.g. California, Norway-type laws, or companies voluntarily waiving their patents. This highlights the strong case for a fully resourced patents commons for green technologies that is underpinned by strong regulation (e.g. as in CFC gases) and policies to transfer knowledge and technology. Ultimately this will require a strengthening of international governance and institutional cooperation at a level unseen since Bretton Woods.

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1. Data from EV Volumes (2022) [↑](#footnote-ref-2)
2. Similar conclusions can be found in Borrell (2007), who using the same sample of developing countries for 1995-2005 also found that drug prices were higher under patent regimes. [↑](#footnote-ref-3)