frontier economics

INTEROPERABILITY IN CONSUMER IOT

A Study for Huawei

16 MARCH 2022

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EXECUTIVE SUMMARY

Frontier Economics (Frontier) has been engaged by Huawei to undertake a study which considers the principles and practice of interoperability in digital markets, with a focus on consumer IoT.[1] Interoperability is not a new concept, however, the proliferation and growth of digital markets and services has put renewed focus on the development of the appropriate policies to manage interoperability.

1.1 WHY INTEROPERATE?

Interoperability describes how different systems work together in a way that creates value for suppliers and end users. Interoperability is increasingly important in digital markets where data can be shared across different services and products. Policy makers are also interested in it as a tool to promote positive outcomes for users and mitigate features of digital markets which are considered harmful to competition. Policy makers might have different objectives for requiring interoperability.

- To realise benefits of **economic externalities** whether environmental, to facilitate innovation; or to exploit network effects.
- **Public policy** can justify interoperability for example to promote user “rights” over the data that they hold.
- To overcome **coordination problems** where firms are unable to agree appropriate forms of interoperability.
- To **promote “competitive” outcomes** by mitigating market features which impair effective competition; preventing conduct which would amount to abuse of a dominant position; or by promoting “fair” competitive outcomes.

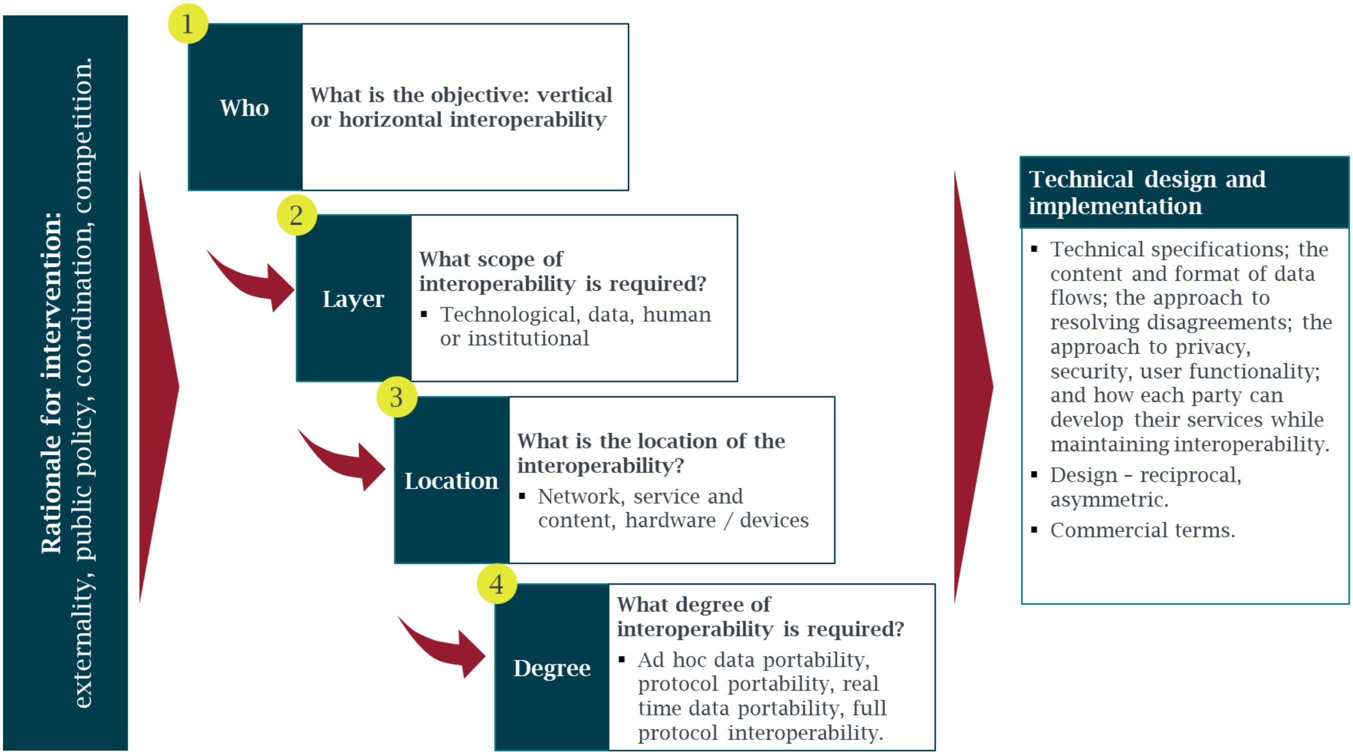
When considered as a policy tool, the precise form of interoperability will be specific to the individual context of the parties wishing to interoperate. The taxonomy developed in this report (Figure 1) describes how interoperability can be applied in a general sense, including for consumer IoT.

- The form of interoperability will depend on **who** it applies to, whether *competitors* (horizontal interoperability) or *providers of complementary devices and services* (vertical interoperability).
- Interoperability can take place at different **“layers”** which determine its scope: technological layer (to physically, or otherwise, connect different systems); data / syntactic layer (using common data formats); human / organisational layer (for aligned processes and responsibilities so data is commonly defined and understood); and the institutional / legal layer (a common and coherent legal and institutional framework to support sharing data).
- Interoperability can take place at different **locations:** on networks used to transmit data; on devices’ operating systems or hardware; or on the apps and content that we use.
- Interoperability can take place to different **degrees**. This can range from the ability to move data from one system to another on an ad hoc basis; to more real time standardised processes and protocols which mean different systems can replicate each other’s services.

[1] Frontier Economics is grateful to Dr. Inge Graef for her comments and review of earlier drafts of this report. Dr. Graef is Associate Professor of Competition Law at Tilburg University with affiliations to the Tilburg Institute for Law, Technology, and Society (TILT) and the Tilburg Law and Economics Center (TILEC).

The form of interoperability will then determine the technical approach and design such as the detailed technical specifications and format of data flows; the approach to resolving disagreements; the commercial terms or any payment flows; the approach to privacy, security, user functionality; and how each party can develop their services while maintaining interoperability.

FIGURE 1 DEFINING INTEROPERABILITY



Source: Frontier

1.2 INTEROPERABILITY IMPLIES COSTS AS WELL AS BENEFITS

Interoperability can bring substantial economic benefits not just in the sectors of the interoperating parties, but across wider parts of the economy, or it can bring wider social externalities such as environmental gains. However, it also involves costs which can differentially affect interoperating parties.

First, interoperability involves transaction costs when agreeing the specific design and form of interoperability, including on the security and privacy implications, in an ongoing way.

Second, interoperability may affect returns on investments made. Firms may seek to avoid competitors or complementary service providers using interoperability to "free ride" on their investments. For example, digital platforms have invested in mapping, navigation, email, cloud data storage and virtual assistants which are in many cases provided to their end users for free, and may risk losing the value of some of this investment to rivals they interoperate with.

Third, platforms face risk where interoperability facilitates greater competition against the platform's own complementary services.

Given that each party will face different costs and risks in relation to any interoperability agreement, aligning incentives to interoperate can be difficult. Even where it is clear to all parties that interoperating will bring benefits it is challenging to coordinate and align incentives.

1.3 INTEROPERABILITY INVOLVES TRADE-OFFS IN COMPETITION AND INNOVATION

Interoperability affects the incentives of providers to compete and innovate. A lack of interoperability means that rival firms must compete hard with each other in order to win customers and to become the market leader. This intensity of competition drives rivals to innovate. Consumers benefit as a result of this "disruptive innovation".

Different forms of interoperability will affect incentives to innovate in different ways. Where there is interoperability between different competing digital platforms ("horizontal interoperability") there is scope to grow *direct network effects* associated with the platform (since interoperability implies access to a larger number of users). However, there will be less incentive to innovate since the benefits to a platform of innovating can be partly captured by rivals that the firm interoperates with. Instead rivals will compete on price or service, and there will be slower innovation around the core platform's technologies and standards ("sustaining innovation").

Interoperability between a digital platform and suppliers of *complementary* services ("vertical interoperability") allows parties to benefit from *indirect network effects* as the value of the platform to users increases, as more services interoperate with it (and vice versa). However, vertical interoperability can decrease the differentiation between different digital platforms (because the same complementary services are available on each platform), which will soften the intensity of competition between the platforms, reducing incentives to innovate.

1.4 HOW IS INTEROPERABILITY ACHIEVED?

It is common for firms to **commercially agree,** bilaterally or multilaterally, to interoperate with each other. In the case of consumer IoT, firms will set out Software Development Kits (SDKs) or Application Programming Interface (APIs) to facilitate interoperability and a testing and certification process will mitigate security and user functionality issues.

However, as noted, even where parties agree that interoperability would be profitable and efficient, it can be difficult to coordinate and align incentives to agree the *form* of interoperability. Pooling Intellectual Property (IP) can help firms align their incentives around a standard, since this provides some commitment that the form of interoperability would not disproportionately benefit one party.

In some digital platform markets the process of coordinating interoperability is made easier in the sense that one party (the platform) largely sets the terms for interoperating between the platform and service providers and device manufacturers. Such an approach mitigates some of the costs and complexity in coordinating, though outcomes can be affected by an asymmetry in the bargaining position of the different parties.

In some cases interoperability can only be achieved with the intervention of government or **Standard Setting Organisations** (SSO). However, the process for agreeing standards is long and protracted and this can lock-in standards at a point in time.

Finally, **interoperability can be imposed** on an ex-ante basis to promote positive welfare impacts or to enable social externalities. For example, it has also been imposed to improve the competitive dynamics of a market (the Open Banking remedy in the UK, the EU Electronic Communication Code, and the draft Digital Markets Act, all impose forms of interoperability to promote welfare outcomes). It can also be required as a behavioural remedy in abuse of dominance cases or as a condition for approval of mergers. For example, during Google's acquisition of Fitbit conditions were imposed so interoperability of Fitbit's rivals with

Google's smartphones and operating system were maintained and that access to Fitbit's Web API remained open.

1.5 HISTORICAL CASE STUDIES DEMONSTRATE BENEFITS AND COSTS OF INTEROPERABILITY

This report considered three case studies to put the topic of interoperability into its historical and economic context.

- The early development of the telephone standard in the US where differing suppliers competed without interoperating with each other.
- The development of shipping containers to make the process of moving goods from land transport to ships more efficient.
- The development of the USB standard which enabled communication and power supply between personal computers and their peripheral devices.

The three case studies illustrate how interoperability brought not just significant efficiency gains, but led to positive externalities of greater competition and innovation in wider markets or environmental benefits. However, they also illustrate how interoperability may not emerge spontaneously given the disparate interests and incentives of different parties. In the case of containers, despite a seemingly simple product around which to interoperate (the size and features of a stackable box), it took over a decade to agree standards in the US, then many more years to agree standards internationally. In early US telephony, it is unlikely that AT&T would have been able to impose its standard on the industry without a supportive regulatory and societal environment which allowed it to become a regulated monopoly. By contrast the USB standard was an example of an industry led approach to interoperability.

The case studies show how sharing Intellectual Property helped parties coordinate around a standard. Containerisation only developed after the pioneer of the container opened up his patent on his own container technology. The USB standard was made possible following the creation of a shared 'patent-pool' for the common standard.

The case studies can also illustrate the trade-offs which can hinder innovation. For example, the adoption of AT&T's standard in the US brought benefits to users who could reach more telephone users but the lack of competition hindered innovation. However, the USB standards case study showed how design improvements and innovation to a common standard can be driven.

1.6 THE CURRENT STATE OF INTEROPERABILITY IN CONSUMER IOT

IoT is a transformative technology that will bring new services, devices and applications to be used across all aspects of daily life. Data collected and processed from a plethora of devices has the potential to unlock welfare and efficiency benefits throughout society: enabling firms to reach consumers, lowering barriers to entry, supporting the development of new and innovative products, and bringing benefits of choice and competition to consumers. It is thus heralded as the next transformative technology which will shape industry and society.

Digital platforms play an important role in avoiding a fragmented user experience by interoperating with devices and apps from many different suppliers. Digital platforms interoperate with tens of thousands of different services. In doing so they overcome coordination problems by effectively setting the terms of interoperability, though terms agreed may be affected by a bargaining asymmetry between the parties.

There are a number of industry led initiatives which support and promote interoperability across different forms of consumer IoT. For example in relation to voice assistants the Voice Interoperability Initiative (VII) (led by Amazon) promotes the ability of consumers to choose from multiple voice assistants on their devices. In relation to smart home devices, “Matter” is a new smart home connectivity standard developed by the Connectivity Standards Alliance which aims to develop and support a common connectivity protocol for smart home devices; and in relation to automotive consumer IoT the Connected Vehicle Systems Alliance (COVESA), the Car Connectivity Consortium (CCC), and the Open Automotive Alliance (OAA) all promote interoperability in different ways.

1.7 SUMMARY CONCLUSIONS

It is important to recognise that interoperability can bring benefits as well as costs, and also creates a trade-off in the forms of innovation. Furthermore, it is not a one size fits all policy instrument. Mandated interoperability is often context specific, and introduced to address a specific policy, environmental or competition concern weighing up the different costs and benefits. Nevertheless, some common messages emerge from our review for policy makers which can guide decisions on how to apply interoperability.

1. **Policy makers should be clear on the rationale for intervention as this will drive the form of interoperability.** While in many cases there is no need to impose interoperability, since firms will have strong incentives to agree terms, sometimes policy makers need to intervene to support public or social objectives; to mitigate competition problems; or to overcome coordination problems. Policy makers should carefully consider the rationale for intervention, as this will directly relate to the precise form of intervention that is proposed or adopted. However, mandated interoperability will not necessarily change any existing bargaining asymmetry between parties.
2. **Policy makers should assess the costs and trade-offs involved in different forms of interoperability**. Whatever form is adopted, it will incur costs to implement, monitor and support privacy and security. Interoperability also involves trade-offs since it can soften incentives for different systems to compete and innovate. However, these trade-offs will be context specific and depend on the precise nature and maturity of competition.
3. **Policy makers should support the process of defining the precise location, layer and degree of interoperability required.** To the extent that interoperability is imposed it should be focused on a specific context and specific objective. Blanket ex-ante requirements for unspecified form of interoperability will not identify the optimal trade-off and hence the appropriate form of interoperability. Hence where policy makers wish to impose interoperability they should be ready to participate in the process of agreeing the detailed form (who, location, layer, degree) as well as the technical design of interoperability.

2 INTRODUCTION

Technological advances in digital markets have brought many benefits to consumers and have revolutionised production and supply processes over the last two decades. The consumer Internet of Things is the latest wave of this technological change. It promises to connect many different devices to communications networks, and crucially with each other. Consumers will benefit as new services and products are created by leveraging the data generated across different devices. Digital platforms are integral to many parts of the consumer IoT sector: they create focal point around which the interests of consumers, device manufactures and service providers can coalesce.

Interoperability lies at the heart of these commercial relationships. Consumers benefit from being able to access digital products and services that interoperate with the platforms they use. Likewise, the suppliers of digital products and services benefit from accessing a platform's consumer base, benefiting from the investments made by the platform in its service, and from interacting with each other to share data and create valuable products.

However, digital markets raise a number of issues which can affect outcomes for users. Where products or services are subject to network effects, the process of competition can be impeded. Some digital platforms are able to enjoy the benefits of network effects that their investments enable, but in a way that can make it more difficult for new entrants to challenge incumbents. Digital markets exhibit strong economies of scale and scope which can in some circumstances be hard to replate. Digital markets also trade on data, which in turn raises issues around protection of privacy and security for users.

It is in this context that policy makers around the world are increasingly interested in interoperability as a commercial practice and a policy tool. The importance of interoperability to commercial interactions between different digital providers is rising. It has also been suggested as a remedy to increase competitive pressure on large digital platforms by making them interoperate with rivals, and enable consumers to easily switch between rival providers.

Frontier Economics (Frontier) has been engaged by Huawei to undertake a study which reviews the current theoretical thinking around the topic of interoperability. This section briefly summarises why firms interoperate, and the different motivations that policy makers may have to impose interoperability as a policy tool. Section 3 considers how interoperability is defined. Section 4 describes the different trade-offs involved in interoperability. Section 5 considers how interoperability comes about and how it is applied as a policy tool. Section 6 examines historical case studies where interoperability has played a key role in bringing efficiency and welfare benefits: the shipping container, the development of the phone system, and the USB hardware interface standard. Section 7 considers the current state of play in three consumer IoT technologies: voice assistants, smart home, and automotive IoT. Finally, Section 8 provides some recommendations for policy makers in relation to applying interoperability.

2.1 WHY INTEROPERATE?

Interoperability is a common feature of many different supply and production processes. It defines the terms of commercial engagement between different systems to enable them to work together to supply a service or good to users (more formal definitions follow in the subsequent section). It enables different suppliers to realise economic complementarities where, by working together, different systems are able to create value in the production and supply of goods or services for end users.

Interoperability is not a new topic. Its role in enabling different systems to work together has been much studied and applies in many "old-world" markets. Section 0 of this report considers historical case studies which demonstrate how interoperability applies across three physical products: shipping containers, the early development of the telephone and the USB computer hardware interface. In all cases, the production process meant that the service provided to end users relied on many different parties supplying services independently: shipping goods internationally required land transport, shipping transport and port services; making long distant phone calls required the use of different telephone networks; and attaching computing peripheral devices to computers required that devices were compatible. It was by interoperating that the individual suppliers could effectively and efficiently coordinate their activities to unlock value for consumers: by offering more efficient and lower cost shipping; or a higher value telephone service with a wider range of potential call recipients; or a greater range of computing peripherals which were compatible with their computer hardware. Interoperating was, in these cases, vastly more efficient than bilaterally contracting on a case by case basis between pairs of suppliers, or by fully integrating their production and supply processes. It provided a standardised way that firms could interact with each other.

However, the value of interoperating goes much further than the direct parties supplying the service and the consumer. In this way interoperating can release "externality benefits". In some cases these externality benefits can dwarf the direct private benefit to the suppliers and consumers of consumer goods that rely on interoperability. In our case studies shipping containers not only lowered costs of shipping but they revolutionised world trade and production and supply processes across all industries, which in turn led to productivity improvements in the world's economies; telephone systems supported competition by enabling businesses to more effectively communicate with users, and brought social benefits enabling communication between disparate communities; the USB standard ushered in a wave of innovation and competition in peripheral devices, but also brought environmental benefits as there was less waste of electronic devices.

These benefits were enabled by interoperability. By agreeing the precise process and terms by which different products could work together, different suppliers were free to invest and innovate. Parties who interoperate need not even directly contract with each other, let alone formally integrate (merge) their production and supply processes to realise the complementarities when two goods or services are supplied together.

Interoperability arguably plays an even more important role in digital markets than in many physical markets. This is because a defining feature of digital services is their ability to gather and process data, that can be valued and used in other services. And the pace of change is likely to increase. Advances in technology will increase the use and diffusion of digital services, and then as a consequence, elevate the role that interoperability has in shaping commercial and competitive outcomes. Section 7 explores how interoperability is currently applied in consumer IoT markets.

2.2 WHEN TO INTERVENE TO PROMOTE INTEROPERABILITY?

As digital markets mature, policy makers are looking for tools to promote the welfare enhancing effects of competition, and some argue that interoperability can be used as a policy tool to promote welfare. However, interoperability can be costly to implement, and there is no standard approach that can apply across all situations. There can be a number of different motivations for policy makers, regulators or competition authorities who wish to promote interoperability as a policy tool.

In most markets, parties will have incentives to interoperate where it creates value for them. However, there can be circumstances where interoperability is not present and where it could lead to welfare benefits; or that the existing form of interoperability is in some way sub-optimal relative to a policy maker's objectives. In these cases, policy makers can choose to intervene to achieve a desired level of interoperability.

The rationale for intervention will reflect different goals (sometimes in combination), such as:

- to realise benefits of economic externalities associated with interoperability;
- public policy reasons;
- to support coordination of interoperability; or
- to promote "competitive" outcomes in markets.

2.2.1 REALISING ECONOMIC EXTERNALITY BENEFITS

Interoperability can bring value not just to the parties interoperating and their direct customers, but potentially much wider benefits. These are termed "externalities" in that they are "external" to the interoperating parties supplying a good or service, and their customers. Typically, given that the parties supplying the service will not consider the economic value of these externalities, they will be under-supplied compared to the socially optimal level. This is therefore a classic market failure rationale for policy intervention: governments intervene to promote the socially optimal level of investment.

There are many examples of externalities that can result from interoperating:

- The USB standard created **environmental benefits** as a result of agreeing common standards for interoperability between hardware devices.
- Using interoperable systems to share healthcare data for research can bring widely felt **research and development benefits,** by facilitating innovation in medicine.
- Interoperability can generate **network externalities.** Direct network effects occur where the value of the good increases as more users consume it, for example with communications services or electronic payment services. Indirect network effects can occur where a platform or service depends on two or more user groups, such as producers and consumers, buyers and sellers, or users and developers. As more people from one group join the platform, the value of the platform to the other group increases.

Policy makers can therefore intervene to promote interoperability as a tool to enable the externalities that would otherwise not be realised. Inevitably, any intervention should carefully consider the costs of interoperability together with the benefits.

2.2.2 PUBLIC POLICY REASONS

There may be public policy rationales for intervening to promote interoperability which are not related to an economic rationale. Policy makers may wish to support a number of objectives which might relate to interoperability: control over data, regulation of content or privacy considerations. Part of the rationale for promoting forms of interoperability in GDPR was to promote the rights of users over their data.

2.2.3 SOLVING COORDINATION PROBLEMS

Interoperability is promoted as a policy tool to solve the coordination problem. This can occur where parties have unilateral incentives to interoperate, though have heterogeneous preferences. Individual firms' preferences will vary depending on their overall business strategy, sunk investments, relative size of their customer base, and the benefits that they derive from interoperating (for example, by exploiting data gathered when interoperating). These differences can make it difficult to coordinate around a standard for interoperating. In some cases, there may therefore be a need for some form of government intervention to support interoperability.

This was clearly illustrated in the development of the shipping container standard (which is explored in Section 6.3). In this case, while different operators understood the value of agreeing a common standard for different logistic systems to interoperate, each operator had strong incentives to design the standard to reflect.

Standard Setting Organisations (SSOs) or direct government intervention can provide a focal point around which different parties can agree to interoperate. SSOs set a common specification for the precise form of interoperability and providers can then design products and services that are compatible with the standard.

2.2.4 MITIGATING COMPETITION PROBLEMS

A third rationale for intervening to promote interoperability is to remedy competition problems observed in the market. It is helpful to distinguish between competition problems that stem from the features of the market, and competition problems associated with conduct of market participants that have market power.

Market features can impede the process of competition in many ways which mean that consumers do not benefit from competition, even where suppliers do not have significant market power. High switching costs or customer inertia can limit competition (since the gains from investing in innovation may be lower). Single-homing may reduce the scope for firms to compete compared with multihoming markets since competitors would have to convince single-homing consumers to abandon their existing supplier. There are certain features of digital markets which can impact competition: economies of scale and scope and networks effects (described above).

In such markets the competitive process can be impaired and policy makers may therefore impose ex-ante requirements to mitigate barriers to competition, or otherwise improve consumer welfare outcomes (Section 5 discusses instances of interoperability used as a policy tool). For example, a form of horizontal interoperability is imposed on mobile markets to mitigate some of the barriers to switching and enable consumers to port their mobile numbers.

In digital markets, suppliers can sometimes attain a strong bargaining position with regard to other suppliers with whom they interoperate. This can affect the process of achieving interoperability. However, while a requirement for a party to offer interoperability can affect market outcomes, it may not necessarily be sufficient on its own to mitigate any existing bargaining asymmetry.

A related but distinct form of policy intervention is the imposition of interoperability requirements (or 'remedies') as a result of an **abuse of a dominant position.** A dominant firm is held to have a special responsibility not to allow its conduct to impair genuine and undistorted competition. Competition authorities may investigate the behaviour of dominant firms, and where they find that an abuse has taken place they may impose behavioural remedies including a requirement to interoperate. Competition authorities and courts may have a preference for structural remedies over behavioural remedies, (such as requirements to interoperate) since a behavioural remedy implies that the competition authority or court may have to specify the design of the remedy and act as a day-to-day enforcer of the detailed obligations in a way that is akin to a regulatory agency. Nonetheless, there are examples where courts have imposed interoperability obligations in abuse of dominance proceedings, or as a merger decision (discussed in Section 5).

Finally, a further and distinct motivation in relation to competition concerns might be to **promote "fair" outcomes**[2]**.** One of the key motivating objectives of the Digital Markets Act is to increase fairness (alongside a co-objective of improving contestability). Fair competition outcomes do not necessarily have as a goal the overall *level* of welfare, rather it relates to the distribution of welfare between different parties[3]. Furthermore, some argue that it is not a necessary condition that a party has a dominant position: firms may impose "unfair" terms even where they do not hold a dominant position, if they are nonetheless able to exercise a degree of bargaining power. It is therefore argued that interoperability can increase fairness in digital platform markets as it means that smaller providers are able to earn a "fairer" (i.e. larger) share of the rents that would otherwise accrue to the digital platform.

However, there can be potential limitations to applying fairness as a motivating rationale for intervention. Fairness (in the context of competition policy relating to the share of welfare) can be difficult to articulate or measure objectively.

2.3 CONCLUSION

There are many different reasons why policy makers may want to intervene in a market to promote interoperability (whether, for example, they are requiring it where it would otherwise not be present, or by specifying a particular form of interoperability). However, as we explore in this report, any form of interoperability will involve costs (implementation costs, or costs to dynamic efficiency and innovation). Therefore, it is incumbent on policy makers to clearly define their objectives, and estimate the scale of the benefits that interoperability will bring. Different objectives will clearly lead to different forms of interoperability which are explored in the following section.

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[2] Fairness as a concept is also relevant in the context of consumer protection law such as the Unfair Terms Directive and the Unfair Commercial Practices Directive.

[3] For example, (Morton, et al., 2021) suggest that "*A current source of discontent with digital platforms stems from the perception both by consumers and small businesses that* ***the rents from digital technology are unfairly accruing to a handful of large platforms, rather than being distributed more equitably according to each party's contribution to surplus****. When a platform enjoys network effects, an individual user or complementary business makes very little marginal contribution to the creation of surplus. Thus, when an individual user or business bargains for a share of surplus, its leverage is low, and the platform's is high. The resulting bargain leaves the platform with the vast majority of the surplus. … Interoperability increases fairness in this setting because it allows entrants to share the same network effects the dominant firm enjoys."* See p.4

3 WHAT IS MEANT BY INTEROPERABILITY?

3.1 DEFINING INTEROPERABILITY

There is no single definition of interoperability. This is partly as its application is context and perspective specific. It can therefore encompass many different types of transaction or relationship. At its most fundamental level interoperability describes the **ability of a product, service or system to communicate and interact with other products, services or systems**. It is a tool that can be used to achieve other goals and outcomes.

Interoperability has been defined within legal texts and by policy makers. The 2009 Software Copyright Directive (Directive 2009/24/EC, 2009) defines interoperability as:

> *"the ability to exchange information and mutually to use the information which has been exchanged."*

In one report for the European Commission (Crémer, et al., 2019), it was defined as follows:

> *"interoperability: Ensures that two systems can fully work together and that complementary services can be provided."*

The European Parliament's proposed amendments (European Parliament, 2021) to the European Commission's draft Digital Markets Act (DMA) define it as:

> *"'Interoperability' means the ability to exchange information and mutually use the information which has been exchanged so that all elements of hardware or software relevant for a given service and used by its provider effectively work with hardware or software relevant for a given services provided by third party providers different from the elements through which the information concerned is originally provided. This shall include the ability to access such information without having to use an application software or other technologies for conversion."*

Finally, Palfrey and Gasser in their seminal book on interoperability (Palfrey & Gasser, 2012) define it as:

> *"the ability to transfer and render useful data and other information across systems, applications or components."*

Interoperability has been defined by a number of other organisations, including the joint technical committee of the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC)[4], and the Institute of Electrical and Electronics Engineers[5] (Hoffmann & Otero, 2020). Whilst the precise definitions differ, they all encompass the same key concepts.

Interoperability can be distinguished from compatibility. Compatibility is a specific, narrow form of interoperability that represents design choices in the development of a system (Palfrey & Gasser, 2012). It means products work with each other, but do not share data in a way that creates value. Compatibility is one of the overall elements of interoperability. Compatibility between products, often through agreed

[4] The joint technical committee of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) define interoperability as 'the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units.'

[5] Interoperability is defined by the Institute of Electrical and Electronics Engineers (IEEE) as 'the ability of two or more systems or components to exchange information and to use the information that has been exchanged'.

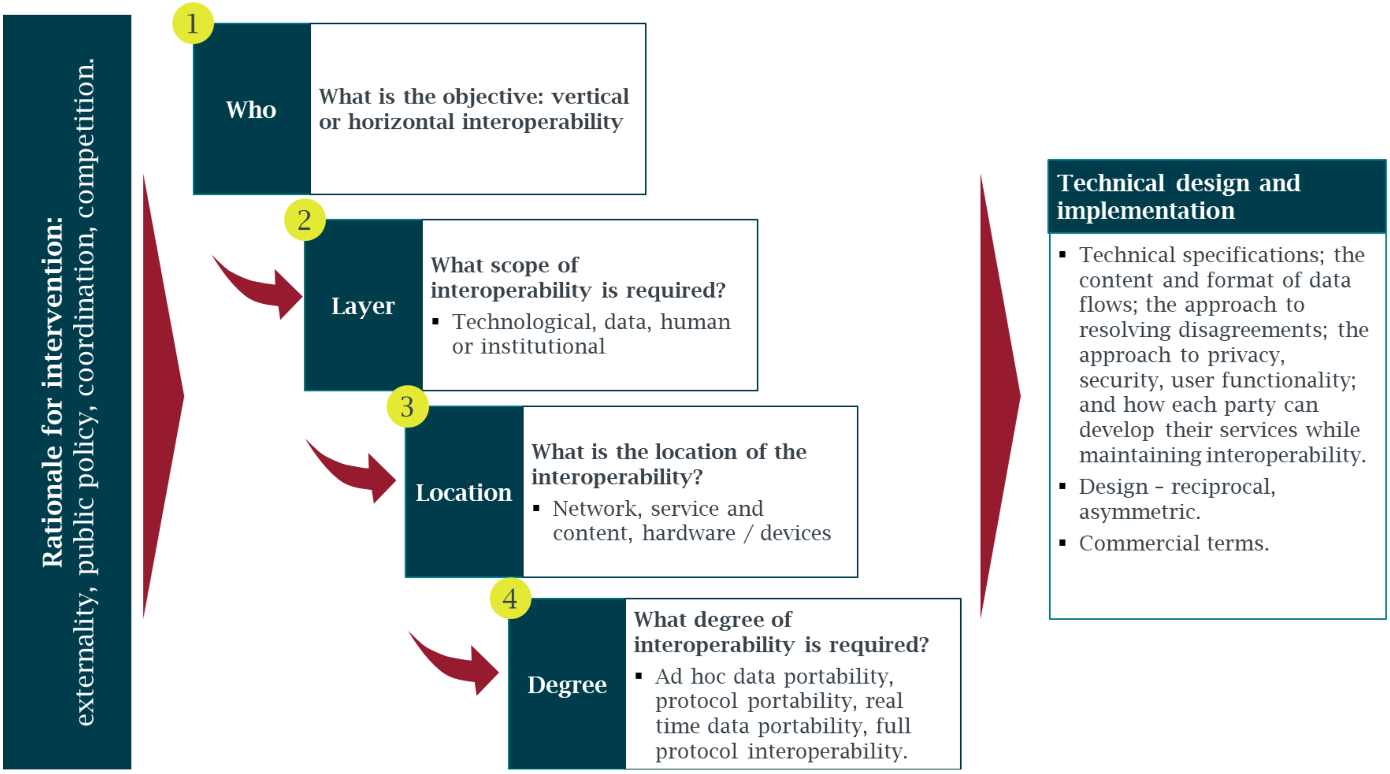
standards, promotes product interoperability. For example, compatibility is often based around technical specifications on hardware or software so that devices work together.

While interoperability is a potential policy tool in a number of different contexts (as explored in Section 5), it is not a "one size fits all" solution. Different forms of interoperability will be used in different contexts. Therefore, having identified the rationale for intervention, it is necessary to define the precise form of interoperability. This can be considered across different dimensions (Figure 2).

- **Who** should interoperate. The relationship between the interoperating parties will be an important defining feature of the interoperating relationship: horizontal interoperability facilitates interaction between competitors; vertical interoperability facilitates interactions between suppliers of *complementary* products which do not compete.[6]
- Different **layers** define the scope of the interoperability relationship, from most narrow (technical interoperability allowing different technologies or systems to interoperate) to the most broad institutional or legal (where different societal institutions are designed to interoperate).
- Interoperability will occur at different **locations**. In the context of consumer IoT this implies that interoperability can be between: network, device hardware, device software, content discovery layer.
- The **degree** of interoperability will determine how deep the interoperability relationship will be. For example, in the context of consumer IoT this relates to the degree to which different systems share and act on data from each other.

[6] Some consumer digital markets can be characterised by digital platforms offering a portfolio of complementary products, adopting a conglomerate strategy, while also offering forms of (vertical) interoperability to third parties. This can mean it can be unclear whether services of a digital platform are substitutes or complements, for example Spotify is a substitute for Apple Music but a complement for Apple's Siri. Nonetheless it is very helpful to distinguish between the different relations given that they imply different incentives to offer interoperability since horizontal interoperability relates to direct competitors whereas vertical interoperability relates to complements that bring value to different parties.

FIGURE 2 DEFINING INTEROPERABILITY



Source: Frontier

3.2 WHICH PARTIES SHOULD INTEROPERATE?

There is an important distinction between forms of interoperability which relate to i) the vertical and ii) horizontal relations between different suppliers.

3.2.1 HORIZONTAL INTEROPERABILITY

Horizontal interoperability describes the interoperability between *competing* or *substitute* products, services or platforms. For example, interoperability between competing communication networks which allows for mobile communications to be made across different networks.

Horizontal interoperability can be welfare enhancing in markets with network effects. Direct network effects exist in a market when consumer benefits grow as the number of users of a service or in a market increase and are common in some digital markets. Indirect network effects are also common in digital markets, where in two sided markets the increase in the number of complements on the platform, such as games and applications, increases the benefit for the consumers joining the market as well. Markets with network effects are prone to concentration because consumers benefit from being on the same network as other users (Stigler Committee on Digital Platforms, 2019).

Horizontal interoperability can have a number of impacts in relation to network effects. Interoperability shares network effects between large and small suppliers. This could lower switching costs and make markets more competitive by lowering barriers to entry or expansion (since it mitigates the advantages to larger suppliers who benefit from network effects). In addition to interoperability, multi-homing, where consumers use more than one substitute service, lessens network effects because a consumer can enjoy the size of both networks, rather than having to choose one.

Different firms will have different incentives to horizontally interoperate with other firms in the market. Some firms, usually smaller firms, have incentives to increase interoperability as they will then be able to access data, information or even the customers of larger firms and benefit from the larger firm's network effects (however, sometimes smaller firms have *opposed* horizontal interoperability – for example during the development of the telephone standards (Section 6.2) smaller rivals to AT&T resisted horizontal interoperability with AT&T as they wished to differentiate their service from AT&T's). Larger firms may not want to offer horizontal interoperability as they may be concerned that they lose their current advantage.

HORIZONTAL INTEROPERABILITY IN SOCIAL NETWORKS

Social media platforms sometimes interoperate with each other to allow their users to interact with the services of other platforms. This improves customer experience and access to content, often by providing the ability to "cross post". This is achieved by the use of specific APIs (cross post or social graph APIs) which enable interoperability of posts. "Cross post" interoperability is not full horizontal interoperability between social media platforms, which might include the interoperability of social connections, contacts and data too.

The UK's CMA created a term for a specific type of horizontal interoperability across social media platforms called content interoperability. This specific form of horizontal interoperability would allow consumers to post, view and engage with content across platforms without having to switch service, but they would still need to be registered on each service (CMA, 2020)[7]. For instance, a consumer could post messages that could be viewed by their contacts on different social media platforms. Some respondents to the CMA's review opposed the idea of mandating content interoperability, with several stating that it would reduce incentives to invest and innovate, could lead to privacy concerns and lead to excessive standardisation, highlighting some of the possible risks from increased interoperability. This form of interoperability would be effective at sharing network effects with smaller players, and mitigating the competitive advantage which result from the network effects of larger players. In the end the CMA felt the risks outweighed the benefits and did not suggest this as a possible intervention in the market.

3.2.2 VERTICAL INTEROPERABILITY

Vertical interoperability refers to the connection and flow of information between products, services or platforms which are *complementary* to each other (companies with an ecosystem of products and devices will ensure their own internal products, by design, work with each other). Often vertical interoperability is seen in digital markets and their complex ecosystems. Digital platforms provide services to end users and simultaneously provide services to third parties, who in turn also supply services to the users of the platform. In this way digital platforms act as both complements to the third party's service, and in some cases competing substitutes for third-party services.

Vertical interoperability can exploit *indirect network effects* on digital platforms. It enables service providers to access the platform's customers, and allows consumers to access service providers. Where

[7] See p.372

more services join a given platform, the value to consumers of being on that platform will increase. This can in turn increase the value to services of joining the platform. In this way, the platform, consumers and service providers can all benefit from increased indirect network effects.

However, there can be a mix of (sometimes conflicting) incentives to vertically interoperate between digital platforms and third-party services.

From the perspective of the third-party service provider, vertically interoperating with a platform could increase demand for the third party's product as the platform's users find it easier to use and access it. This is the case whether or not the platform offers a competing service. The platform benefits by vertically interoperating with third-party service providers as they bring value to the platform (the addition of more third party services increases the value of the platform to end users). In this way there are indirect network effects: the platform is able to benefit from value generated by increasing the number of third party services on its platform.

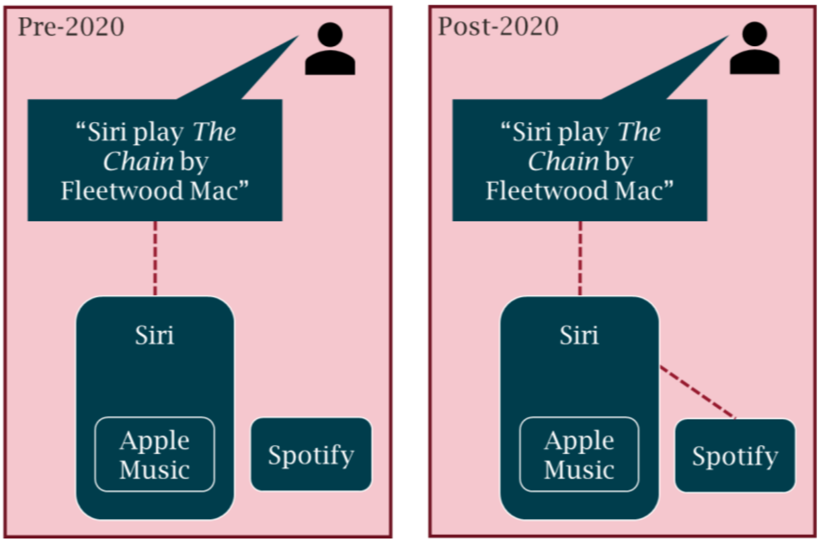
However, if the platform has a competing product the incentives can change. The platform will weigh up the value to it of interoperating with a third-party service, against the loss that it would face by facilitating competition between the third-party service and the platform's own service. This trade-off is likely to be complex. First, the indirect network effects to the platform of adding new third-party services will accrue across the platform's ecosystem (including to its competitors). Second, platforms gain potentially valuable information on the use of the third-party services by the platform's customers. Third, platforms may not face a binary choice of whether to offer interoperability to competing services or not. Instead they may design interoperability in a way that limits the functionality of the third-party services such that it is "optimal" for the platform.

An example of this trade-off is Apple's decision to allow its voice assistant Siri to interoperate with Spotify, a rival music streaming service that competes with its Apple Music service. Between 2015 and 2020, Apple's voice assistant Siri would only enable music related requests to use Apple's proprietary applications such as Apple Music.[8] Therefore, Apple's voice assistant was not vertically interoperable with Spotify. It was only in April 2020 that Apple opened Siri up so that Siri would support third-party music services with the release of iOS 13. It was then interoperable with Spotify.[9] There could be many reasons for the lack of interoperability prior to 2020, but one could be that Apple did not want its customers to have easy access to a rival music streaming service. Siri now allows requests to be played from Spotify. This change could have been made due to the growth of Spotify, meaning that allowing Siri to access it could actually benefit Apple's smart speaker and smart device sales. It could also be affected by competition from alternative voice assistant platforms which did offer interoperability with Spotify before Siri did.

[8] iDROPNEWS, *Spotify Says Apple Still Has a Long Way to Go Before It's a 'Fair Platform',* Accessed Feb 22 - https://www.idropnews.com/news/spotify-says-apple-still-has-a-long-way-to-go-before-its-an-open-and-fair-platform/135260/

[9] Digital Trends, *The Spotify-Siri integration that Apple users have been asking for is here,* Accessed Feb 22 - https://www.digitaltrends.com/home-theater/spotify-siri-integration-ios13-airpods-homepod/

FIGURE 3 ILLUSTRATION OF THE INTEROPERABILITY CHANGES BETWEEN SPOTIFY AND APPLE'S SIRI



Source: Frontier Economics

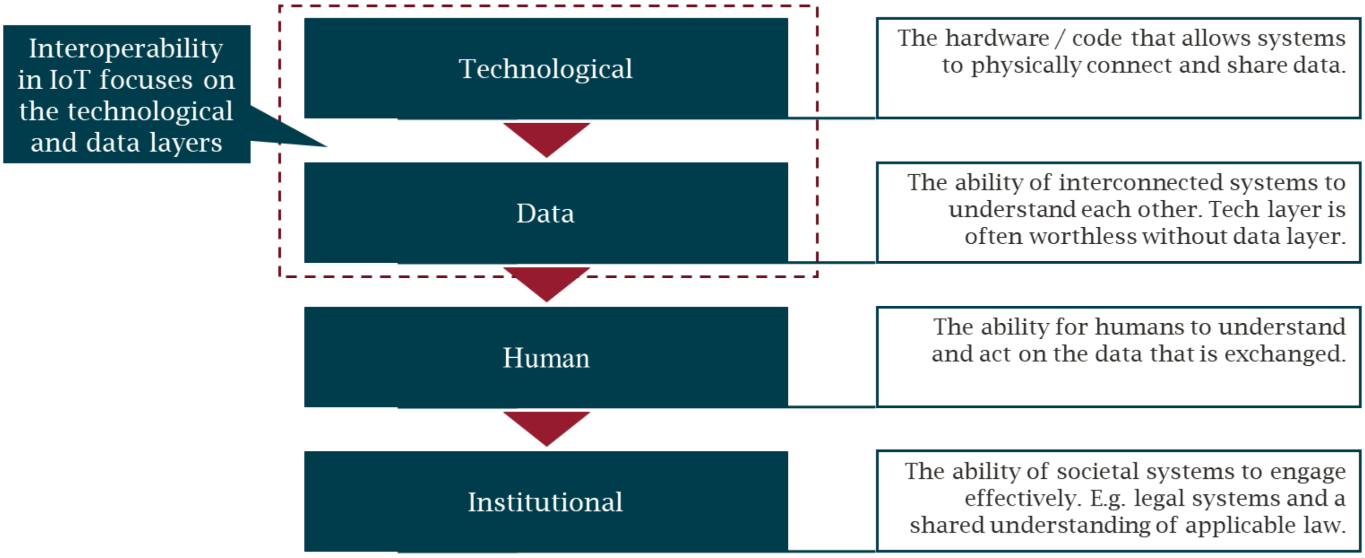
Matutes and Regibeau (1988) modelled and studied compatibility and interoperability decisions by firms. Their paper showed that increased vertical interoperability or vertical product compatibility can be beneficial to consumers as it increases consumer choice as they can flexibly mix and match the items used in their system. But increased vertical interoperability or vertical product compatibility can also lead to higher prices or less price competition. This happens because when products in a system are compatible or interoperable, one firm cutting the price of one good will increase the sales of all systems and products that can also interoperate with that component, including those made by other firms. Since some of the benefit of the price drop will be captured by other firms, each firm will have fewer incentives to compete aggressively on price, potentially leading to higher prices than in the case of less interoperability. The trade-offs and incentives around vertical interoperability will be further discussed in Section 4.

3.3 THE SCOPE OF INTEROPERABILITY CAN BE DEFINED BY DIFFERENT "LAYERS"

In considering how two distinct systems can interoperate it is first necessary to consider the rationale for intervention. This will determine the scope of the relationship between the parties: what elements of the firms' systems should be subject to joint and agreed terms to facilitate interoperating. This can be defined from the most narrow (technical interoperating to enable different systems to connect to each other), to the broadest scope (where different systems jointly create integrated decision making structures to integrate systems on an on-going and dynamic basis). It is therefore possible to define various layers between these extremes that broadly define the deepness of an interoperability relationship.

Palfrey and Gasser describe a generally applicable model of interoperability across four layers. These layers can identify and describe, in a given context, *what* is interoperable given the objectives of the parties.

FIGURE 4 LAYERS OF INTEROPERABILITY



Source: (Palfrey & Gasser, 2012)

Without interoperability at the technology and data layers, the deeper interoperability enabled at the higher layers in the model – the human and institutional layers – is often impossible. For example, in the shipping container case study described in Section 0, the standardised container was designed at the technological level to enable different transport networks to interoperate using a common container technical specification. However, over time higher layers of interoperability have been developed. Data on each container's contents and onward journey can be shared between shipping companies and ports which enables ports to optimise loading, unloading and storage of the many thousands of containers processed each day. Furthermore, there have been calls for further institutional interoperability to make the process of processing containers at ports more efficient and effective by aligning common customs documents and procedures.

Interoperability has been studied from different perspectives and the layers can be classified in different ways, depending on the precise focus of the interoperability relationship: whether sharing of data for conceptual modelling[10], organisational structures to support data flows[11], Industrial IoT[12], or frameworks to enable smart applications to dynamically interoperate in changing environments[13]. Some of these frameworks are set out for comparison in Table 11. All these frameworks share common structure and themes. The initial three levels are broadly common across different frameworks. Whereas at higher levels, the approach tends to vary according to the author's aims. In most cases the layers determine the conceptual approach to interoperability, but in the case Hazra et al (2021) the levels 4-6 partly describe the *technical* approach and *location* used to enable a specific form of interoperability.

10 Tolk & Muguira, 2003.

11 Such as the European Interoperability Framework (EIF), Accessed Feb 22 - https://ec.europa.eu/isa2/eif_en

12 Hazra, et al., 2021.

13 Pantsar-Syväniemi, et al., 2012.

TABLE 1 LAYERS OF INTEROPERABILITY

PURPOSE OF INTER-OPERABILITY	GENERAL APPLICATION	TECHNICAL STANDARDS FOR TELECOMS	USE OF DATA IN CONCEPTUAL MODELLING	INSTITUTION INTEROPERABILITY TO SUPPORT DATA FLOWS BETWEEN PUBLIC BODIES	THE APPROACH TO SUPPORTING INDUSTRIAL IOT APPLICATIONS
Source	Palfrey & Gasser, 2012	van der Veer & Wiles, 2008	Tolk & Muguira, 2003	European Interoperability Framework	Hazra, et al., 2021
Layer 1	**Technological** – compatibility of hardware / code that allows systems to physically connect	**Technical** – compatibility of hardware and software components	**Documented Data** with common protocols	**Technical** - interface specifications, interconnection, data integration services, data presentation, security.	**Technical** – exchange of data over IIoT devices over standard protocols
Layer 2	**Data** – ability of interconnected systems to understand each other	**Syntactic** – common format of exchanged data	**Aligned Static Data** – using common description of the data and	**Semantic** - format and meaning of exchanged data	**Syntatic** - common format of exchanged data
Layer 3	**Human** – The ability of users to act on the data exchanged	**Semantic** – common understanding of exchanged information	**Aligned Dynamic Data** –Common understanding of how data is used across two systems	**Organisational** – aligned business processes, responsibilities and expectations	**Semantic** – unambiguous meaning for exchanged data
Layer 4	**Institutional** – the ability of societal systems to engage effectively	**Organisational** – different organisations can share data	**Harmonized** Data – different systems have a common modelling approach.	**Legal** – common or consistent legal framework governing the interoperability relationship	**Pragmatic** - communicate seamlessly, meaning is understood, across different networks
Layer 5					**Platform** – a common framework between heterogeneous applications and devices (eg cloud based)
Layer 6					**Conceptual** – heterogeneous devices exchange data and act on data in a distributed way (eg via edge or cloud-fog computing)

Source: Frontier Economics

Note: Edge and cloud fog computing describes a network architecture where devices undertake processing, computation, storage and communication locally rather than in the data cloud (the word "fog" refers to its cloud-like properties, but closer to the "ground")

One example of the layers of interoperability is with mobile payments (Gasser, 2015). Mobile payments use a mobile device (often connected to a debit or credit card account), usually a smartphone, rather than a plastic card for transactions and are becoming increasingly popular. Mobile payment platforms include Apple Pay, Google Pay and LoopPay. Mobile payment systems rely on each of the different layers of interoperability due to the number of actors involved in a single payment transaction including customer's devices, payment networks, banks and merchants selling the goods. Different systems have allowed for different types and degrees of interoperability across the four layers outlined in Figure 5.

FIGURE 5 LAYERS OF INTEROPERABILITY IN MOBILE PAYMENT SYSTEMS

Technological	Successful mobile payment systems (MPS) require technological connections between players, such as between banks, devices and retailer payment terminals. For example, devices must be able to connect with payment terminals to exchange payment data. One way this occurs is through NFC technology.
Data	MPS also need to allow transfer of usable data between actors (often in MPS this is tokenised for increased security). For example, the system would not work if the retailer's reader could not process data from a payment platform (such as Apple Pay) as it may be unable to register who has paid or if the payment has gone through.
Human	The systems also need to be interoperable or understood by the users. Increasing interoperability in the human layer could involve making the use of the payment platforms easier and making signing up the services as simple as possible.
Institutional	To increase interoperability the mobile payments systems also need to work alongside the wider global payment processing system which already has established rules and norms to ensure banks and retailers are fairly compensated.

Source: (Palfrey & Gasser, 2012)

The mobile payments example shows how each of the layers of interoperability can be important to achieve the outcome the system is aiming for. This example also highlights the varying possible degrees of interoperability that exist in any specific situation which are discussed in Section3.4. For example, at the technological layer Google Pay interoperates with both Apple and Android smartphones, but Apple Pay has a lower level of interoperability and only interoperates and works on Apple smartphones.

3.4 THE DEGREE OF INTEROPERABILITY

Interoperability is not a binary choice, there is a continuum of degrees of interoperability and different degrees could be appropriate for different market settings. Even at different layers (described in Section 3.3) there could be different degrees which reflect the impact that interoperability has within each layer. For example at the data layer, data could be exchanged on a continuum between irregularly and continuously; at the human semantic layer, the degree of interoperability could be based around which parties integrate their processes for developing and implementing interoperability.

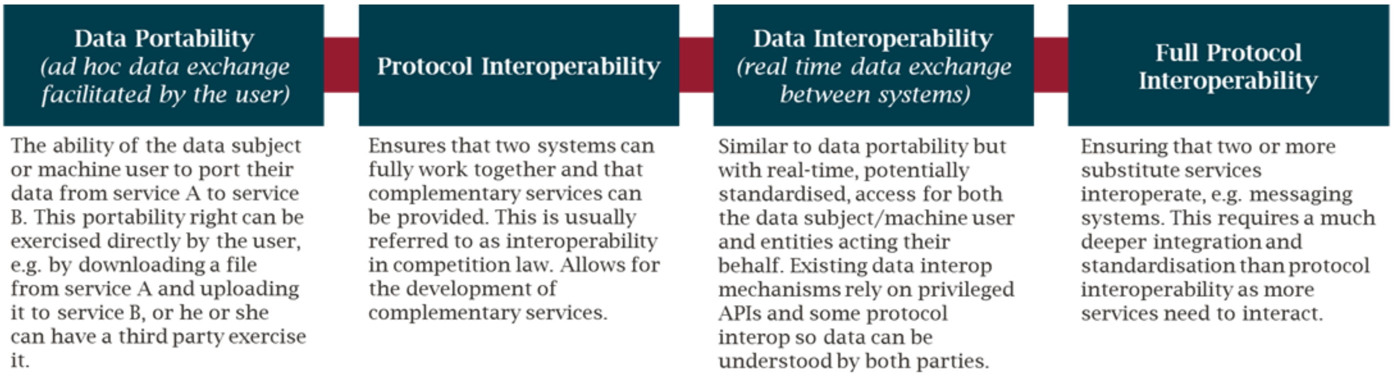
Inevitably there may be some overlap with the concept of the layer (describing the scope of interoperability) since institutional / organisational and human / semantic layers imply a higher degree of interoperability than interoperability confined to technical or data / syntactic layers. Nonetheless considering the *degree* of and the *layer* of interoperability provides a more specific description of the form of interoperability.

The degree of interoperability in digital markets has been considered in a number of different ways.

3.4.1 DATA PORTING TO FULL PROTOCOL INTEROPERABILITY

Crémer et al (2019) map out four versions of interoperability in relation to the *data layer* described in Section 3.3 and Figure 4 (similar continuums could be considered for the other layers). The continuum described by Crémer et al (2019) ranges from less interoperability with data portability to greater interoperability with full protocol interoperability.

FIGURE 6 DEFINITIONS OF DIFFERENT DEGREES OF INTEROPERABILITY



Source: (Crémer, et al., 2019)

The lowest form of interoperability is **data portability** (note the distinction in this framework between "data portability" which refers to irregular downloading of data from one system to be transferred to a different system, from "data interoperability" which implies real time sharing of data between systems). It brings some of the benefits of interoperability in a limited way, though potentially without many of the costs associated with implementing higher forms of interoperability (though costs are not necessarily lower). Data portability is referenced in the European Commission's Digital Markets Act[14], and the EU's General Data Protection Regulation (GDPR) has introduced a limited right to data portability as a means to avoid data-driven consumer lock-ins (Crémer, et al., 2019)[15]. Data portability allows more flexibility between two services or products with an aim to prevent lock-in and facilitate switching. It is not full interoperability since it does not imply the seamless exchange of data - there are still questions around when and how regularly the data can be transferred and also about the form the data is ported in.

Under data portability users can take their personal data from service A and port it (e.g. upload it) to service B. Typically it is the user who actions this process and the data may only relate to data volunteered by the user (or potentially observed of the user) to the data controller, and may exclude data which is inferred or generated by the data platform on the user. Examples of data portability include the ability of users to port some of the data collected about them to other services. For example, Facebook has a tool which enables users to copy their posts and notes to Blogger, Google Docs and WordPress, and to transfer their photos and videos to some other services.[16] Data portability is enshrined in European legislation as

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[14] Article 6.1.h, (European Commission, 2020) - *In respect of each of its core platform services identified pursuant to Article 3(7), a gatekeeper shall: provide effective portability of data generated through the activity of a business user or end user and shall, in particular, provide tools for end users to facilitate the exercise of data portability, in line with Regulation EU 2016/679, including by the provision of continuous and real-time access.*

[15] See p.58

[16] Facebook (Meta), *Transfer Your Facebook Posts and Notes with Our Expanded Data Portability Tool*, Accessed Feb 22 - https://about.fb.com/news/2021/04/transfer-your-facebook-posts-and-notes-with-our-expanded-data-portability-tool/amp/

part of the GDPR (see Section 5.2.1 for more detail). However, according to Krämer et al. data portability is not widely used (Krämer, et al., 2020). The authors consider this is because collection of personal data is highly concentrated (i.e. a limited number of digital suppliers gather a disproportionately large share of personal data) and currently few providers accept ported data from users. Where ported data is accepted it is using non-standardised processes. This in turn means there is limited appetite for consumers to try to port data. The Data Transfer Project aims to make it easier for consumers to port their data. Contributors to the project include Apple, Google, Facebook, Microsoft, Twitter and many others and they are trying to build a common open-source framework which will enable direct, user initiated portability of data.[17]

GDPR does not require continuous, real time data access or the ability to request data interoperability (as defined on Crémer et al.'s scale) between two or more services used by a consumer, but simply it is a right to receive a copy of a user's past data from a service. It supports users switching between services, but it does not facilitate multi-homing or the offering of complementary services, which would rely on continuous and potentially real time data access.

The next level of interoperability is **protocol interoperability**. This is often what is commonly thought of as interoperability in IoT and would imply that a range of IoT devices interconnect with each other. It enables two or more systems to work together to exploit complementarities and create new services. It also means that different services can work together. For example, B's software is compatible with (and complementary to) A's operating system. This was similar to the interoperability envisaged and imposed in the Microsoft v. Commission case when, due to an abuse of its dominant position, Microsoft had to license technical information the work group server operating systems needed to interoperate with Microsoft's PC operating system Windows (see Section **Error! Reference source not found.**). Sometimes to aid protocol i nteroperability standards will need to be developed between complementary services.

Data interoperability is the next degree of interoperability and extends protocol interoperability to include the real time, machine readable exchange of data. This is a much more valuable form of interoperability since it enables third parties to create complementary services which use data supplied by another parties' services. An example of data interoperability can be seen through the UK's Open Banking regulations which are a secure way for consumers to give providers access to their financial information. Open Banking requires that, at a consumer's request, firms such as banks or building societies must share specified account information with a third party in a standardised way, often through APIs (Coyle, et al., 2019). This means that consumers can elect to have current real time information from accounts and transactions held across multiple providers shared with one app, making traditional bank accounts more interoperable with third-party services (see Section 5.2.1 for further detail). The draft Digital Markets Act also has a requirement for real time data portability (art 6(1)(h) see Section 5.2.1).

The highest form of interoperability according to Crémer et al is **full protocol interoperability.** This implies that the different systems are effectively able to replicate each other's' services. It would imply that substitute services interconnect and work with each other. Full protocol interoperability is required in telecommunications markets where different telecommunications operators are required to interconnect with each other. Full protocol interoperability would decrease network effect driven lock-in as the network effects within a service provider would be spread through all interconnecting services. But it would also most likely require deep standardisation across companies to be possible.

[17] Data Transfer Project - https://datatransferproject.dev/

ATTEMPTS AT FULL PROTOCOL INTEROPERABILITY IN SOCIAL NETWORKS

In response to the lack of interoperability between different social networks there have been a number of attempts to create standards that facilitate full protocol interoperability between different social networks that participate. For example Mastodon[18], Diaspora[19], and friendica[20]. These use open standards (such as ActivityPub) which are designed to enable full protocol interoperability including access to profiles, following content, streams, commenting, liking content, and messaging. Though they still require multiple user registrations and log-ins to each social network which can be accessed by the services. However, according to a 2017 study the different services had in many cases limited success at full interoperability with each other, even where they were using common protocols[21] (Sebastian Göndör, 2017).

Each of these degrees outlined can have a varying impact on competition and innovation if implemented within a market and can have a range of costs and benefits which are further discussed in Section 4.

3.4.2 THE MATURITY OF INTEROPERABILITY

Rezaei, Chiew and Lee (2014) use an alternative approach to considering the degree of interoperability defining it by the "maturity" of interoperability. This defines "*the stages through which systems should logically progress, or "mature," in order to improve their capabilities to interoperate*". Here, the least mature implies minimal readiness to implement interoperability up to the most mature which offers the highest readiness to implement interoperability. The authors set out five levels to describe how mature different systems are to interoperate.

- Level 0 – Default level. In this step, the systems are in the first stages of becoming familiar with interoperability concepts and some measures are taken for establishing interoperability.
- Level 1 – Initiating level. In this step, the initial steps for establishing interoperability are taken and systems are oriented toward the interoperability objectives.
- Level 2 – Enabling level. This level focuses on enabling interoperability. At this level, interoperable systems are implemented and deployed, data are managed and business processes are performed in technical and organizational domains of interoperability.
- Level 3 – Integrating level. At this level of maturity, security is established in the technical domain and services are managed and monitored in the organizational domain. The services are coordinated at the systematic level and service repairmen mechanisms are implemented when failure occurs and clients become aware of service changes.
- Level 4 – Interoperating level. At this level, which is the last level of interoperability maturity, interoperability services are published and resources are managed during runtime. At this level,

[18] Mastodon, Accessed Feb 22 - https://joinmastodon.org/

[19] Diaspora*, Accessed Feb 22 - https://diasporafoundation.org/

[20] Friendica, Accessed Feb 22 - https://friendi.ca/

[21] The study noted that *"One of the possible reasons for the incompatibilities between the surveyed OSN services may be the lack of proper reliable documentation of interfaces and data formats. Some interfaces are not described at all, while others simply rely on listing API endpoints to which requests should be directed. A lack of a thorough and detailed description of all API endpoints, including data formats, response messages, and communication flows might be the main reason causing problems and incompatibility in communication between different service platforms. … The survey shows that a holistic standard for OSN interoperability that covers all functionality of today's OSN services is needed."* (Sebastian Göndör, 2017).

services are dynamically managed, and, in order to completely establish interoperability, some agreements are made between service providers and clients.

The actions taken by the systems to facilitate interoperability at different layers, can be defined as a matrix.

While helpful at describing the organisation processes used by different systems to prepare for and enable interoperability at different layers, this approach is less focused on the precise form of interoperability than the "degree" presented in Section 3.4.1. For this reason this report uses the approach suggested by Crémer et al (2019).

3.5 INTEROPERABILITY CAN APPLY AT DIFFERENT "LOCATIONS"

Interoperability can be challenging to achieve in consumer IoT markets given the very heterogeneous nature of the sector. It encompasses many different types of devices, applications, networks and platforms. Devices range from high cost, high powered devices with high battery power (such as smart phones) to lower cost sensors with minimal computing or battery power. Devices may be mobile / nomadic or in a fixed location implying different networking technologies. They may require ongoing and reliable network connections or infrequent and irregular connections; they may need only short range networking or very long range networking requirements. Devices may connect to a number of different IoT platforms which may include platforms supported by large digital providers (Google, Amazon or Apple) or more domain specific platforms (a smart home IoT platform, or a health IoT platform).

Given this heterogeneity interoperability between different systems implies an understanding of exactly where and how the systems will interoperate. In consumer IoT, interoperability may occur at different points in the consumer IoT data ecosystems including the network level, the device level or the application level.

- **Network level** interoperability implies interoperability with or between different networks. For example with telecommunications, this would be the interconnectivity with different physical fixed or wireless networks, or virtual networks (software defined networks). The network layer will be made up of a number of discrete components; (i) the backbone networks, i.e. the links between the remote server and a consumer's internet access service (IAS) provider; (ii) the internet access network controlled by the IAS provider up until (and sometimes including) the customer's router/modem (i.e. the last mile network); and (iii) the customer's private network (e.g. a Wi-Fi network established by the router) (Feasey & Krämer, 2021). Different networks will use different protocols to communicate with devices and therefore a lack of interoperability between different network protocols can limit interoperability between different devices. For example consumer IoT in the smart home uses a number of different network solutions such as Bluetooth, ZigBee or Z-Wave, in addition to IP based networks (Wi-Fi). However, the two most prominent communication protocols, Zigbee and Z-Wave, do not allow for interoperability among smart devices using one or the other (as discussed in Section 7.2) (European Commission, 2021a).

- **Service and content level interoperability:** Depending on the service or content there may be different layers between which interoperability would apply. For example, content provided over the internet may be mediated by a Content Discovery Layer such as search engines or online intermediation services (comparison or aggregation sites). Different services and content would have to be interoperable with networks and devices. Consumers will benefit where their chosen IoT services are interoperable with all their preferred devices. As voice assistants have a growing role in the content discovery layer, they can present specific issues around the use of preferencing and defaults to promote the voice assistant platform's own services. This is because in many cases they operate without a visual interface and therefore a voice assistant platform is able to exert greater control over user behaviour in providing content in response to user request.

- **Devices level:** The device is the user facing element where content is consumed. Feasey (2021) notes that devices may have a number of distinct layers. (i) The hardware layer denotes the physical device. This includes both fixed components (e.g. the network card, built-in sensors, and a secure element chip) as well as ancillary and exchangeable components such as memory cards or SIM cards. (ii) The operating system (OS) layer. The OS is separate from the hardware layer, because an OS can run on several different physical hardwares. The OS may restrict 3rd party access (i.e. prevent interoperability) with certain aspects of the hardware for security or functionality reasons; (iii) similar to the Content Discovery Layer, the app discovery layer includes those applications that are crucial for consumers to access other apps or web content (app stores and browsers). (iv) The app layer denotes all the apps (including web apps and websites) that can be used on a device. Content and content discovery may occur inside an app (e.g. a browser), so that it is logically located below the 'online content' layers discussed above.

Depending on the specific concerns or requirements, the approach to interoperability could apply in different ways. As set out in Figure 5 mobile payment systems require a complex mix of different approaches to interoperability across multiple devices, software and services. In principle there may be many different providers of each of the different layers within the network / service and content / device layers. Any given application may require interoperability between any or all of the different layers. Different suppliers across the different layers will have different roles in enabling interoperability between the different layers using proprietary (where a license is needed) or open standards (where a license is not required), common standards (standards set by a Standard Setting Organisation (SSO)) or privately set standards.

3.6 TECHNICAL DESIGN AND SPECIFICATION OF INTEROPERABILITY

It is only after having agreed on the optimal form of interoperability (i.e. who, layer, location and degree) that different parties can then agree the specific technical and design of the process for creating and maintaining interoperability. Parties will have to agree many factors such as detailed technical specifications; the content and format of data flows; the approach to resolving disagreements; any payment flows; the approach to privacy, security, user functionality; or how the services can be developed while maintaining interoperability.

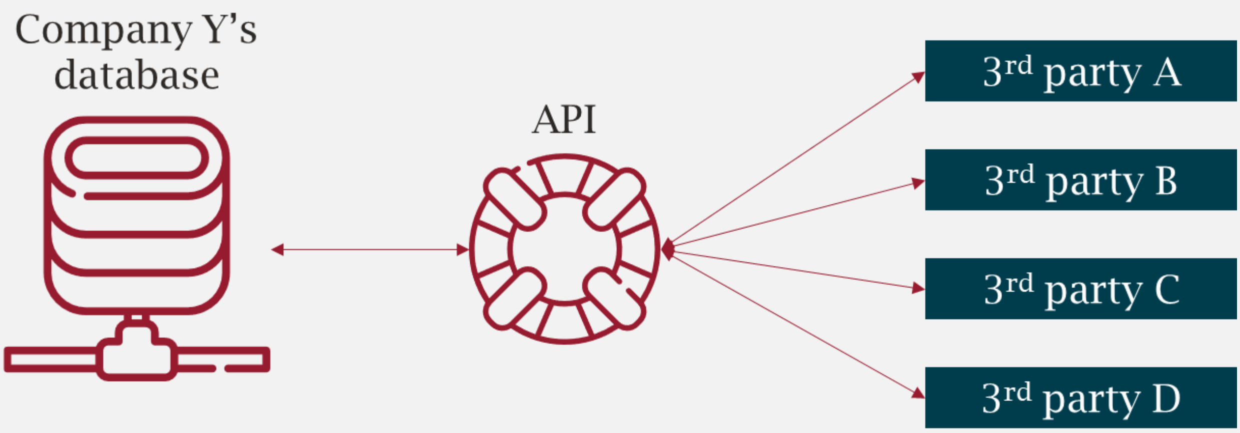
3.6.1 DEFINING THE TECHNICAL APPROACH TO INTEROPERABILITY

At a practical level, in the context of consumer IoT markets, the content of these technical specifications, data sharing arrangements and design guidelines are in many cases determined by one of the interoperating parties. This party shares a range of technical documentation and guidelines, usually including an Application Programming Interface (API) and/or a Software Development Kit (SDK) to enable the other to interoperate, as well as specifying the data exchange arrangement involved in integration. After developing the integration using the provided technical documentation, the interoperating party will usually go through a testing process to ensure the integration functions correctly and meets any requirements or guidelines set out by the other party. While there are also many instances of more balanced bilateral negotiations, whereby a greater degree of collaboration takes place between the integrating parties, the extent to which this occurs depends on the bargaining position of each party. The exchange of real-time data is achieved through Application Programming Interfaces (APIs). These APIs enable the exchange of data to support the creation of complementary services.

APPLICATION PROGRAMMING INTERFACES (APIs)

APIs are a key tool to enable interoperability between different software systems. APIs are a type of computer program interface or piece of software that lets one program access and interact with another program, sharing data and functionality (CMA, 2020). They enable machine-to-machine communication and the seamless exchange of data between programs and can therefore be useful facilitators of increased interoperability. They can be open where any third party can access them, or they can be more private APIs where the source firm or program controls access, often through access tokens.

Access to APIs increases interoperability as it allows third-party developers to access data and information from another party's database. This can allow third parties to build and develop complementary services that work with the services offered by the owner of the database.



Note however, that while the standard design of APIs promotes openness and interoperability, they are not created by default. Whether to allow access through an API is a service's own decision to make, and services have control over who can use the API and what data and information is shared through it.

As an example, Meta maintains thousands of APIs across its applications including Facebook and Instagram, with each API allowing access to a specific set of data or information. This is beneficial to third-party developers. However, API access and the data shared can be degraded. Changes to APIs' technical specifications can make it harder for third parties to access the API or in the extreme case API access can be revoked. An example of this is when in 2013 Facebook disabled Vine's access to Facebook's 'Find Contacts' API after Twitter had acquired Vine. The API had previously allowed Vine users to easily begin using the Vine platform by finding friends that they already knew on the Facebook platform.

It is argued that regulated open APIs which can be used by industry participants are the route to promoting interoperability (Krämer, et al., 2020). For example, to support the UK's Open Banking Programme the UK's CMA forced the nine largest banks and building societies to fund and cooperate with a new independent body, Open Banking Implementation Entity (OBIE). *"The OBIE developed, within a fixed (and short) timeframe, read-only open and common technical and product data standards and read-and-write open and common banking standards for the sharing of transaction data."*

Data needs to be gathered, recorded and exchanged in a way that can be recognised by the two systems interoperating. This means that the format and data structure of exchanged data needs to be consistent (i.e the data layer interoperability described in Figure 4). This implies that data is provided according to predefined rules. Furthermore, interoperability may also imply not only that data is accurately exchanged between different systems, but that the different systems can understand and interpret the data in a meaningful way (i.e. the "human / semantic layer" described inTable 1).[22] This means that the data models, units of measurement must be consistent between different systems.

3.7 EX-ANTE OBLIGATIONS - NEUTRALITY ALONGSIDE INTEROPERABILITY

The adoption of obligations around neutrality are sometimes suggested to work alongside interoperability. That is because while interoperating with each other, firms will also compete with each other and therefore some authors consider that interoperating firms (or a subset that have market power or otherwise hold an asymmetric strong bargaining position) should be required to apply interoperability "neutrally" with regard to their own services. For example, "*Equitable interoperability" means that not only can an entrant join the platform [as a result of interoperability], but it can join on qualitatively equal terms as others, without being discriminated against by the dominant platform that might have its own competing service. Equitable interoperability effectively prohibits self-preferencing and discrimination against firms that are not part of the dominant ecosystem.* (Morton, et al., 2021). This obligation implies that firms have an obligation to interoperate ***and*** not to discriminate and is characterised as a "light touch" regulatory tool.

The concept of neutrality can be applied to the framework set out in this section. It can apply to specific layers (data and technical), degree (to facilitate a certain degree of interoperability) and location (for example at a device). For example it has been argued that forms of device neutrality can promote interoperability between content and devices by restricting discrimination.[23]

In practice it is not clear that an obligation to provide reasonable requests for interoperability and on a non-discriminatory basis would result in "light touch" regulation. The regulations of vertically integrated telecommunications networks illustrates some of the practical difficulties with applying non-discrimination principles. In telecommunications services, even where regulation is imposed which specifies the products offered and the regulated prices, National Regulatory Authorities (NRAs) find it necessary to impose strong and intrusive ex-ante regulation to enforce non-discrimination.[24] This can be by requiring vertically integrated firms to use outputs which are equivalent to those used by competitors ("Equivalence of Outputs"); changes to internal systems and construction of internal "Chinese walls" to prevent discrimination; and requirements that the vertically integrated firm uses the same inputs that are used by competitors (i.e. to reorganise their internal systems such that a firm "buys" interoperability from an internal supplier in the same way that a third party does – "Equivalence of Inputs"). At the extreme NRAs can require firms to functionally or fully separate to enforce neutrality. All these interventions impose costs and require significant intervention from regulatory authorities. It is likely that any regulatory oversight to enforce non-discrimination in digital and IoT markets could be complex given the very heterogeneous nature of the products and services.

[22] Semantic interoperability "means enabling different agents, services, and applications to exchange information, data and knowledge in a meaningful way, on and off the Web" W3C Semantic Integration & Interoperability Using RDF and OWL

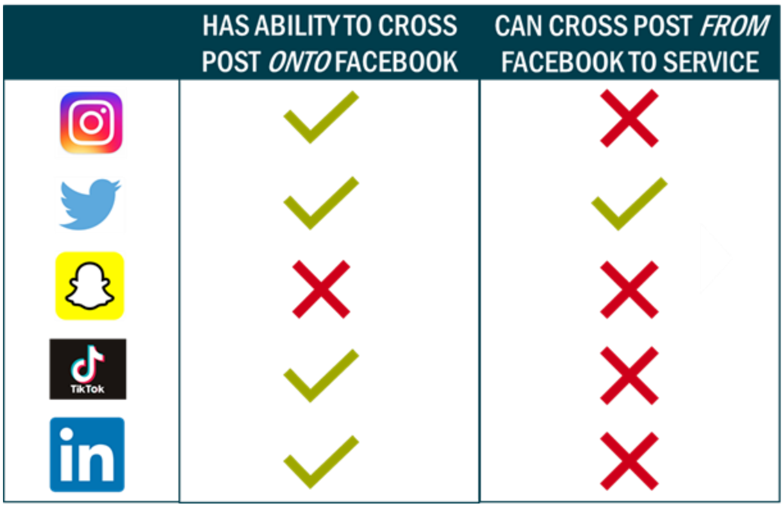
[23] However, it is argued that implementing device neutrality would be complex: *"a coherent 'neutrality' regulation would need to be applied to all layers of the internet access value chain, and not just to parts of it. However, regulating ‚device neutrality' on all layers (as opposed to just the network layer in case of net neutrality) would be much more complex and would require deep expertise by regulators at all layers, which is currently scant"* (Feasey & Krämer, 2021)

[24] See for example: Cave, M (2007) Six Degrees of Separation : Operational Separation as a Remedy in European Telecommunications Regulation.

3.7.1 DIRECTIONAL INTEROPERABILITY

It may be necessary to define the direction of interoperability between different parties. This can be reciprocal or one-way (i.e. non-reciprocal). For example, pre-2018, Facebook featured a 'Publish Actions' API allowing consumers to post content onto Facebook from other social media platforms and from Facebook onto other platforms. However, Facebook degraded this functionality in August 2018 restricting consumer's ability to post content from Facebook onto other Platforms and explained that this was due to concerns about safety and data privacy (CMA, 2020)[25]. This current relationship is shown in Figure 7. The clear asymmetry in posting interoperability could favour Facebook by leading to greater and more varied content being able to be shared on Facebook compared to the other social media platforms (CMA, 2020).

FIGURE 7 CROSS-POSTING CAPABILITIES BETWEEN FACEBOOK.COM AND OTHER SOCIAL MEDIA PLATFORMS REMAIN ASYMMETRIC



Source: (CMA, 2020)

3.7.2 ASYMMETRIC APPLICATION OF INTEROPERABILITY

Interoperability obligations may be applied to all parties ("symmetric" application) or only a subset of parties with particular characteristics such as dominant parties or gatekeepers ("asymmetric" application). Examples of asymmetric interoperability include the following.

- The European Commission's draft Digital Markets Act would only impose restrictions and obligations on a set of 'gatekeepers' who meet certain thresholds, not across all the undertakings in the markets, or "core platform services", the gatekeepers are active in (European Commission, 2020). Gatekeepers could face rulings and obligations such as improved data portability which other firms in their markets will not face.

- Dominant firms or merging parties may face "asymmetric" requirements (behavioural remedies or commitments) to limit anti-competitive effects. A lack of interoperability is a potential concern in markets with dominant firms as it could limit some forms of competition and innovation. However, as noted in Section 4 there are complex trade-offs in requiring interoperability around the costs of implementation and the form of competition and innovation which is enabled by different degrees of interoperability. Regulators may act to reduce the ability and incentives to

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[25] See p.371

exploit dominance by imposing interoperability requirements. One example is when the European Commission intervened to increase interoperability in the Microsoft v. Commission case (Microsoft, 2007). The intervention aimed to prevent the possible leveraging of Microsoft's dominance of its market power in PC operating systems into workgroup server operating systems which could foreclose rivals.

- When the CMA's study on digital advertising concluded, its findings on interoperability between social media platforms suggested interoperability be applied asymmetrically to Facebook if considered by policy makers (CMA, 2020)[26]. The study said, *"Given the market position of Facebook and the extent to which it benefits from network effects, we think that such interventions should apply to Facebook in the first instance (e.g. Facebook should offer a defined find contacts service to users of a third-party platform, but rival platforms should not be required reciprocate)".*

- In addition, the UK's Open Banking legislation imposed a remedy that required that the nine largest current account providers in the UK produce a standardised API to share customer information on bank transactions and account details securely when requested by the customers (see Section 5.2.1). This was an asymmetric intervention as some current account providers were not required to do this, although in this case the majority were.[27]

3.7.3 COMMERCIAL TERMS OF SUPPLY OF INTEROPERABILITY

Policy makers may have to adjudicate on commercial terms of interoperability. Commercial forms of interoperability in most cases occur without charge, and under GDPR legislation charging for data porting is prohibited. However, if more intrusive forms of interoperability are imposed on digital platforms it may be necessary to agree commercial terms. This is particularly important where data gathered by one party is the result of significant investments in the platform (relating to map services, email, data storage, hardware personal assistants). Potential rivals who acquire regulated access to the data may be reasonably expected to contribute to the costs of investments that have generated the data.

While there are many examples of regulated access pricing in network industries such as telecommunications, it is likely that arriving at an appropriate access price could be significantly more complex to determine or adjudicate an appropriate price for interoperability. This is for a number of reasons: identifying the investments (including many intangible assets) that have generated value will be more complex than in network industries, the form of access for different interoperating parties will be very heterogeneous, and attributing (often international) investments to specific users could be problematic.

3.8 CONCLUSION

Interoperability is a complex concept which can be applied differently in various settings. There is a continuum of degrees of interoperability and the optimal level will vary across this continuum for each specific market setting. In IoT in particular, finding the optimal level of interoperability might be even more complex due to the range of actors active in the consumer IoT market but also because of the different ways that interoperability could occur.

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[26] See p.374

[27] The Open Banking Programme applied to the nine largest UK banks and building societies (Allied Irish Bank, Bank of Ireland, Barclays, Danske, HSBC, Lloyds Banking Group, Nationwide, RBS Group and Santander) but not smaller banks.

4 COSTS AND TRADE-OFFS OF INTEROPERABILITY

4.1 THE APPLICATION OF INTEROPERABILITY IMPLIES TRADE-OFFS

Interoperability is not a one size fits all solution to issues in digital markets. It is more of a policy option or measure that can be considered to achieve other goals within markets such as the promotion of innovation or improved consumer outcomes. The degree of interoperability required depends on the market situation and there is a trade-off between the costs and benefits associated with any increase in interoperability.

Interoperability has been promoted as having many benefits. It has been suggested as a potential policy tool by many studies considering options to address the market power/position of strong players in digital markets, and the specific features of these markets, including the Vestager, Furman and Stigler reviews (Coyle, et al., 2019; Crémer, et al., 2019). The Stigler Committee's report on digital platforms (Stigler Committee on Digital Platforms, 2019) highlighted some of the perceived benefits of increased interoperability in digital markets;

> *"Interoperability would facilitate ongoing competition on the merits of the user experience, rather than on the size of the installed base, and potentially stimulate robust competition… With easy interoperability, users will be free to make a real choice about which service they prefer. This will encourage new market entry and vigorous competition between providers." (Stigler Committee on Digital Platforms, 2019)*[28]

However, the reports also highlight the potential costs and trade-offs to the market that follow increased interoperability. For example, the Vestager report notes;

> *"Full protocol interoperability has the benefit that positive network effects stemming from the large user base of one platform extend to other platforms – in other words, through the imposition of interoperability requirements, the benefits of positive network effects can be shared among direct competitors…*
>
> *In this perspective, interconnection could be an efficient instrument to address concentration tendencies. On the other hand, full protocol interoperability can come at a high price: the need for strong standardisation across several competing platforms could significantly dampen their ability to innovate and to differentiate the type(s) of service(s) they provide. One of the most important grounds for continuing competition between platforms, and possibly for competition for the market, could therefore be weakened or even eliminated. Furthermore, the need for coordination between the firms affected by the requirement would provide opportunities for collusive behaviour, for instance to limit innovation." (Crémer, et al., 2019)*[29]

Similarly the UK's Furman review noted;

> *"Open standards, and the interoperability they deliver, are widely recognised as delivering significant benefits. They enable firms to create applications that are able to work seamlessly with other applications based on the same standards. This also ensures that consumers aren't locked in to products from one business." (Coyle, et al., 2019)*[30]

Therefore, the optimal level of interoperability will weigh up the relative costs and benefits of different approaches, in the specific market context. Understanding these trade-offs and realising what trade-offs

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[28] See p.118

[29] See p.59

[30] See p.73

exist in specific market conditions can allow policy makers to make more informed decisions about the appropriate and optimal degree of interoperability for a specific market (Yoo, 2015).

4.2 INTEROPERABILITY CAN AFFECT INNOVATION

4.2.1 THE DISRUPTIVE AND SUSTAINING INNOVATION TRADE-OFF

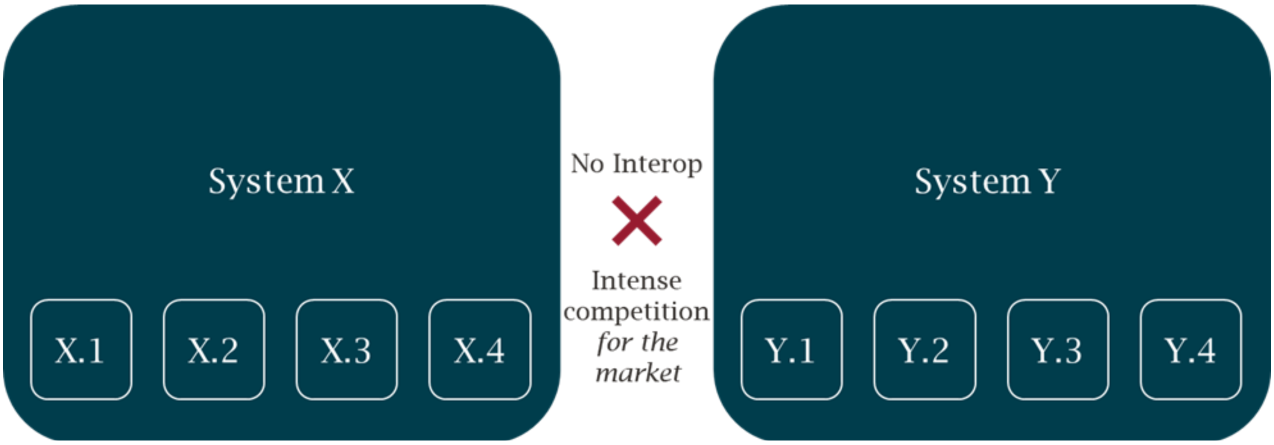
There are lots of factors that can affect the level of competition and innovation in a market, including the market power of different players, the contestability of the market and the size of the market. Interoperability can also have an impact. Interoperability affects the incentives to compete, and by doing so it can affect the incentives to innovate. This can lead to a trade-off between different types of competition and innovation that result from greater interoperability. Therefore, it is helpful to distinguish between different forms of innovation and competition.

DISRUPTIVE INNOVATION

Disruptive innovations are innovations which are often led by new entrant firms, are riskier and take a longer time, but could bring large benefits to the market and consumers if they come through, such as increased quality (Brown, 2020; Christensen, 1997). This type of innovation is more likely to come from the incentives created by dynamic competition *for the market* which could result in an incumbent, or an incumbents technology, being pushed aside by a new competitor. For example, games consoles compete on their technology features and content with limited interoperability.

If there is no horizontal interoperability, there are strong incentives for systems to compete with each other. They will therefore invest in innovation to differentiate their service and attract users away from their competitor's system. For example in Figure 8, system X and system Y compete with each other offering products 1-4 to each of their respective customers. But a customer of system X would not be able to access Y's products without buying system Y. Here there is greater scope for disruptive innovation. For example, system Y could seek to differentiate its platform by introducing a new product, Y.5, to entice system X's customers to switch and disrupt all users of system X. These have been termed "isolated islands", where consumers can only communicate within the platform they connect to and are unable to communicate across different platforms.

FIGURE 8 NO INTEROPERABILITY LEADS TO CONDITIONS FOR COMPETITION FOR THE MARKET AND DISRUPTIVE INNOVATION



Source: Frontier Economics

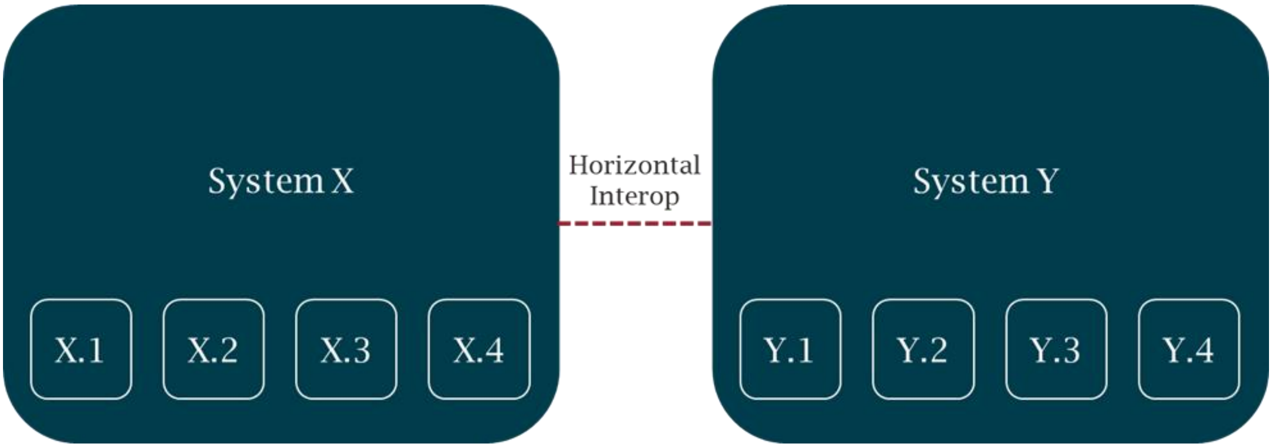
SUSTAINING INNOVATION

Sustaining innovations are innovations which improve the performance or functions of an established product or system, incrementally bringing shorter term, more certain, but likely smaller benefits to the market. These can then often be easily copied by competitors (Christensen, 1997). Sustaining innovations make up the majority of innovations and are driven by competition that happens *within the market*.

Competition in the market places firms under pressure to operate as efficiently as possible and to innovate in order to gain an advantage over competitors. The incentives to achieve a massive 'disruptive' innovation could be reduced, however, in the absence of the prospect of large innovation rents for the market leader, which might be competed away by competition within the market.

For example, in Figure 9, where there is horizontal interoperability between systems, there is less incentive for each system to invest in disruptive innovation as the gains to innovation will be lower (since system X can interoperate and reach system Y's customers). There is less incentive for system Y to innovate to introduce a new product, Y.5, since system X's customers will be able to access the product. Instead they will seek to refine their existing suite of products.

FIGURE 9 HORIZONTAL INTEROPERABILITY BETWEEN SYSTEMS CAN LEAD TO COMPETITION WITHIN THE MARKET



Source: Frontier Economics

INCENTIVES TO INNOVATE WITH VERTICAL INTEROPERABILITY WILL VARY

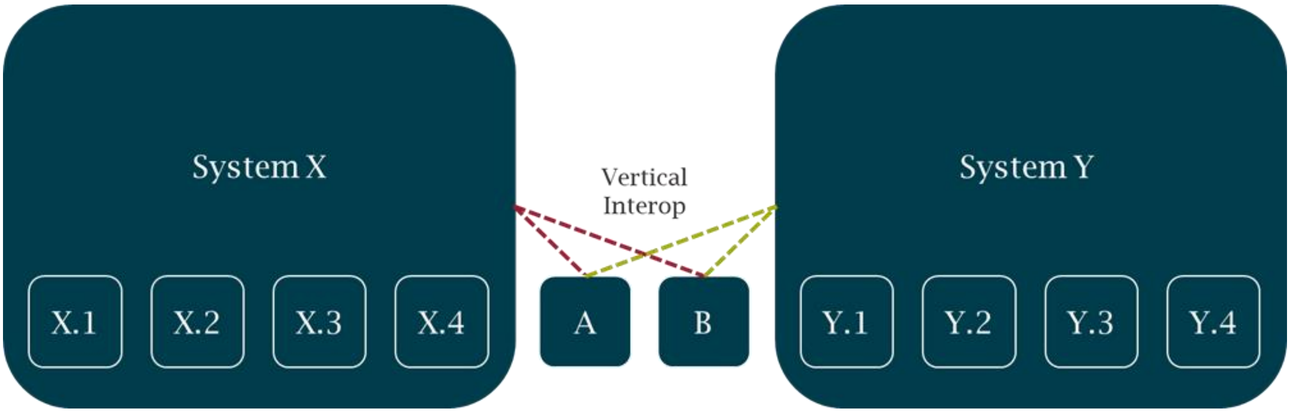
In relation to vertical interoperability, benefits will include the increased value that companies derive from offering complementary products. However, by interoperating with third parties, companies may not be able to fully internalise the benefits that they derive from incremental investments (for example to create a new product), as illustrated in Figure 10Figure 10, where third party producers A and B would benefit from investments in innovation by System X.

Furthermore, where both systems offer vertical interoperability which enables third parties to offer complementary services, differentiation between the different systems may reduce. Here there may be greater incentives to innovate to differentiate their system, even where some of the benefits of the investment are appropriated by third parties interoperating with their system (A and B in Figure 10 10).

Systems may therefore have an incentive to seek to agree exclusivity or other restrictive vertical supply terms with third parties such that they remain differentiated from rival systems. For example, games consoles may agree exclusivity agreements with games developers such that a given game is only available on one console.

In theory, firms could provide interoperability in return for an access charge to reflect the investments made in their platform, such that they would be indifferent between i) offering interoperability with an access charge, or ii) withholding interoperability to protect the value of their investments.

FIGURE 10 VERTICAL INTEROPERABILITY BETWEEN SYSTEMS CAN ALSO LEAD TO COMPETITION WITHIN THE MARKET



Source: Frontier Economics

TRADING OFF DIFFERENT FORMS OF INNOVATION AND COMPETITION

Therefore, a decision about the "optimal" form of interoperability is a decision about the desired form of competition and innovation. Increased interoperability through policies such as easier and faster data portability and the interconnection between systems, would encourage more static competition within a market and encourage "sustaining innovation". Whereas lower interoperability would increase dynamic competition for the market as a whole, and encourage potential "disruptive innovation". In addition, it is important to note that innovation, particularly disruptive innovation, remains an unpredictable process which is not only influenced by degrees of interoperability.

The Stigler report highlights this trade-off with increased interoperability, which might be created through open standards, when discussing consumer IoT devices in a smart home environment. It argues that, although increased interoperability might reduce innovation for the market, or for the main smart home interface, it would increase incentives to innovate on the platform itself:

> *"It is possible that such open standards can slow down innovation that depends on the interface, but open standards will drastically reduce lock-in and market power, leading to greater incentive to innovate on the service itself." (Stigler Committee on Digital Platforms, 2019)*[31]

[31] See pg.113

The Vestager report also debates the trade-offs of different types of innovation from different degrees of interoperability:

> *"Although it can favour competition in mature markets, data interoperability can also have some anticompetitive consequences by limiting the incentives for new forms of collection of data." (Crémer, et al., 2019)*[32]

This trade-off around benefits of interoperability against the impact on innovation also formed the basis of arguments around the Microsoft v. Commission case (Microsoft, 2007).

MICROSOFT V. COMMISSION (2007)

In 2007, the European Court of First Instance (CFI) made its judgement on the Microsoft v. Commission case. The case started in 1998, when Sun Microsystems lodged a complaint with the Commission stating that Microsoft violated Article 102 TFEU by refusing to license technical information that work group server operating systems needed to interoperate with Microsoft's PC operating system, Windows. This refusal had only started once Microsoft had developed its own competing work group server OS, and before that, the technical information needed for interoperability had been shared. By not sharing the information Sun argued Microsoft was trying to extend its dominance in PC operating systems to work group server OS.

In 2004, the Commission's decision, which was then appealed, stated Microsoft had abused a dominant position by refusing to supply competitors with "interoperability information" (Microsoft, 2007).[33] In the end following the court's decision in 2007, a duty to license interoperability information was imposed on the basis of the abuse of dominance regime of European competition law (Graef, 2014).

TRADE-OFFS HIGHLIGHTED

One of the debates the Commission and Microsoft had about the refusal to supply the interoperability information highlights the trade-offs associated with increased interoperability. The Commission argued that Microsoft's refusal to supply the information limited technical development. They argued that due to the lack of interoperability the prospects of competitors' innovations were limited, discouraging any innovation within the market as competitors were unable to access it (Microsoft, 2004).[34] The Commission also argued that increased interoperability would drive innovation:

> *"Microsoft's research and development efforts are indeed spurred by the innovative steps its competitors take in the work group server operating system market. Were such competitors to disappear, this would diminish Microsoft's incentives to innovate. By contrast, were Microsoft to supply Sun and other work group server operating systems with the interoperability information at stake in this case, the competitive landscape would liven up as Microsoft's work group server operating system products would have to compete with implementations interoperable with the Windows domain architecture. Microsoft would no longer benefit from a lock-in effect that drives consumers towards a homogeneous Microsoft solution, and such competitive pressure would increase Microsoft's own incentives to innovate." (Microsoft, 2004)*[35]

[32] See pg.59

[33] The Commission also judged on the tying of Windows client PC operating system and Windows Media Player, but this report will focus on the aspects relating to interoperability.

[34] See pg.186

[35] See pg.194

In response, Microsoft argued that opening up the market would stifle innovation and released a statement saying that *"The Commission is seeking to make new law that will have an adverse impact on intellectual property rights and the ability of dominant firms to innovate"*.[36] Microsoft argued that increasing interoperability would hinder competition for the domain architecture of the whole market. However, the Commission argued that in this situation, where Microsoft held a significant market share, competition for the market would be difficult so interoperability is needed to spur competition:

> *"In that setting, Microsoft is able to impose the Windows domain architecture as the de facto standard for work group computing of which PCs are a key component. Once Microsoft establishes privileged support for a given work group service technology in its dominant PC operating system, alternative solutions cannot compete." (Microsoft, 2004)*[37]

Larouche argues that in making these arguments the Commission and the CFI seem to prefer competition in the market and sustaining innovation over competition for the market and disruptive innovation (Larouche, 2009).[38] Larouche notes that this preference is not explicit in the decisions but that the preference to try and intervene for competition in the market may be driven by Microsoft's dominant position, suggesting this preference could hold in future situations involving dominant players.

4.2.2 IMPACT OF INTEROPERABILITY ON COMPETITION

Increasing interoperability, particularly horizontal interoperability, can lead to increased competition within a system of products, which can drive down prices and also improve quality as players compete to lead *within* the system. Increased interoperability can reduce lock-in of consumers and lower barriers to entry due to network effects now being shared, making it easier for competing products to enter the market.

However, as discussed in Section 3.2.2, some academics have also found that increased vertical interoperability may actually reduce competition and lead to increased prices, since increased interoperability means that any reduction in prices, or a demand increasing strategic decision by one part of a system, will increase demand for the whole system of complements which now vertically integrate (Matutes & Regibeau, 1988; Economides, 1989). Therefore, the firm that lowers prices will not capture all of the accompanying benefits and will have lower incentives to compete on price. However, this may depend on the degree of interoperability that is implemented.

Increased user choice and flexibility is also seen as a benefit of increased interoperability (Gasser, 2015). Interoperability can lead to more services on a system, which leads to more choice for consumers at specific levels of the market. With increased vertical interoperability, consumers would also be able to mix and match between brands across the vertical system. In some cases however, consumers may not enjoy the increased connectivity and flexibility and may actually prefer a market where they are able to multi-home across systems that do not interoperate, where systems are differentiated (for example offering access to different social user groups) (Arnold, et al., 2020).

Increased interoperability could also have environmental benefits. It would mean less energy spent investing in different versions that will work in different systems, which might reduce the environmental impact. For example, the recent European Commission proposal of common chargers for electronic devices

[36] CNet News, *Microsoft commentary slams EU ruling*, Accessed Feb 22 - http://www.cn-c114.net/582/a303449.html

[37] See pg.187

[38] See pg.628

increases the interoperability between devices and chargers and will reduce e-waste. This is seen as a major benefit of increased interoperability in this scenario.[39] [40]

4.3 COSTS OF INCREASED INTEROPERABILITY

However, there are also costs and drawbacks beyond those discussed in Section 4.2.1 associated with different forms of competition and innovation.

It is argued that in some cases increased technical interoperability increases security risks as it provides more opportunities and entry points to exploit a system's security vulnerabilities. As well as more entry points, increased interoperability might mean that systems face a trade-off between offering interoperability and security and might compromise on a lower security standard to enable wider or deeper interoperability (Bundeskartellamt, 2021). Alternatively, a high standard of security may be set as a requirement for systems to access interoperability. The proposed European Digital Markets Act also highlights the possible security risks. As discussed in Section 5.2.1, in Article 6 (1)(c) of the European Commission's draft Digital Markets Act there is an acknowledgement of the trade-offs and possible privacy and security costs as it notes that gatekeepers will not be prevented from taking proportionate measures to protect the integrity of their systems if required to allow the interoperability of app stores and third party software applications with gatekeepers' operating system (European Commission, 2020).[41] However, although interoperability may increase the scope for security issues it is not the cause of the security vulnerabilities themselves. Some argue that a system should be able to be designed with interoperability that is secure. In the same way, systems that are not interoperable at all are just as likely to have damaging security issues if proper precautions are not in place (Gasser, 2015).

In a similar way, it is argued that interoperability, especially horizontal interoperability, and the increased connections it brings could decrease privacy. However, even with increased interoperability, privacy regulations such as GDPR should set minimum standards to protect privacy. In addition, research on consumers' online behaviour has shown differences between reported feelings towards privacy and consumers' actual behaviour, a concept often referred to as a 'privacy paradox'. More specifically, research has shown that while users *claim* to be very concerned about their privacy, they often do little to protect their personal data online (Barth & De Jong, 2017). There could be many reasons for this, including lack of knowledge on how to protect personal data online and difficulties doing it on websites. However, it could also be due to a willingness to give some personal information away for a service, suggesting lower privacy from interoperability may not be a significant cost to some.

Both security and privacy concerns, while valid, may be mitigated against with appropriate design and policies around the method of interoperability. Riley argued that Facebook's "Cambridge Analytica" case, regarding the collection of personal data about users' Facebook friends, arose due to Facebook's 'Graph 1.0' API, allowing users to authorise a third party to access some information regarding their Facebook friends without the direct permission of those individuals (Riley, 2020). Although this happened due to increased interoperability between Facebook and third party applications, it was not the *interoperability* per se that gave rise to the issue. According to the author, the case highlighted the risks of interoperability,

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[39] European Commission, *Pulling the plug on consumer frustration and e-waste: Commission proposes a common charger for electronic devices*, Accessed Feb 22 - https://ec.europa.eu/commission/presscorner/detail/en/IP_21_4613

[40] The proposal is for a Directive amending Directive 2014/53/EU on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment (COM (2021) 547 – Proposal for a directive)

[41] See p.40

but also that risks might be mitigated with careful design of policies. A recent survey of relevant companies by the German Bundeskartellamt, which focussed on the possible impact of increased interoperability on data quality and protection as part of its sector inquiry into messenger and video services, highlighted that some surveyed companies think that the privacy and security concerns around interoperability could be solved at a technical level, provided there is willingness to invest (Bundeskartellamt, 2021).[42]

Another risk is that as a system grows larger, with more and more players interconnected due to increased interoperability, the system could become more complex and degrade the user experience by being less reliable, prone to technical errors and have a lack of accountability due to the range of services available.

Finally, a significant cost of interoperability are the transaction costs incurred to facilitate it. These relate to the time, resources and energy needed to design and maintain interoperability. Coordinating interoperability standards is necessarily complex but costs would be higher for the following reasons:

- **The number of parties.** Where the number of parties wishing to interoperate is high there might be higher costs. For example, Amazon reports that its Alexa voice assistant had approximately 80,000 “skills” (integrations) in the US and nearly 40,000 in the UK with service providers, which each require a degree of coordination for both Amazon and the parties wishing to interoperate.
- **The approach to agreeing terms.** This will depend on whether interoperability is the result of balanced bilateral or multi-lateral negotiation, which may require complex and ongoing negotiation; or is characterised more by terms set by one party.
- **The layer of interoperability,** with institutional interoperability implying greater costs than technical interoperability.
- **The degree of interoperability,** with deeper interoperability relationships requiring more set up and ongoing costs than lighter forms of interoperability.

In addition, due to information asymmetries, it can be difficult for policy makers to assess and verify claims of adverse impacts of interoperability (security or privacy) and how to mitigate these risks in a proportionate way. In competition law proceedings, the burden of proof for demonstrating a justification for a potential abuse of a dominant position (which may include restricting interoperability) passes to defendants to “*raise any plea of objective justification and to support it with arguments and evidence*” (Microsoft, 2007)[43].[44] However, where policy makers are considering applying ex-ante interoperability requirements, the burden is reversed, and policy makers should demonstrate that the proposals are reasonable and proportionate.

[42] See p.VII

[43] See pg.3830

[44] See Section 4.2.1 for a broader discussion of Microsoft v Commission (2007)

4.4 DIGITAL PLATFORMS WEIGH UP OPPOSING INCENTIVES TO INTEROPERATE

Platforms are designed to bring together many customer groups and third-party devices and services and therefore, on one hand, have strong incentives to interoperate.[45] However, they also often offer their own first-party services via the platform which compete with third-party services that interoperate with the platform. This brings more complex trade-offs. Platforms will balance incentives to interoperate by increasing the value of the platform through offering complementary third-party services; while facing incentives to restrict interoperability to maximise profits of its first-party services offered via the platform. The balance of these two incentives will determine its preferred level of interoperability (though, as noted in Section 3.7.3 firms could provide interoperability in return for an commercial payment to reflect the investments made in their platform and to maintain their incentives to invest). Given the central role that digital platforms have in modern digital markets, there can be bargaining asymmetries in the parties wishing to interoperate, which can further add to the complexity of coordinating.

Furthermore, many consumer IoT platforms offer a wide range of loosely complementary services (such as VOD TV, music streaming, smart speaker hardware, communication devices such as tablets or phones, smart home devices, automotive IoT services and delivery services). Such a strategy can build and maintain customer loyalty since consumers benefit from using a portfolio of complementary services. However, this also implies that consumers could face switching costs, since by switching one of their services, they may lose the "complementary benefits" that are associated with consuming the service alongside the platform's other services. This may lead to a degree of consumer "stickiness", and at the extreme, a degree of consumer lock-in where consumers face relative high switching costs. Furthermore, it may shape competition where competitors need to replicate the portfolio of services in order to entice consumers to switch away from the platform. These costs are likely to be raised where interoperability is restricted.

The resulting strategy (i.e. a strategy to create customer value and loyalty through complementary products and limiting interoperability) has been termed "platform annexation". This describes a strategy that restricts consumers from multihoming or prevents third parties from multi-homing (Athey & Morton, 2021). However, platforms may have justifiable commercial reasons to want to protect the value of their investments in their platform, and therefore limit interoperability with rivals. Furthermore, as set out above, such a strategy (of limiting interoperability) can intensify competition *between* platforms, increasing investment in innovation which platforms undertake to attract customers.

[45] Separately, dominant firms may wish to restrict interoperability to foreclose rivals. For example, dominant firms may choose to restrict interoperability in order to foreclose related complementary markets. Firms that do not have significant market power are unlikely to have the incentive and ability to withhold interoperability to foreclose rivals.

5 INTEROPERABILITY AS A POLICY TOOL TO PROMOTE COMPETITION AND POSITIVE ECONOMIC OUTCOMES

Interoperability can be used as a tool by policy makers to achieve certain outcomes in markets. This section considers the potential different paths to increased interoperability and what incentives might determine which path is followed and finally provides an overview of where interoperability has been used as a policy tool, particularly in digital and telecommunication markets.

5.1 PATHS TO INTEROPERABILITY

There are many different paths to achieving an optimal degree of interoperability. Which path is taken may be dependent on the market players' incentives and whether they see private benefits from interoperability. Without this regulatory intervention may be needed. There are four broad paths to interoperability which are discussed below.

5.1.1 "ORGANIC" COMMERCIAL DEVELOPMENT OF INTEROPERABILITY

The most common form of interoperability is the result of commercial agreements. Market participants may come to commercial agreements on the form of interoperability, or make unilateral decisions, to ensure interoperability is possible. These commercial agreements also may be around creating a reference architecture to provide a technical template for the products in the system. Examples of commercial agreements and decisions leading to increased interoperability include:

- social media platforms such as Facebook and Twitter open up APIs to application developers to enable the integration of new applications on their platforms;
- Apple's App Store's decision to allow third-party developers to create and share apps through the store allows vertical interoperability between developers and Apple.

There are benefits to this path to interoperability which can be implemented faster and may be less costly than decisions that need many different parties to agree. However, there are also costs. Unless there are long-term contracts there may not be any long-term security around the commercial agreements. Decisions such as opening up APIs could be reversed or limited to certain companies. In addition, depending on the bargaining positions in an agreement the degree of interoperability decided on may only benefit one of the firms and might not be best for consumer outcomes.

However, commercial agreements require complex coordination (see Section 2.2.3). There may be many parties to the interoperability agreement (or even thousands of parties in the case of interoperability with digital platforms). Different parties to any negotiation have different incentives to agree interoperability. Some parties will not want to agree a certain form of interoperability if their existing investments risk being stranded if they are not compatible with a proposed interoperability standard.[46] Negotiation of standards via a committee of interested parties is time consuming and may not lead to an optimal standard. As is discussed in Section 6.3, in relation to the design of the shipping container, the standard that was agreed on after over a decade of discussion, was felt not to be optimal for any user. This coordination problem is mitigated where one party sets the terms of interoperability, but parties wishing to interoperate may consider that the terms offered are not optimal for them individually.

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[46] See Section 6.3 for discussion of how this issue delayed agreement of standards in shipping containers. See also Farrell & Simcoe, 2012.

5.1.2 IP LICENSING AS A ROUTE TO INTEROPERABILITY

The key to enabling interoperability is to agree on a standard. One way to coordinate that has been observed is through IP licensing where one party (or multiple parties) licenses technology, specifications, and/or rights associated with the technology's use (Gasser, 2015)[47]. Another version of this approach is technical collaboration which enables a shared use of IP as was adopted by the USB standards group, which can often happen through a standard setting organisation. The case studies in Section 6 discuss the role that licensing of IP played in coordinating on a common standard to interoperate. The standard for the shipping container was only developed after a leading provider offered to license his design for free. The development of the USB standard for computer interface was enabled by parties forming a "patent pool" where relevant patents would be offered and shared by all members of the group on a royalty free basis. However, the effectiveness of a licensing approach to interoperability not only depends on the availability of a licence but on the terms on which it is offered and how willing the party is for their standard to be used. As set out in Section 6.4, one of the factors that inhibited the adoption of the Apple's Firewire 400 as a connection device was that it was only offered on license at $1 per port,[48] whereas the competing USB standard was offered on a free licence to members and for a small fee to non-members.[49]

5.1.3 STANDARD SETTING

Standard setting allows standard setting organisations (SSOs) to agree technical specifications or rules which can make interoperability easier. Often these standards are set through market discussions which are co-ordinated by SSOs such as the International Telecommunication Union (ITU) or the Internet Engineering Task Force (IETF). Standards can be developed for safety and performance but they can also aid interoperability.

There are benefits to this path to interoperability as the collaborative nature of agreeing standards means there is potential for a high degree of interoperability and also for more participants to adopt the standards. Also, clear, basic and easily accessible standards in a market could lower barriers to entry. However, the chosen or agreed standards may only represent the best standards at that time and the process could lack flexibility which might stifle innovation. Standards can lock markets on paths which may not be optimal as technology changes and make take up of new technologies more difficult.

Agreeing on standards this way can also be time-consuming, complex and difficult to agree if many parties are involved. Farrell and Saloner developed a model to compare outcomes in a situation where increased interoperability through compatibility comes from organic competition compared to standard setting which highlights this trade-off (Farrell & Saloner, 1988). The paper concludes that SSOs may lead to agreement on interoperability more often, but organic competition selects the winning standards more quickly. Overall, their model suggests that the delay which happens through SSOs is costly, but that this path to interoperability produces a better outcome.

[47] See p.17

[48] Arstechnica, *The tragedy of FireWire: Collaborative tech torpedoed by corporations,* Accessed Feb 22 - https://arstechnica.com/gadgets/2017/06/the-rise-and-fall-of-firewire-the-standard-everyone-couldnt-quite-agree-on/

[49] USB, *Getting a Vendor ID* , Accessed Feb 22 - https://www.usb.org/getting-vendor-id#:~:text=The%20licensing%20fee%20is%20US,for%20USB%2DIF%20members).&text=If%20your%20company%20does%20not,Vendor%20ID%20is%20US%246%2C000 .

5.1.4 REGULATORY INTERVENTION

Regulatory intervention may be needed in scenarios where firms do not have strong private incentives for interoperability, where there are public externalities for interoperability or where coordination is not possible.

Some models have suggested that firms will have unilateral incentives to offer interoperability, especially vertical interoperability, as the decision should be clear as prices and profits will be higher for firms who allow for interoperability due to a reduction in competition (Matutes & Regibeau, 1988; Economides, 1989). Some papers have found that in markets with network externalities or where one firm has a cost or technological advantage, this may not be the case and firms with dominant positions or a large installed base may not have incentives to offer increased interoperability (Katz & Shapiro, 1985; Farrell & Klemperer, 2007). Katz and Shapiro compare the private and social incentives to produce interoperable products and find that firms with good reputations or large existing networks will not have incentives for interoperability as the switching costs and network effects limit consumer switching. But firms with small networks will favour interoperability and overall private incentives for interoperability may be lower than the overall social incentives. Due to this mix of possible incentives between players in a market, regulatory intervention or guidance may be needed to increase the degree of interoperability.

Intervention by governments can be positive if there are clear outcomes and benefits for consumers from imposing interoperability or standards. But regulatory involvement can also be a slow process bringing in a degree of inflexibility to the interoperability. The process may also not lead to the optimal method in fast moving markets. One way to do this efficiently could be for regulators or governments to enforce or mandate increased interoperability but set up a standard setting organisation which may more efficiently decide on the appropriate methods and standards.

5.2 EXAMPLES OF WHERE INTEROPERABILITY HAS BEEN USED AS A POLICY TOOL

Service providers in digital markets, as with any market, will have different business models, strategies and comparative advantages meaning it can be difficult to align incentives to be able to reach the socially optimal level of interoperability in a market. Ultimately, some form of intervention may be required to facilitate interoperability if deemed desirable based on the trade-offs discussed above. The possible need for regulatory intervention due to lack of private incentives was clearly outlined in the UK's digital competition expert panel's report on Unlocking Digital Competition (Coyle, et al., 2019)

> *In some cases the obstacles to interoperability are technical, in some cases due to lack of co-ordination; but in other cases the obstacles are due to misaligned incentives as such interoperability might have broader benefits but to the cost of the dominant companies. Email standards emerged due to co-operation but phone number portability only came about when it was required by regulators. Private efforts by digital platforms will be similarly hampered by misaligned incentives.*[50]

Given this regulators and policy makers are increasingly considering interoperability as a policy instrument to promote more effective and efficient functioning of markets. Policy makers have recently also proposed "ex-ante" regulations or rules in digital markets on issues including interoperability as market investigations or standard ex-post competition policy can be viewed as too slow to take effect, particularly

[50] See p.33

in fast moving digital markets (Coyle, et al., 2019). Tirole notes this when discussing current competition policy;

> *…[Competition policy] is slow. A fine on an incumbent for anticompetitive behaviour may serve as a deterrent for future such behaviour, but it does not really help the entrant that went belly up in between. (Tirole, 2020)*[51]

> *Competition policy in the digital age must achieve speedy and decisive resolution and must be agile to react to new environments and benefit from learning by doing. (Tirole, 2020)*[52]

There is a long history of using interoperability as a policy tool used by regulators to reduce switching costs, increase competition and also as remedies to competition concerns in markets such as telecommunications, banking and digital services.[53] It is noteworthy that there have been decisions by competition authorities or NRAs which have limited the ability of firms to integrate their *internal* data systems in order to meet competition objectives.[54]

5.2.1 INTEROPERABILITY AS A POLICY TOOL

There have been a number of legislative actions in the European Union, national legislative activities, and other countries such as the US where interoperability has legislated or is proposed.

EUROPEAN LEGISLATION ON INTEROPERABILITY

Following the gradual liberalisation of Europe's telecommunications sector in the 1980s and 1990s, interoperability between different networks was mandated. In 1997 the principles of Open Network Provision, which allowed public fixed telecommunications networks to be used by any operator, were used to ensure interoperability in telecommunications across Europe (Directive 97/33/EC, 1997). Building on this, interoperability was further codified at a European level in the **EU's Access Directive** 2002 which established a regulatory framework for electronic communications networks across Europe and had interconnection at its centre. The directive aimed to establish a regulatory framework that would result in sustainable competition, interoperability of electronic communications services and consumer benefits (Directive 2002/19/EC, 2002). The directive also encouraged the use of standards and/or specifications to ensure interoperability of services and to improve freedom of choice for users.

The European Electronic Communications Code (EECC) directive consolidated, reformed and updated the framework for the regulation of electronic communications services and networks across the European Economic Area. A key aim of the directive is to enable "*interoperability of electronic communications services" (*Article 1). The EECC gave powers to National Regulatory Authorities (NRAs) to impose interoperability between number independent interpersonal communications services (NI-ICS) (which are Over the Top communications service which do not require a number to support ensuring end-to-end

[51] See p.6

[52] See p.7

[53] Note that there have been no examples that we have seen where interoperability was prohibited between separate companies as a remedy due to concerns it might lead to further anti-competition effects or market power.

[54] For example the decision by the German BKartA prohibited Meta / Facebook from integrating its data across its different platforms. Similarly in economic network regulation there can be an obligation on vertically integrated network providers with Significant Market Power to functionally separate their wholesale and retail operations to mitigate risks of retail foreclosure. Though both these examples are not a prohibition of interoperability, since they relate to sharing of data *within* a single company.

connectivity) and other services (Article 61). Although it does not mandate interoperability for these services, it outlines it as a potential future action which goes further than previous policies. There are concerns that with the increased use of these services as opposed to number dependent services which are already within an interoperable ecosystem, the lack of sufficient interoperability between NI-ICS services could affect end-users. The article outlines that national regulators may be able to impose interoperability obligations on NI-ICSs if end-to-end communication between end users is endangered. These obligations can only be imposed if they are proportionate and when the Commission, after consulting BEREC, has found an appreciable threat to end-to-end connectivity between end-users throughout the Union or in at least three Member States (Directive 2018/1972, 2018). The code is currently in the process of being transposed into member state's laws.[55]

In addition, Article 20 of **European GDPR regulation** gives users the right to data portability which as shown in Section 3.4 is a tool that can support increased interoperability in the market for data (Regulation (EU) 2016/679, 2016).

> *The data subject shall have the right to receive the personal data concerning him or her, which he or she has provided to a controller, in a structured, commonly used and machine-readable format and have the right to transmit those data to another controller without hindrance from the controller to which the personal data have been provided (Article 20 (1)).*

Despite being in place, a recent survey of messenger and video service companies by the German Bundeskartellamt, as part of their sector inquiry into messenger and video services, suggested that the number of requests for data portability was negligible in relation to the number of registered users of the respective service (Bundeskartellamt, 2021)[56]. Although research into widespread usage has not so far been done, these findings may be an indicator of low take-up in other areas too. This shows that regulations can be a starting point to make increased interoperability possible, but encouraging consumer usage could also be important to ensure the targeted outcomes from increased interoperability can be achieved.

The data portability outlined here is a tool which can lead to increased interoperability across the data layers of systems, but further requirements such as for the data to be understandable by competing devices or systems could enhance interoperability further. The rationale for this approach was partly provided to empower "data subjects" who had rights over how their data was used. However, it was also intended to facilitate competition. The Article 29 Working Party (Art. 29 WP) (which was the independent European working party that dealt with issues relating to the protection of privacy and personal data until 25 May 2018) considered that data portability rationale related to:

> *"empower[ing] data subjects and let[ting] them benefit more from digital services. In addition, it can foster a more competitive market environment, by allowing customers more easily to switch providers (e.g., in the context of online banking or in case of energy suppliers in a smart grid environment). Finally, it can also contribute to the development of additional value-added services by third parties who may be able to access the customers' data at the request and based on the consent of the customers. In this perspective, data portability is therefore not only good for data protection, but also for competition and consumer protection."[57] (De Hert, et al., 2018)*

[55] This process is currently taking longer than the initial timelines which outlined that the code should be transposed by the 21st of December 2020. 18 member states have still not transposed the code. *European Commission, EU Electronic Communications Code: Commission calls on Member States to fully transpose new telecom rules into national law, September 2021*

[56] See p.34

[57] This quotation is taken from the academic study referenced which provides an overview of the Article 29 Working Parties work.

The European Commission's draft **Digital Markets Act (DMA)**[58] which was published in December 2020 set out some limited provisions for interoperability.[59] The DMA imposes a number ex-ante obligations and prohibitions on digital gatekeepers. These included a number of provisions related to interoperability. However, the draft stopped short of mandating general interoperability. Instead it requires mandated interoperability of app stores and third-party software applications with operating systems of gatekeepers (Art 6(1)(c)), "ancillary services" (Art 6(1)(f)); real-time data portability (Art 6(1)(h)); and business-user access to their own and end-user data (Art 6(1)(i)). Article 6(1)(c) acknowledges the trade-offs and possible privacy and security costs which could be associated with increased interoperability as it mentions that "*The gatekeeper shall not be prevented from taking proportionate measures to ensure that third party software applications or software application stores do not endanger the integrity of the hardware or operating system provided by the gatekeeper*" (European Commission, 2020)[60]. Article 6(1)(f) relates only to "ancillary services" such as sign in or payment and not to the gatekeeper's core service. Article 6(1)(h) provides a form of data portability. It requires gatekeepers to enable data portability to third-party platforms but in real time. However, this will require significant consideration as to how data will technically be ported from one provider to another in real time.

In February 2022, the European Commission put forward their proposed **Data Act** (European Commission, 2022b). The Act aims to foster access to and increase the use and sharing of data in the European economy and it aims to ensure fairness in the allocation of value from data that is used. Part of the Act aims to improve data use across sectors of the economy which will rely on interoperability of data. One of the ways it aims to do this is through promoting interoperability across European data spaces through open interoperability standards. The Act imposes new obligations on manufacturers of products that collect data to share such data with the users of their products, related services and with third parties at a user's request. In this sense it extends the GDPR right of portability of personal data to non-personal data created by the user. It also imposes additional technical requirements on cloud, edge and other data processing services to make switching between them easier. The Act will now go through a legislative process before it is finalised and entered into force.

[58] Since the publication of the draft DMA in December 2020 there has been debate the Act. As of writing the Act is not yet finalised but in December 2021, the European Parliament put forward proposed amendments to the DMA which included additional provisions for interoperability, beyond those listed in the draft (European Parliament, 2021). The amendments maintained the obligation for gatekeepers to allow the effective interoperability of third-party software applications with operating systems of gatekeepers (Art 6(1)(c)) but included an additional requirement that any measures that are introduced to maintain the integrity of the system need to be "*duly justified by the gatekeeper*". Art 6(1)(f) has been amended to apply beyond ancillary services and now suggests that gatekeepers will need to allow third-party business users, providers of services and providers of hardware the ability to interoperate with the same hardware and software features that are accessed or controlled via an operating system that are available to first-party services or devices provided by the gatekeeper. This is an increase in the degree of interoperability from that was initially proposed. In addition, two additional sub-points have been added to Art 6(1)(f). Art 6(1)(fa) would mandate interoperability on request between NI-ICS and gatekeeper's NI-ICS and Art 6(1)(fb) would mandate interoperability and interconnection between social network services and gatekeeper's social network services.

[59] An 'Interoperability Directive', was discussed by the Commission as part of the actions related to the 2010 Digital Agenda for Europe. In a Staff Working document on the feasibility of ex ante enforcement of interoperability the Commission wrote that such a policy of compulsory licensing of interoperability information might address cases where market players were unwilling to license interoperability information and where this negatively impacts the functioning of the single market (SWD 209 Final, 2013, p. 13). But the policy was not considered in the end due to concerns about proportionality and costs of implementation (Graef, 2014, p. 17).

[60] See p.40

The **second payment services directive** (PSD2) mandated for data interoperability in the electronic payments market across Europe aiming to make internet and mobile payments easier and help customers manage their accounts through a range of applications allowing them to find the best products. PSD2 made it clear that customers had the right to use third-party payment and information service providers and that traditional financial institutions should allow the necessary data and information to be shared with these services. PSD2 provided the legislative and regulatory foundations for Open Banking.[61]

The European Commission's "Common Charger" initiative has progressively increased interoperability between mobile devices and chargers by setting a framework to agree common standards. The European Commission facilitated a voluntary agreement on the "harmonisation of a charging capability for mobile phones", resulting in a first Memorandum of Understanding (MoU) signed by most mobile device equipment suppliers to adopt the Micro-USB in 2009. More recently the European Commission has put forward legislation to establish a common charging solution for all relevant devices (European Commission, 2021c). The proposal to revise the Radio Equipment Directive, will allow increased interoperability between chargers and devices. USB-C will become the standard port for all smartphones, tablets, cameras, headphones, portable speakers and handheld videogame consoles and the revision proposes the unbundling of the sale of chargers from the sale of electronic devices. The policy aims to reduce e-waste and improve consumers' convenience. It is also expected to reduce costs for consumers who can now have one common charger, however the Commission acknowledges that this increased interoperability could potentially impose costs on manufacturers and constrain innovation (European Commission, 2021d)[62].

EUROPEAN MEMBER STATE LEGISLATION ON INTEROPERABILITY

European member states have also initiated individual actions which promote interoperability at a national level.

The Netherlands has published a **non-paper on the European Commission's proposed Data Act** to contribute to the discussion around the Act (Netherlands PermRep EU, 2021). It argues that due to a lack of interoperability between data, individuals and organisations are hesitant or unable to share their data. They argue this limits the potential of data to drive innovation and it also leads to competition problems such as lock-in or excessive bundling of services which highlights the costs of low interoperability in this situation. The non-paper proposes that the Data Act should outline interoperability requirements on firms and should create "*a framework for development and implementation of the standards necessary to increase interoperability"* so that the benefits of data portability can be realised (Netherlands PermRep EU, 2021)[63]. The non-paper also acknowledges the costs associated with increased interoperability and the importance of understanding the optimal degree in each sector as it proposes that the European Commission determine for which sectors, services and products increased interoperability should be prioritized.

In the retail banking sector in the UK, the CMA has implemented legislation to increase interoperability with the aim of increasing competition in retail banking markets. **Open Banking** was mandated by the CMA following its retail banking market investigation and they set up an independent organisation to oversee

[61] UK Finance FAQs, *Frequently Asked Questions on Payment Services Directive 2 and Open Banking* , Accessed Feb 22 - https://www.ukfinance.org.uk/system/files/Frequently-Asked-Questions-on-PSD2-and-Open-Banking.pdf

[62] See p.75

[63] See p.1

the process. The CMA found that older, larger banks did not have to work hard enough for customers' business, while smaller and newer banks found it difficult to grow and access the market. As a result, the bigger banks had commanded a very large share of the market for decades.[64] As a result Open Banking was introduced as a remedy to boost competition and innovation in the retail banking market through increased data interoperability between complementary services. The remedy required that the nine largest current account providers in the UK provide a standardised API to share customer information on bank transactions and account details securely when requested by the customers. The protocols and standards for the APIs are regulated by the Open Banking Implementation Entity (OBIE) to ensure it is easy for third parties to access the open APIs and also to ensure security standards are maintained. The OBIE was set up following the CMA's market investigation as an independent organisation to oversee the implementation of Open Banking and the practical steps this required. The policy has succeeded in increasing interoperability but it might be too early to assess the impact on competition and innovation due to slow consumer take-up, similar to the low use of data portability in GDPR referred to in Section 5.2.1 above. Innovation has occurred within retail banking markets but perhaps not at the speed expected. For example, the adoption of Open Banking services in the UK continues to grow with 8% of digitally enabled consumers estimated to be regular users of at least one open banking service, up from 5.5% in December 2020 and there are now 119 firms offering live to market open banking-enabled products and services.[65] But, the market share of the nine largest providers of current accounts has not changed meaningfully since the intervention.

France's communications regulator, **ARCEP**, published a report which considered the case for "device neutrality" considering whether devices should not discriminate or preference the suppliers' services (whether by design of the hardware or the operating system) (ARCEP, 2018). The report recommended measures both for limiting the bias that devices induce over the content consumed, such as the ability to delete pre-installed apps, and to impose access obligations for device manufacturers APIs.

US LEGISLATION ON INTEROPERABILITY

The US Congress has introduced a bill which as currently drafted would mandate a broad requirement for interoperability for digital services. **The ACCESS (Augmented Compatibility and Competition by Enabling Service Switching) Act** is a proposed bill in the United States which is currently in the process of being reported to the House of Representatives and aims to promote competition, lower entry barriers, and reduce switching costs for consumers and businesses online (117th Congress - 1st Session, 2021). The bill proposes that large online platforms, determined by users and annual sales, would be required to maintain their platforms so that they are interoperable with competing businesses and so that user data can be portable.[66] On interoperability the Act states that;

> *"A covered platform shall maintain a set of transparent, third-party-accessible interfaces (including application programming interfaces) to facilitate and maintain interoperability with a competing business or a potential competing business that complies with the standards issued" (Section 6(c)).*

[64] Competition and Markets Authority Blog, *Celebrating the first anniversary of Open Banking*, Accessed Feb 22 - https://competitionandmarkets.blog.gov.uk/2019/01/11/open-banking-anniversary/

[65] OBIE, *The Open Banking Impact Report*, Accessed Feb 22 - https://insights.openbanking.org.uk/the-open-banking-impact-report-october-2021-ug/home/

[66] White & Case, *House Bill Mandating User Data Portability and Platform Interoperability Could Impact Digital Companies of All Sizes*, Accessed Feb 22 - https://www.whitecase.com/publications/alert/house-bill-mandating-user-data-portability-and-platform-interoperability-could

If passed the Act would require the Federal Trade Commission in the US to establish standards for interoperability, data portability, data security and data privacy between digital platforms and their competitors. By setting these standards for interoperability the act is aiming to encourage entry and competition by sharing the network effects that large online platforms benefits from with all competitors. This bill goes further than other legislation to mandate interoperability and debates and decisions around it could influence other policy makers globally.

5.2.2 INTEROPERABILITY AS A TOOL TO PROMOTE OR MAINTAIN COMPETITION

Interoperability obligations have also been discussed and imposed by competition authorities in relation to merger control and to address competition concerns. In merger review in Europe, the European Commission may adopt commitments that are offered by the parties in order to address competition concerns including interoperability commitments. In addition, a refusal to give competitors access to interoperability information may constitute an abuse of dominance under Article 102 of the Treaty on the Functioning of the European Union (TFEU) and the Commission can impose interoperability obligations due to this.

Interoperability has been introduced as a remedy to merger control in a few cases across the healthcare industry, software industry and digital markets. Some examples are shown below.

- In 2010 the European Commission approved the acquisition of **Tandberg**, a firm that produced videoconferencing products, **by Cisco** which among other aspects is present in the market for videoconferencing solutions. Due to the Commission's concerns about the horizontal overlaps between the two firms and concerns about how the merged entity would interoperate with competitors, there were conditions to the approval (Graef, 2014). First, Cisco committed to transferring its intellectual property rights relating to the Telepresence Interoperability Protocol (TIP) to an independent industry body, which would be free to join, and would be responsible for updating and managing the protocol and would help develop an industry standard for videoconferencing. The TIP protocol allows different videoconferencing systems to communicate with each other (CISCO/ TANDBERG, 2010). Second, Cisco committed to the creation of a source code library of the new version of TIP which would be accessible to third parties. Third, Cisco committed to continue to implement and support the TIP protocol so that interoperability between it and competitors using the standard was ensured. Here the commission used a commitment to interoperability through an independent body to ensure the market remained competitive.

- In 2011 the Commission approved the acquisition of **McAfee by Intel** subject to commitments by Intel. Intel and McAfee are active in complementary product markets as in order to develop new security solutions, security technology firms such as McAfee need access to information about CPUs, which Intel are the leading producer of, to ensure their programs run on the latest versions. The Commission was concerned that the acquisition could lead to other security technology firms being unable to work with, or suffer from reduced interoperability with Intel CPUs (Graef, 2014). To remove concerns Intel committed to ensure interoperability of future products in both markets with those of competitors.

- In 2016 the European Commission approved the acquisition of **LinkedIn by Microsoft** subject to conditions, including interoperability requirements, which aimed to preserve competition between professional social networks in Europe. The conditions were imposed based on concerns that after the merger, Microsoft could use its position in operating systems and productivity software to strengthen LinkedIn's position among professional social networks. The conditions relating to interoperability were that Microsoft had to commit to allowing competing professional social network providers to maintain current levels of interoperability with Microsoft's Office suite of products and Microsoft had to continue to grant access to various APIs for other professional social networks (Microsoft / LinkedIn, 2016).

- The 2018 European Commission decision which approved the acquisition of **Shazam by Apple** was an example where increased or mandated interoperability was not required as a condition of a merger, despite interoperability concerns being raised by competing automatic content recognition (ACR) software solutions (which include music recognition apps like Shazam). Concerns were raised that post-merger Apple could degrade the interoperability of other ACR services provided by Shazam's competitors with Apple's operating system or Apple's device microphones (Apple / Shazam, 2018). However, the Commission concluded that Apple would not have the incentive to do this and that even if they did it would not have a significant negative impact on competition. This example highlights how increased interoperability is not always the answer and the degree of interoperability needed can be market specific.

- In 2020, the European Commission approved the acquisition of **Fitbit by Google** subject to compliance with a commitments package. Similar conditions requiring the maintenance of interoperability for competitors and access to APIs were imposed. There were concerns that after the acquisition Google could reduce access to Fitbit's Web API which other players rely on for their services and Google could reduce the interoperability of other smart devices with its android operating system and smartphones. Conditions were imposed to ensure the interoperability with Google's smartphones and operating system were maintained and that access to Fitbit's Web API remained open (Case M.9660 – GOOGLE/FITBIT, 2020). These conditions from the Commission again highlight the important role interoperability can play in allowing competition in markets and how the degree of interoperability and who controls it should be monitored.

Interoperability has also been imposed as a behavioural remedy or accepted as a commitment following an investigation into abuse of dominance in relation to restricted interoperability.

- In 1980, the Commission had alleged that IBM abused its dominant position in the market for CPUs and operating systems for its most powerful computers, the System/370 by failing to provide other manufacturers with timely technical information needed to allow their products to be used with System/370 (Graef, 2014). In response IBM committed to disclose timely and sufficient interface information to enable competing companies to develop products that could work with the System/370 and interconnect with it. However, this commitment was not legally enforceable and was made in good faith so does not provide any insight on when the refusal to share interoperability information could be considered an abuse of dominance.

- As noted in Section 4.2.1, in 1998, Sun complained that Microsoft violated Article 102 TFEU by refusing to license technical information that work group server operating systems needed to interoperate with Microsoft's PC operating system Windows. This refusal had only started once Microsoft had developed its own work group server operating system and before that the technical information needed for interoperability had been shared. By keeping this information to itself Sun argued Microsoft was trying to extend its dominance in PC operating systems to work group server operating systems. In 2004 the Commission's decision stated that Microsoft had abused its dominant position in PC operating systems and in 2007, following an appeal, the General Court upheld this finding and required Microsoft to disclose the interoperability information it had withheld (Graef, 2014).[67]

5.3 CONCLUSIONS

In Europe both merger control and the competition policy regime offer scope to enforce interoperability under competition law. However, when these interventions can take place and the issues of legal certainty around them create some issues. For example, merger control remedies can only be imposed if a merger is proposed whilst competition intervention under abuse of dominance can only happen ex-post and is a long process from abuse to remedy (Graef, 2014).

Policy makers have in different settings implemented or proposed ex-ante regime interoperability requirements. However, competition authorities need to carefully consider the rationale for ex-ante intervention as a to remedy competition concerns since by definition it imposes costs on parties (who otherwise would not interoperate, or interoperate in a different manner to what is envisaged in ex-ante regulation).

[67] Discussion of relevant case law and legal precedent can be found on p.10-11 of Graef, I., 2014. How can Software Interoperability be achieved under European Competition Law and Related Regimes?. *Journal of European Competition Law & Practice*, 5(1)

6 LESSONS ON INTEROPERABILITY FROM HISTORICAL CASE STUDIES

6.1 OVERVIEW OF CASE STUDIES

6.1.1 INTRODUCTION

There are many examples of how interoperability has led to significant improvements in economic welfare. This section introduces three case studies to put the topic of interoperability into its historical and economic context. The cases have been selected to illustrate the different features of interoperability outlined in previous sections. Each case study has been developed using the same structure and examines (1) the market situation before the interoperable standard was developed, (2) the path to interoperability (3) the impact of the interoperable standard, and (4) the key lessons that can be learnt in the context of current debates. The case studies and key lessons are summarized below.

6.1.2 CASE STUDY 1 – THE DEVELOPMENT OF THE TELEPHONE STANDARD

The commercial development of the telephone began in 1877 in the United States. After a period of initial monopolisation by the American Bell Telephone Company (later AT&T), the expiry of Alexander Graham Bell's patents in 1894 led to a period of intense competition. However, competition also brought a lack of interoperability between competing networks who were unwilling to interconnect. By the 1920s, AT&T had imposed a de-facto technical standard on the market as the firm once again became a monopoly power.

6.1.3 CASE STUDY 2 - SHIPPING CONTAINERS

American trucking entrepreneur Malcom McLean developed the intermodal container to ship goods in 1956 to make the process of moving goods from land transport to ships more efficient. McLean's innovation was to use the same container for both land transport and shipping (hence it was "intermodal"). Containerisation has revolutionised land and sea distribution networks by making them interoperable.

6.1.4 CASE STUDY 3 – THE USB STANDARD

The USB is an industry standard that establishes specifications for cables, connectors and protocols for connection, communication and power supply between personal computers and their peripheral devices, or between a device and the external power supply. The USB standard streamlined several port types to one, allowing hardware interfaces to interoperate more effectively. Hardware interfaces are the plugs, cables, or electronic signals transported from the computer to the peripheral device or network.

6.1.5 IMPLICATIONS FOR INTEROPERABILITY

When considered together, there are a number of key common themes to take away from the historical case studies:

All the case studies demonstrate that a lack of interoperability creates inefficiencies and can harm consumers. Prior to containerisation, there was no coordination between different distribution networks, and shipping was costly, risky and time consuming. Before the USB standard was developed, consumers faced the inefficient process of requiring different types of connectors for different devices. In early US telephone networks, users often required two separate telephone sets and connections in order to call all those in the same city. For each case study, the lack of common standard created inconvenience and added costs, which were often borne by end consumers.

Interoperability enabled significant efficiencies and positive externalities. The development of an interoperable standard brought cost saving efficiencies in every case study. Loading and unloading times in the shipping industry dropped considerably following containerisation. The standardisation meant that many different stakeholders in the transportation industry could make investments in their own infrastructure (whether ports, ships, trucks, railways) without coordinating directly, which also led to wider externalities in world trade and globalisation. The USB standard generated efficiency gains for consumers and developers due to the ease of attaching peripheral devices and also stimulated innovation in these devices. In early US telephony, the common standard eliminated the inefficiencies of dual service and allowed AT&T to use its market power to realise economies of scale, invest heavily in wider R&D and incrementally enhance its services.

While there are many different paths to interoperability, it may not emerge spontaneously. In each of the case studies, interoperability was achieved through a different process, but in each case it did not develop automatically. Different stakeholders have individual, and in many cases, conflicting incentives which can act as a barrier to interoperability. In early US telephony, it is unlikely that AT&T would have been able to impose its standard on the industry without a supportive regulatory and societal environment which allowed it to become a regulated monopoly. In the case of containers, it took over a decade to agree standards in the US, then many more years to agree standards internationally. Shipping companies, ports and land based transportation had all invested in their own incompatible technologies and were unwilling to leave this investment stranded if other standards were adopted. Longshoremen that worked in the ports were a barrier to adopting, fearing (correctly) that their jobs were at risk as a result of the innovation. However, the USB standard was a counter example where many different firms sought to collaborate to agree an industry led standard without regulatory and policy support.

Sharing the Intellectual Property was one way to coordinate around a given standard. Containerisation only developed after McLean opened the patent on his own container, before formal standards were agreed by independent national and international bodies. For the USB standard, a significant degree of coordination was required for Intel to marshal an industry-led effort to create a ‘patent-pool’ for the common standard.

Achieving interoperability is often a trade-off, and some paths to interoperability may be more costly than others. Common standards, while bringing efficiencies and positive externalities, can also have some negative welfare effects. There can also be a trade-off between common standards and competition, which can hinder innovation. For example, the common standard that developed as AT&T monopolised early US telephone networks came at the cost of competition. This competition had previously incentivised firms to expand, lower prices and drive innovation. After imposing its standard on the market, AT&T was slow to adopt non-AT&T innovations and used its dominance to restrict innovation in downstream markets. This may have led to delays in the development of early internet technology. The case of early US telephony clearly illustrates the dangers of achieving interoperability alongside the dominance of a single firm.

Interoperability is not static and can be incrementally improved over time. In each case study, interoperability was improved over time, even after an initial common standard was developed. Interoperability in shipping improved after containerisation through the expansion of ports, further international standards and ship adaptations. Since the invention of the first USB standard there have been multiple improved versions which has allowed for the connection of even more peripheral devices and facilitated quicker data transfer speeds. After AT&T imposed its standard on early telephone networks it proceeded to incrementally improve interoperability, for example, through the development of a nationwide numbering plan and direct-distance dialling.

6.1.6 SUMMARY OF CONCLUSIONS

Each of the selected case studies represents a unique story on the development and effects of interoperability. While the examples in this report are taken from very different markets and distinct time periods, a number of common themes are apparent. Interoperability can be extremely beneficial, generating efficiencies and positive externalities. However, it is unlikely that interoperability will emerge spontaneously and different paths to interoperability can have very different effects. Achieving interoperability through, for example, the dominance of a single firm could potentially create a situation where the negative trade-offs associated with interoperability outweigh the positive effects.

6.2 CASE STUDY 1: THE DEVELOPMENT OF THE TELEPHONE STANDARD

The early history of US telephony highlights the costs and benefits of interoperability when it is due to the dominance of a single firm. That firm was Alexander Graham Bell's AT&T. The standards AT&T entrenched cut out inefficiencies and reduced calling costs, but also stifled competition and innovation, slowing the development of the industry as a whole.

BEFORE THE STANDARD

Bell was granted a patent for his telephone in 1876 (Coe, 1995). Before long AT&T was the monopoly telephone network and, through its subsidiary Western Electric, the sole legal manufacturer of telephones in the country until 1894. Telephone penetration spread slowly during this initial monopoly period. By 1895, just 4.8 per 1,000 Americans had a phone (Hyman, et al., 1987).

As soon as the last of AT&T's patents expired in 1894, competitors rushed in. By the end of that year, 80 new independent network operators had grabbed 5% of the market. By 1907 non-AT&T firms accounted for 51% of local-network business (Brock, 1981).

During the early stages of competition, AT&T refused to give outside firms access to its long-distance networks. AT&T reckoned the full value it could collect from maintaining a monopoly was greater than the gains it could make from tapping a limited number of extra users. Perhaps surprisingly, most independents did not mind (Mueller, 1997). They did not see AT&T's long-distance lines as important for their subscribers, who were mostly making local calls.

The consequence of having two sets of competing, non-interoperable networks was dual service areas. Someone connected to one network could not call a user of another unless they had two separate phone lines. This costly duplication was a recipe for inefficiency. Businesses would often need separate phones and directories to reach suppliers and customers. Callers had to know which network their contact's phone was connected to. Advertisements listed multiple phone numbers (Brooks, 1975). By 1904, 60% of cities were dual service (Mueller, 1997).

Despite the obvious drawbacks, the lack of interconnection brought some benefits as AT&T and the independents raced to sign up subscribers and expand their networks. The competitive frenzy increased telephone penetration across America (MacDougall, 2005). Prices fell sharply; independents' rates were as much as a half lower than AT&T's. And competition drove innovation: it was independent entrants to the market – not AT&T - that pioneered the use of automatic switching technology to connect customers' telephone lines (Nix & Gabel, 1996).

WHAT LED TO THE STANDARD

By the mid-1920s, however, AT&T had reasserted its leading market position and imposed industry standards (Kavassalis, et al., 1996). The US telephone network was interoperable. Three factors were crucial to this outcome: AT&T's adoption of a 'Universal Service' strategy, enabling regulation and public pressure for a consolidated network.

Universal Service. Faced with a shrinking market share, AT&T did a policy U-turn in 1901 and began interconnecting with independent exchanges as long as they met three conditions: an exchange could not be in direct competition with any AT&T company exchange; it could use only (AT&T owned) Western Electric telephones; and it had to agree to connect only with AT&T long-distance lines (Brooks, 1975).

From 1907, AT&T relaxed its stance further and began to publicly promote a Universal Service strategy. This led to a surge in networks using AT&T's standards. The percentage of independent telephones interconnected to AT&T networks increased from 14% in 1907 to 67% in 1914 (Mueller, 1997). By that time, fully 89% of independent telephones on non-competing networks were linked up to AT&T. This severely hampered attempts to set up a rival regional and long-distance network, while AT&T's widening reach increased the value of its service to current and prospective subscribers.

Enabling regulation. To avoid antitrust litigation, AT&T agreed with the federal government in 1913 to stop acquiring competing independent exchanges and to interconnect all non-competing exchanges to its long-distance network (Bolter, et al., 1990). The deal was known as the Kingsbury Commitment. The agreement appeared to halt the spread of AT&T's standard, but in practice it did not.

The Kingsbury Commitment was costly for independents because it meant they had to meet AT&T's technical standards. And the ban on acquisitions only briefly slowed AT&T's march to monopoly. As support for dual service competition waned, the Kingsbury Commitment was the only obstacle in the path of acquisitions that the public, state governments and local independent operators all desired (Mueller, 1997).

Accordingly, the federal government agreed to make exceptions to the commitment as long as AT&T's acquisitions were in dual service areas and AT&T sold off another local network to an independent (Brock, 1981). The impact of what one critic has called a "*lax and malleable regulatory regime*" was striking (Weiman & Levin, 1994). By 1924, AT&T had snapped up 223 of the 234 independent telephone companies (Lloyd, 2010). Once again it dominated the industry and had succeeded in imposing its private technological standard.

Social pressure. Underlying the regulation that enabled AT&T's universal service was growing public pressure for interoperability. AT&T did most of the early lobbying for a unified service itself. AT&T companies orchestrated media campaigns to sway public opinion to view the industry as a natural monopoly while highlighting the damaging effects of dual service (Weiman & Levin, 1994).

HOW THE STANDARD CHANGED OUTCOMES

Sixty percent of American cities had competing networks in 1904, but by the mid-1920s dual service had been eliminated. Users now required only a single telephone and paid a single rate. As well as saving money they enjoyed increased network effects as they were able to call all those with telephones in their city and further afield. Interoperability magnified the benefits of telephony, including greater societal integration, quicker communication for businesses and reduced transaction costs.

AT&T's standardisation ideology, which put the priority on stability, reliability and uniformity, was seen by some as crucial in helping the company tackle the complexity entailed by rapid expansion of the telephone service. Between 1920 and 1938, the number of telephones on AT&T networks jumped from 7.7 million to more than 19 million (Russell, 2014).

But the effect of AT&T's imposed standard on innovation was mixed. AT&T shunned radical or disruptive innovations in favour of incremental change. This meant it was late adopting a number of key technologies, setting back the development of the industry as a whole. For example, it was cheaper and more efficient to use machines rather than humans to connect calls, but AT&T did not incorporate automatic switching into its standards until 1919, more than 20 years after independent operators started to make the change (Russell, 2014).

AT&T also severely restricted the use of non-AT&T approved telephones or third-party equipment, effectively prohibiting external innovation in network devices. When regulators overturned these de-facto bans in 1968 and 1975, competition and innovation in downstream markets blossomed (Wu, 2007). People were able to buy telephones with an array of different features. Mass consumer versions of the fax machine were developed. Most importantly, the way was cleared for the rapid development of the modem and the early internet (Oxman, 1999). It is entirely possible that these innovations could have seen the light of day earlier but for AT&T's iron grip.

Nevertheless, AT&T's control of industry standards allowed it to keep improving interoperability. The time needed to connect a transcontinental call dropped from 14 minutes in 1920 to 1 minute by 1950. Direct distance dialling became commonplace from 1960. By 1970, a three-minute transcontinental call cost $1.35, down from $16.50 in 1920 (Abler, 1977).

CONCLUSION

The early US telephone networks provide a compelling case study in the pros and cons of interoperability. There are a number of key takeaways.

First, there are sometimes limited commercial incentives for interoperability. In the early years of competition, AT&T and most independent entrants opposed both vertical and horizontal interconnection. By not interconnecting, both sides could appropriate the full value of their respective networks, and both thought they could win the competition for new users.

Second, while a lack of interoperability can cause duplication, it can also yield significant gains for society. Competing firms had strong incentives to expand their networks, minimise costs and innovate.

Third, a supportive regulatory environment helped AT&T to impose a common interoperable standard. AT&T may not have achieved its goal of Universal Service without accompanying enabling regulation and social pressure. The implementation of antitrust law from 1913 onwards encouraged AT&T companies to acquire independents as a means to eliminate dual service. This lax regulatory regime helped AT&T impose its standards and achieve monopoly status.

Fourth, achieving interoperability through the dominance of a single firm can have harmful effects. AT&T invested heavily and enhanced its services, but it used its dominance to restrict innovations that threatened its power. This may have delayed the development of early internet technology. A dominant firm may also seek to leverage its market position to push into related markets.

Fifth, interoperability could have been achieved in other ways, but these also had drawbacks. One option considered during the early 1900s was mandated interconnection. However, this was almost always rejected by both sets of networks, the courts and users. Mandated interconnection might have led to subscribers converging towards a single network at the local level, effectively ending local competition. Furthermore, vertical interoperability would have removed the incentive for independent entrants to develop their own short-haul networks, which was key in increasing network coverage.

RELEVANCE TO TODAY'S SOCIAL MESSAGING NETWORKS

Parallels can be drawn between this case study and current debates over modern social messaging networks, such as WhatsApp or Snapchat. These networks are not interoperable. As with early telephone markets, this has spurred firms to compete aggressively for users by trying to boost the coverage of their networks and launching innovative services. While interoperability between these messaging apps may yield greater network effects, it could also lead to less product differentiation and reduce incentives to innovate.

The incentive to interoperate may be stronger for new messaging entrants because they would instantly be able to tap into the networks of the big established firms. These incumbents would have comparatively little to gain from interoperability. They would give up the benefits of network effects accrued in building up their customer base but would get little in return from accessing the smaller networks of new entrants.

But there are two big differences from the early days of telephony. First, the cost of subscribing to multiple messaging networks is close to zero. Dual telephone service, by contrast, called for expensive duplicated equipment. Second, modern messaging applications are more differentiated such that users may prefer multiple applications for their different social groups (business, family or friends etc).

6.3 CASE STUDY 2: THE DEVELOPMENT OF SHIPPING CONTAINERS

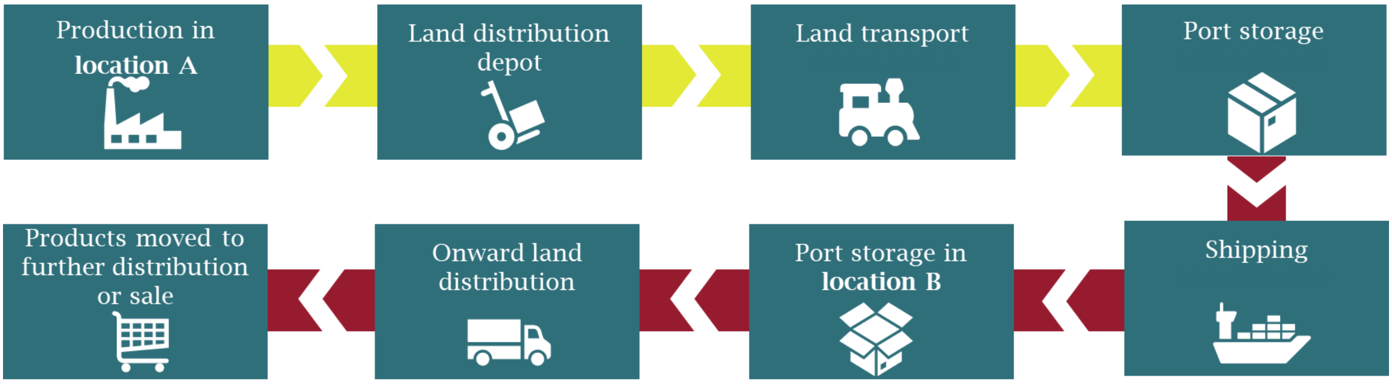
In the logistics industry, year zero is 1956. That was when American trucking entrepreneur Malcom McLean came up with the idea of using the same container for both land transport and shipping. The resulting interoperability revolutionised land and sea distribution networks.

BEFORE THE STANDARD

Before containers were widely adopted, homogeneous cargoes, such as oil or cereals, could be loaded and unloaded relatively efficiently at ports with specialised facilities. But most goods were shipped as break-bulk, the term used to describe the tedious process of transferring diverse types of cargo from lorries into sacks, barrels and wooden crates directly onto ships (Song & Panayidas, 2012).

It could take up to three weeks to load each ship as dockworkers squeezed as many items as possible onboard. They had to distribute the weight carefully to make sure the cargo couldn't move during the voyage, for fear of damaging the goods or even causing the ship to capsize (Levinson, 2006). There was no coordination with road and rail networks, so the costly break-bulk process had to be repeated at each distinct, non-interoperable distribution node.

FIGURE 11 STAGES REQUIRED TO TRANSPORT GOODS FROM PRODUCTION TO CONSUMPTION



Source: Frontier Economics

This lengthy process led to ships spending two-thirds of their productive time in port (Bernhofen, et al., 2016). The scope for economies of scale that could be realised from larger vessels was reduced. High levels of theft, loss and accidents increased insurance costs, while disputes with strong labour unions were common.

WHAT LED TO THE STANDARD

McLean did not invent the shipping container. The idea of moving goods in a box already existed. His insight was to make the same standardised container usable on ships, in ports and on land rather than being suitable for one network but not for others (Thompson, 2018).

In 1956 McLean remodelled his ships so containers could be stacked to increase capacity. Decks were widened and hatches expanded to give cranes access. The first converted ship sailed from Port Newark to Houston in 1956 carrying just 58 containers. The cost of transport came out at just $0.16 per tonne compared with the normal break-bulk rate at the time of $5.83 (Levinson, 2006).

The idea of containerisation started to gain popularity, but there was initially little change in the type of ship used because firms would design containers for their goods and for the vessels they already had (Tomlinson, 2009).

FORMAL STANDARDS

Shipping firms could not reach a consensus on a standard since they used different dimensions and materials for their containers, depending on their business model and customer base. Each company needed its own port infrastructure. What's more, ships designed to one standard could not be sold to a firm using a different standard, thus limiting their resale value.

Efforts to agree on a common standard began in the US in 1958. But the going was tough. Implementing new norms could have a big cost or commercial impact on a multitude of stakeholders. After various US government agencies became involved, agreement was eventually reached in 1961, and by 1968 the International Standards Organisation (ISO) had settled on a global standard for the size of containers.

Other norms were agreed to ensure the system's interoperability between distribution nodes, including a common fixing system so that different containers could be stacked or lifted. Again, the negotiations were difficult. The breakthrough came when McLean released his patent on his container fixings, free of charge and without conditions, paving the way for it to become the basis for the US standard (Ham, et al., 2012).

The international standard subsequently adopted by the ISO in 1970, after much haggling and compromise, was widely viewed as sub-optimal (Levinson, 2006). Nevertheless, it would go on to revolutionise world trade.

THE STANDARD UNLEASHED INVESTMENT

The standard may not have been the most efficient, but it permitted interoperability. Businesses could have confidence that almost every train, truck, port and ship could transport a standard container. The design of ships duly changed to accommodate the containers' specifications. Companies could invest in larger and faster vessels. The average ship length increased from 180m in the 1960s to 275m in 1973 (Levinson, 2006). The largest modern container vessels can be 400m long.[68] The ships grew in size due to the economies of scale that could be achieved from the rapid loading times made possible by the standardised container (Tomlinson, 2009).

Ports were initially resistant to change. But once containerisation proved to be effective and profitable, ports raced to build new terminals with the modern infrastructure needed to be competitive. Between 1973 and 1989, American ports spent $2.3 billion on container handling facilities (Levinson, 2006).

HOW THE STANDARD IMPROVED OUTCOMES

Efficiency. Economies of scale allowed for larger ships and more specialised port equipment, cutting delivery times and costs. In 1965, dock labour could move only 1.7 tonnes of cargo per hour; by 1970, that had jumped to 30 tonnes. Losses and damage due to repeated loading and unloading fell, slashing insurance premiums to one-sixth of pre-containerisation levels (Bernhofen, et al., 2016).

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[68] Marine Insight, *10 Smart Ship Technologies For The Maritime Industry*, September 2021 - https://www.marineinsight.com/know-more/10-smart-ship-technologies-that-maritime-industry/

Further efficiency gains are still possible today to speed up global cargo flows. Many countries have their own systems to check goods, often using paper forms. Freight forwarders are campaigning for standard digital trade documents and improvements are starting to be made.[69] It has also been suggested that this further interoperability could increase exports, decrease costs and have environmental benefits (Duval & Hardy, 2021).[70]

Globalisation. There were wider externalities from containerisation. The world became more interconnected. Once containerisation reduced the cost of shipping, it became economic for manufacturers to move factories to countries with lower labour costs or readily available raw materials (Song & Panayidas, 2012).

Containerisation also gave manufacturers greater confidence to ship components and finished goods around the globe. One academic study found that in a subset of countries trade soared by 320% over five years after the container was introduced (Bernhofen, et al., 2016).[71] Firms could calculate the speed of unloading and loading more accurately (Tomlinson, 2009). As shipping became more consistent and reliable, just-in-time production flourished. As well as saving money on goods storage and reducing waste, this allowed manufacturers to respond more quickly to changes in the market.

The upshot was exploitation of comparative advantages through greater specialisation. Companies no longer needed to be vertically integrated. Rather than making a product from start to finish, containerisation allowed them to outsource production of parts to specialised manufacturers and transport them somewhere else to be assembled. International supply chains duly lengthened (El-Sahli, 2013).

Globalisation has lowered the cost and increased the range of goods available to consumers. Developing countries that were able to plug into global supply chains have prospered, notably China. But globalisation has also capped the wages of certain groups, particularly unskilled workers in advanced economies (Morris, 2015).

CONCLUSION

Containerisation has dramatically reduced transport costs, boosted world trade and transformed global supply chains. It demonstrates many important features of interoperability.

First, standardisation cut costs and saved time when shipping goods. This in turn led to a wave of investment in distribution infrastructure. Each of the new inventions was interoperable through the shipping container, allowing different stakeholders to make their own investments – in ports, ships, trucks and railways - without explicitly coordinating.

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[69] Port Technology, *Shift in political thought needed to prepare supply chain for future crises*, July 2021 - https://www.porttechnology.org/news/shift-in-political-thought-needed-to-prepare-supply-chain-for-future-crises/

[70] In addition to Duval and Hardy's work on estimating the emissions savings from paperless trade, work commissioned by the ICC (International Chamber of Commerce) suggests that the facilitation of paperless trade (exchange of trade-related data and documents in electronic form across borders) could reduce costs as a share of total trade across the G7 by 76% through improvements such as reduced compliance times and could create $267 billion of additional exports by 2026 compared to base forecast. Further digitalising of the trade ecosystem could create as much as $6 trillion in extra exports by 2026. ICC, *G7 | Creating a Modern Digital Trade Ecosystem - Cutting the Cost And Complexity of Trade*, 2021 - https://www.iccgermany.de/wp-content/uploads/2021/10/Creating-a-Modern-Digital-Trade-Ecosystem-G7.pdf

[71] In comparison, the paper found that bilateral free-trade agreements only increased trade by 45% over 20 years.

Second, achieving interoperability is complex. Even with something as simple as a stackable box, the process for agreeing on standards was exhausting because of conflicting incentives and vested interests. In the case of containers, the involvement of independent coordinating standards bodies and the US government was necessary to forge consensus.

Third, Malcolm McLean hastened standardisation by opening up the patent on his container. If he had not, it might have been harder to agree on an interoperable standard. Of course, McLean was not acting out of altruism. He recognised that opening up the patent would increase the size of the market for transporting goods.

Fourth, interoperability creates winners and losers. Groups unwilling to adapt will inevitably resist. In this case, dockworkers stood to lose and initially put obstacles in the way of the adoption of the standard.

Fifth, interoperability is not simply a binary choice. The development of the container has made the global transportation of goods vastly more efficient. But further improvements are possible, notably by switching to standard digital trade documents. Encouragingly, progress is being made on this front (Thompson, 2018).

Sixth, perhaps most importantly, containerisation shows that interoperability can unlock much wider economic benefits. These can dwarf the efficiency gains that interoperability makes possible in a particular market – in this case, the transportation of goods. The profound changes to world trade and the structure of the global economy witnessed in the last half century can in part be put down to the interoperability characteristics of a standardised steel box.

6.4 CASE STUDY 3: THE DEVELOPMENT OF THE USB STANDARD

In 1994, Intel teamed up with several other companies to create the Universal Serial Bus (USB) as an industry standard to improve hardware interface interoperability. Hardware interfaces are the ports, plugs, cables or electronic signals carried from a computer to a peripheral device or network.

The standard was developed in response to the problems caused by the use of many different types of cable to transfer data and power, and to attach peripheral devices to computer hardware. This time-consuming multiplicity meant that devices were often incompatible with users' computer hardware. The USB soon replaced a wide variety of ports. It has since become an accepted universal standard to attach many peripheral devices, such as keyboards, printers and mobile devices, to computer hardware.

BEFORE THE STANDARD

Before the USB became standard, users needed multiple hardware interfaces to connect computing devices and for data transfer and charging. Every accessory had its own connection configuration and hardware requirement, which was often specific to a particular device.[72] This resulted in computers having various cable ports and products having various cables, often making them incompatible.[73]

This meant that certain types of computer hardware and peripheral devices could not be connected with each other. Naturally, this was a big headache for consumers. They had to check carefully that their accessories were compatible with their hardware or buy a port extension.

Even if the cable and cable ports were compatible, each device communicated differently with the computer hardware. To get around that problem, the user had to install separate software. As they added more devices, the computer might become slower and occasionally crash.

THE IMPACT OF MULTIPLE STANDARDS

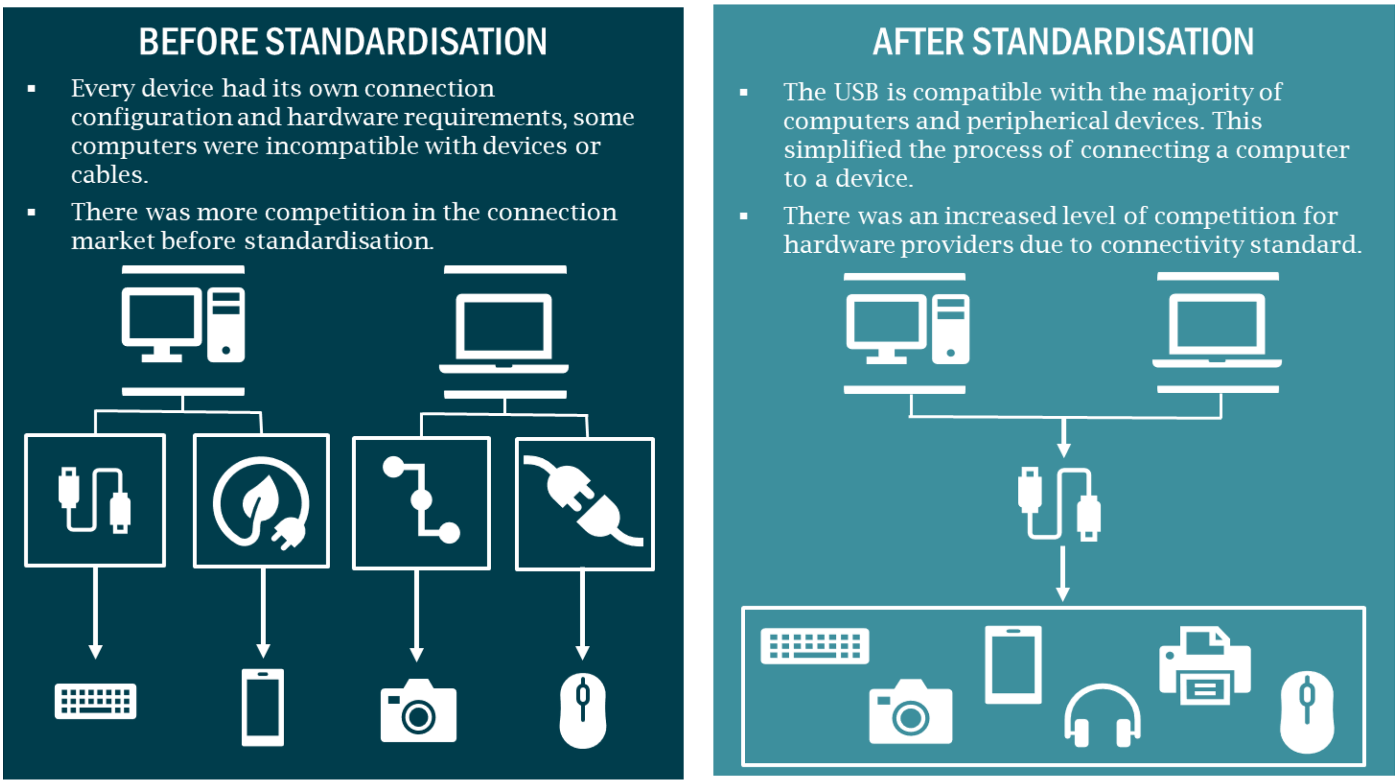
In short, before standardisation consumers had a tough job choosing interoperable devices and cables. Computer hardware manufacturers had to choose which ports and connections to include in their hardware. Physical space, user functionality and licensing fees tended to limit the number of ports offered. The lack of standards weakened competition between computer hardware providers.

Consumers who had invested in peripherals supported by one manufacturer were wary of buying hardware from another maker if their peripheral devices were not compatible. As a result, they were "locked in" to a degree to the original supplier. Furthermore, the existence of multiple standards lessened competition for peripherals since consumers tended to choose accessories compatible with their computers. Moreover, manufacturers were unwilling to invest in devices using standards which had only limited take-up.

[72] Arc Technica, *A brief history of USB, what it replaced, and what has failed to replace it*, August 2014 - https://arstechnica.com/gadgets/2014/08/a-brief-history-of-usb-what-it-replaced-and-what-has-failed-to-replace-it/

[73] Kensington, *The Evolution of USB: What the New WSB-IF Specifications Mean for Users*, October 2020 - https://www.kensington.com/en-gb/News-Index---Blogs--Press-Center/Docking--Connectivity-Blog/the-evolution-of-usb-what-the-new-usb-if-specifications-mean-for-users/

FIGURE 12 PROCESS OF CONNECTING COMPUTER HARDWARE TO PERIPHERAL DEVICES



Source: Frontier Economics

WHAT LED TO THE STANDARD

The development of the USB was an example of private companies collaborating to set standards that benefited the whole industry. Intel took the initiative in 1992 with the aim of simplifying computer connectivity. The first USB was designed to be small and cheap. It worked by acting as a translator for the different communication methods of peripheral devices. By enabling computers to process requests from multiple competing accessories, a large number of devices could be used at the same time.

Intel was granted a patent for the USB technology in 1997. However, patents can be problematic for companies trying to establish standards. That's because they are designed to give the patent holder control of how the new technology is used - or even to exclude other companies from using it. A tight grip over the patent, or high licensing fees, would have prevented the USB's widespread adoption.

Intel, then, needed to involve more firms if it wanted companies and consumers to trust the USB.[74] The group of companies developing the standard had to be small enough to respond quickly to change, but large enough to be representative of the entire industry. This led to Intel to set up the "USB Promoter Group". There were six members initially - Apple, Hewlett-Packard, LSI, Compaq, IBM and Microsoft – but Apple later quit because it was producing FireWire, a USB rival.

To overcome the barriers to industry collaboration, Intel assigned its patent to a "patent pool". In such a pool, the associated rights are aggregated among multiple patent holders and each one is allocated a share

[74] European Patent office, *A truly universal connection*, January 2017 - https://www.epo.org/news-events/events/european-inventor/finalists/2013/bhatt/feature.html

of the licensing fees. The arrangement meant that participants in the pool were free to create products that supported the USB standard.

Patent pools are often used for standardisation because common standards rely on complementary technology created by competing firms. The main advantage is increased efficiency. The creation of a patent pool acknowledges that collaborating rivals are more likely than a standalone company to produce a universal standard.

To spur the development and use of USB technology, the initial promoters set up a support group of more than 700 companies. This "Implementers Forum" (USB-IF) was tasked with encouraging a wide range of firms, not just computer manufacturers and software providers, to adopt the USB.[75] The diverse membership of the group was vital to the USB's adoption and continuous development.

Initially, however, there was a reluctance to rely solely on the USB as a connector. It was not until the late 1990s that computer companies began to use it more widely. By 2011, seven billion USB-equipped devices were produced globally.[76] The USB has evolved over the years. There have been many different versions, with varying connection speeds and types of cables. However, the port has remained a constant for most peripheral devices, including mice, keyboards and printers. In 2019, manufacturers worldwide churned out USB devices valued at $31 billion.[77]

COMPETING STANDARDS MAY HAVE SPURRED INNOVATION

The first version of the USB in 1996 transferred data at a speed of 1.56Mbps. With the 2019 version the speed had reached 40,000Mbps. Each iteration down the years has also improved the power transfer rate and provided additional functionality.

Competing connection and port technologies may have acted as a spur to the continued enhancement of the USB. Apple in particular established a number of standards for use on its own hardware and devices that it licensed to third parties. Notably, FireWire, developed in the late 1990s, offered much faster speeds (400Mbps) than the USB available at the time. And, unlike the USB, FireWire was able to transfer data in both directions simultaneously.

As FireWire gained market share in high-end storage products and video equipment, USB developers responded in 2000 by launching the USB 2.0. This nominally boasted better maximum performance (480Mbps) than FireWire, though it performed less well in some tests.[78] Ultimately, the USB's widespread compatibility and low licence fees limited demand for FireWire. By 2003, Apple was using the USB in combination with FireWire on its own hardware, and by 2005 it had withdrawn FireWire 400.

[75] USB-IF, About USB-IF - https://www.usb.org/about

[76] European Patent office, *A truly universal connection*, January 2017 - https://www.epo.org/news-events/events/european-inventor/finalists/2013/bhatt/feature.html

[77] Business wire, *Global USB Devices Market Forecast to 2027*, April 2021- https://www.businesswire.com/news/home/20210406005601/en/Global-USB-Devices-Market-Forecast-to-2027---Surging-Adoption-of-USB-Type-C-in-Medical-Industry-Presents-Opportunities---ResearchAndMarkets.com

[78] Daniel Knight, *Why FireWire Failed- but Thunderbolt won't*, May 2011 - https://lowendmac.com/2011/why-firewire-failed-and-thunderbolt-wont/

HOW THE STANDARD IMPROVED OUTCOMES

Cable standardisation has made life more convenient. Instead of wasting time hunting for compatible peripheral devices, consumers can choose any accessory with a USB connection and know it will be compatible. And they have a galaxy of suppliers to choose from.

The wide membership of the USB-IF has maintained pressure to keep improving the standard, benefiting both consumers and developers of new software and hardware. It is, of course, difficult to know how port and connection technology would have evolved without the USB. Wired or wireless technologies might have developed more rapidly if companies had not been married to the standard; the spread of wireless chargers and data transfer may have been held back.

On the other hand, standardisation has ensured that manufacturers can take a clear view of how their products will be connected with computers, reducing the risks inherent in designing new devices. This has led to a wave of innovation. The standardised port has enabled greater connectivity with Wi-Fi adapters, optical drives, Ethernet ports and mobile network dongles.

By making users' existing accessories compatible with any new hardware, the standardised USB port means fewer electronic devices are discarded, reducing waste. This lowers demand for raw materials and cuts CO2 emissions from the production of accessories and cables.

CONCLUSION

The conclusions to be drawn from the development of the common USB standard are broadly positive.

First, there have been clear benefits for consumers. By making it easier to attach peripheral devices and transfer data, the USB has led to efficiency gains for consumers - and also for developers.

Second, the standard has intensified competition in computer hardware and peripherals. Suppliers have a wider pool of potential customers, while consumers are less likely to be locked in to a specific standard.

Third, the common standard has brought environmental benefits. There are positive externalities from the USB, including reductions in electronic waste, the use of resources and CO2 emissions.

Fourth, the patent pool has enabled disparate suppliers to coalesce around an agreed standard. Without the patent pool, it would arguably have been much harder for suppliers to settle on a standard. The USB paved the way for competing companies to collaborate on innovations.

Fifth, the standard has not led to ossification. The USB continues to develop as a standard, supported by its industry bodies. Cooperation within the industry was an essential factor. Many firms collaborated to ensure the USB was fit for purpose. However, it is at least possible that competing standards would also have driven innovation.

Sixth, a degree of competition around the standard persists that is likely to incentivise innovation. The competition comes from innovative technologies developed by major companies, including Apple and Intel, as well as from alternatives to the USB such as wireless connectivity and charging.

7 CURRENT ISSUES AND CHALLENGES WITH INTEROPERABILITY IN CONSUMER IOT

The innovation enabled by IoT relies on a transformational change in how data is generated and analysed to improve our lives, production processes and supply practices. The increasing take up and use of consumer IoT is driven by developments in battery power, technology making devices smaller and less power intensive, and increased availability of networks. Many consumer IoT devices are created specifically to be able to share data with each other via a web of networks, whether mobile, fixed, Local Access Networks or other specific wireless protocols for consumer IoT.

The value generated by consumer IoT is partly created from the ability to combine and share data to support services, applications and devices. In this sense IoT has been described as a "System of Systems", that is a series of inter-related systems that can mutually exchange data. Data from smart home systems, smart health systems, transport, leisure and entertaining, safety and security, can be combined to support new consumer IoT devices, applications and networks. It is through this process that new innovative products can be created. These will offer economic "complementarities" i.e. where the value created by different products working together is greater than the value that can be generated by each product working in isolation.

This means that many consumer IoT devices will need to be interoperable with each other to different degrees. Consumer IoT such as smart home devices, voice assistants and automotive infotainment systems exist in complex ecosystems of inter-related markets for devices, hardware, networks, services and applications. The opportunities offered by IoT markets will depend on many different forms of interoperability between different devices, systems and applications. This means that interoperability is inherently complex, and the complexity increases with the number of parties to which interoperability will apply. Each party will have their own incentives, strategies and sunk investments on which they want to make return.

This section gives an insight into the current state of interoperability in some key consumer IoT sectors. These are:

- voice assistants;
- smart home devices; and,
- automotive infotainment systems.

7.1 VOICE ASSISTANTS

Voice assistants comprise software installed on a variety of devices that use voice recognition, language processing algorithms and voice synthesis to listen to user commands and return relevant information or perform certain tasks. Voice assistants can act both as gateways to other services and information, and as user interfaces to control other services or devices. Advancements in natural language processing have increased the functionality of voice assistants leading to increased use over recent years as portals for smart phone functionality, smart speakers and increasingly car infotainment systems. By the end of 2020, there were an estimated 4.2 billion voice-enabled devices in use and (since they are installed on many common smart devices such as smartphones and laptops), this is forecast to rise to over 8.4 billion devices by 2024.[79] Despite this high level of access, overall engagements of voice assistants by consumers is still at

[79] Juniper Research, *Number of voice assistant devices in use to overtake world population by 2024, reaching 8.4bn, led by smartphones,* Accessed Feb 22 - https://www.juniperresearch.com/press/number-of-voice-assistant-devices-in-use

an early stage of market maturity. In 2020, only an estimated 11% of surveyed EU citizens had used a voice assistant. The high proliferation of devices that can access voice assistants means there is potential for dynamic changes in the market with unprecedented increases in usage possible should consumer habits or needs change (Arnold, et al., 2019).

The process of user interaction is depicted in Figure 13 below. First, the user activates the voice assistant, often by saying a "wake word" such as "Hey Siri" or "OK Google" before issuing an instruction or command such as "What is the weather forecast?".

FIGURE 13 PROCESS OF INTERACTION WITH VOICE ASSISTANT

Source: Frontier Economics based on European Commission (2022)
Note: Activation can also occur through touching the smart device or a button on the device

This command is processed using speech recognition software before the assistant executes its highest ranking response or responds with a list of options. Through repeated interactions voice assistants are designed to adapt to a user's preferences over time via machine learning which helps cut down errors and improves the user experience.[80][81]

Major suppliers of voice assistant services on a global basis include Apple, Google, Amazon and Baidu . When considering the number of worldwide shipments for voice assistant enabled devices, Future Source Consulting estimated in 2020 that Apple's Siri (25%), Google's Assistant (22%) and Baidu (14%) hold the largest shares globally.[82] However, assessing shares in the market for voice assistants is highly dependent on the geography (language availability impacts on geographic take up), the metric for measuring (shipments, penetration or usage), and type of device considered.[83]

For example, shares vary across types of device (e.g. smartphones, smart speakers and cars). Based on usage on smartphones in the US, in 2020 Siri held a 45% share, Google Assistant 29.9% and Alexa 18.3%.[84]

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[80] Wired, *The Year Alexa Grew Up,* Accessed Feb 22 - https://www.wired.com/story/amazon-alexa-2018-machine-learning/

[81] Subcommittee on Antitrust, Commercial and Administrative Law of the US Committee of the Judiciary, *Investigation of Competition in Digital Markets,* Accessed Feb 22 - https://judiciary.house.gov/uploadedfiles/competition_in_digital_markets.pdf?utm_campaign=4493-519

[82] Future Source Consulting, *Virtual Assistants Market Projected to Double by 2024,* Accessed Feb 22 - https://www.futuresource-consulting.com/insights/posts/2021/january/virtual-assistants-market-projected-to-double-by-2024/?locale=en

[83] For example, the European Commission indicates that Amazon's Alexa, Google's Google Assistant, Apple's Siri and Samsung's Bixby are the most widely used general voice assistants in the EU (European Commission, 2021a). On the other hand, survey data from the US and UK suggest that Amazon's Alexa has a higher market share in terms of consumer usage, with no significant share for Chinese voice assistants from firms such as Baidu. For the US see Microsoft, *Voice Report,* Accessed Feb 22 - https://advertiseonbing-blob.azureedge.net/blob/bingads/media/insight/whitepapers/2019/04%20apr/voice-report/bingads_2019_voicereport.pdf. For the UK see Voxly Digital, *The State of UK Voice Market,* Accessed Feb 22 - https://assets.website-files.com/60016c00f0a12751945f1f39/6183e475f5124d7d08fe34e7_VoxlyDigital_UK_Q4_2021_Voice%20Survey.pdf

[84] Voicebot.ai, *Voice Assistant use on smartphones rise, Siri maintains top spot for total user in the US*, Accessed Feb 22 - https://voicebot.ai/2020/11/05/voice-assistant-use-on-smartphones-rise-siri-maintains-top-spot-for-total-users-in-the-u-s/

However, for smart speakers in the US, Amazon held an estimated 69% share of installed devices, compared to Google's 25% and Apple's 5%.[85] Customer survey results also show a clear variation in smart speaker ownership between brand across different countries, with over 70% of smart speaker owners having a Amazon Echo in the US, UK and Germany, compared to less than 20% in Nordic countries where Google and Sonos products have a higher market share.[86]

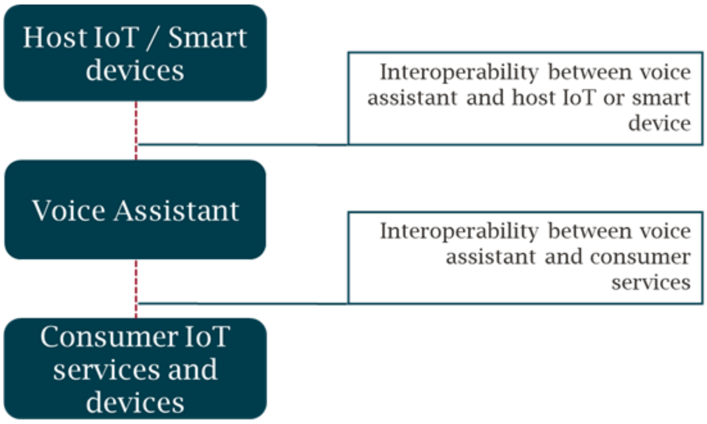
7.1.1 CURRENT STATE OF INTEROPERABILITY

Interoperability of voice assistants can be considered across two dimensions: vertical interoperability between voice assistant platforms and IoT devices and services; and horizontal interoperability between competing voice assistants on the same device.

VERTICAL INTEROPERABILITY

While there are a number of aspects of vertical interoperability, it is helpful to distinguish between two broad types: interoperability between voice assistant platforms and consumer IoT services (i.e. music streaming) and devices (i.e. smart lightbulbs); and interoperability between voice assistant platforms and the host IoT device (i.e. smart speaker) that they run on.

FIGURE 14 ASPECTS OF VOICE ASSISTANT VERTICAL INTEROPERABILITY



Source: Frontier Economics

Interoperability between host devices and voice assistants

Voice assistants integrate with a range of host IoT devices, including mobile phones, smart home devices and cars. These "built-in" integrations allow the user to access a range of functionality. With embedded voice assistant software, consumers can use the voice assistant to control both the host device as well as any consumer IoT services integrated with the device or, in some cases, other devices. The leading general voice assistants often integrate with both the platforms' own first party devices (for example Alexa with Amazon Echo speaker) as well as third-party devices.[87]

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[85] Geekwire, *Amazon maintain big lead over Google and Apple in US smart speaker market, new study says,* Accessed Feb 22 - https://www.geekwire.com/2021/amazon-maintains-big-lead-google-apple-u-s-smart-speaker-market-new-study-says/

[86] Audience Project, *Insights 2020,* Accessed Feb 22 - https://www.audienceproject.com/wp-content/uploads/audienceproject_study_device_usage_2020.pdf?x45637

[87] Until recently, Siri, Apple's voice assistant, could only be built-in on Apple's own first party devices

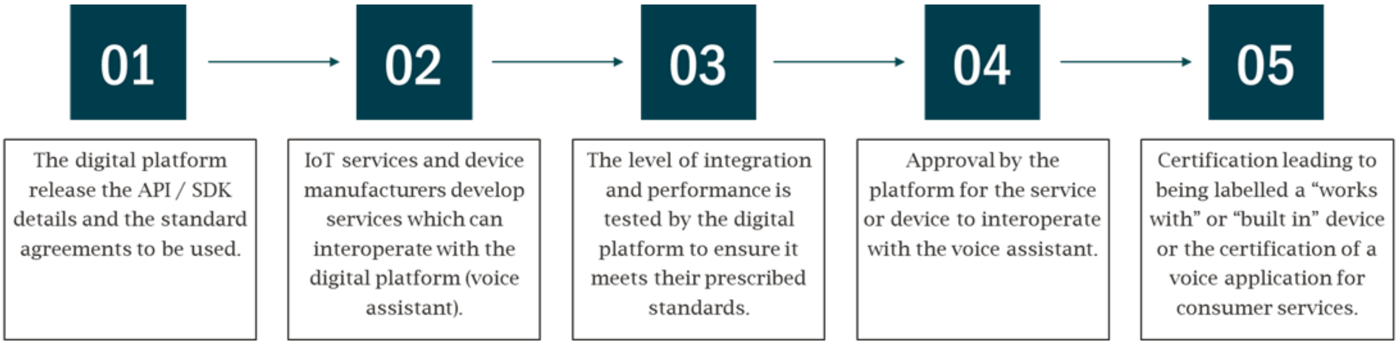
Interoperability between voice assistants and non-host devices and consumer IoT services

Voice assistants vertically interoperate with a wide range of consumer IoT services such as music streaming, health and fitness services, security and logistic services.[88] These integrations allow users to navigate consumer IoT services using voice commands. Voice assistants also integrate with a range of non-host devices (also known as "works-with") including smart plugs, lighting, thermostats, security devices and many more. These devices do not have a voice assistant built in and require an additional device with an embedded assistant to receive the voice command before relaying it to the works with device. Many voice assistants offered by digital platforms are designed to integrate with both the platform's own first-party consumer IoT services and devices (for example, Apple's Siri integrating with Apple Music) and interoperate with third-party services and devices.

How interoperability is achieved in practice

In practice, to connect and interoperate with voice assistants, third party device manufacturers and service providers, in most cases, go through a standard development and certification process set out by each voice assistant company to ensure they meet certain required standards. This general process begins with voice assistant providers publishing APIs/SDKs developers can use to integrate their products with the assistant and is summarized in Figure 15 below. While this process is used in most cases, there are exceptions. For example, Google's documentation for developers wishing to interoperate with Google Assistant suggests that in certain cases they grant particular third-party partners greater access to resources and work with them to build custom integrations, outside of this standardized process. [89]

FIGURE 15 PROCESS FOR ENABLING INTEROPERABILITY BETWEEN VOICE ASSISTANTS AND CONSUMER IOT SERVICES OR DEVICES



HORIZONTAL INTEROPERABILITY

A form of horizontal compatibility (a very limited form of interoperability) for voice assistants is required for different assistants to operate simultaneously on the same device. While many devices (whether host devices or "works with" devices) support more than one voice assistant (around two-thirds according to

[88] For examples of the range of applications voice assistants integrate with, see the following pages for Amazon's Alexa and Google's Assistant. Amazon, *Alexa Skills,* Accessed, Feb 22 - https://www.amazon.com/alexa-skills/b?ie=UTF8&node=13727921011 Google Assistant, *Explore,* Accessed Feb 22- https://assistant.google.com/explore

[89] Google, *How Google Assistant Actions are built,* Accessed Feb 22 - https://developers.google.com/assistant/howassistantworks/developers

the European Commission (2022a)[90]) they usually do not permit multiple assistants to be used simultaneously and co-exist with different "wake words" or work with each other.[91] [92] However, there are examples of simultaneous use, showing that it is technically feasible. For example, a Samsung smart fridge allows users to use simultaneously switch between Samsung's Bixby voice assistant or Amazon's Alexa which is already built into the fridge.[93] Facebook's Portal device also allows simultaneous use of its own voice assistant and Amazon's Alexa.

7.1.2 CURRENT EFFORTS TO PROMOTE INTEROPERABILITY[94]

The Voice Interoperability Initiative (VII) is an Amazon-led initiative that launched in September 2019 which aims to promote interoperability for voice assistants.[95] Today it has approximately 80 members. The VII's objective is to provide customers with the ability to choose their preferred voice assistant for any task, by using multiple voice assistants concurrently on a single device. Customers could activate any of those voice assistants by saying the relevant activation word. While the VII involves other partners such as Garmin, Sonos, Xiaomi and Baidu, fellow market leaders Google and Apple are, notably, not involved.[96] In fact, in 2021, Sonos claimed that the contractual terms of Google Assistant integrations explicitly prohibit smart speaker device manufacturers from having simultaneous assistants if one is Google Assistant.[97] This has meant that seamless switching between voice assistants is largely limited to just Amazon's Alexa and other less widespread voice assistants. More involved switching is possible across most smart devices as multiple voice assistants can now be installed on devices. Rather than "wake words" being used to switch seamlessly between voice assistants, this might involve users having to edit their settings or preferences to ensure one voice assistant is used over another, or to first go into the alternative voice assistants

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[90] See p.19

[91] In these scenarios both voice assistants need to be able to vertically interoperate with their host device, but would also need some degree of interconnection or communication with the substitute or competing voice assistant to ensure requests are appropriately assigned and for a smooth user experience. This limited degree of horizontal interoperability is already being seen in practice through the implementation of an interoperability pattern called Agent Transfer. During an Agent Transfer a user might make a request of one voice assistant who cannot fulfil the request, however given a degree of horizontal interoperability between the two voice assistants, that voice assistant might be aware of another voice assistant on the device that can fulfil the request. The first voice assistant can then summon the second voice assistant to deal with the users request which would need to be repeated. Further horizontal interoperability could be where two separate voice assistants on one host device work together when actioning a user request. However, this is not a feature of current voice assistant products. Voice Interoperability Initiative, *Agent Transfer,* Accessed Mar 22 - https://developer.amazon.com/en-US/alexa/voice-interoperability/design-guide/agent-transfer

[92] For example, Sonos smart speakers offer both Amazon's Alexa and Google Assistant built-in but users must select which voice assistant they wish to use in the settings tab of the Sonos app . See, Sonos, *Set up the Google Assistant with a voice-enabled Sonos product*, Accessed Feb 22 - https://support.sonos.com/s/article/3467?language=en_US and Sonos, *Set up Amazon Alexa with a voice-enabled Sonos speaker,* Accessed Feb 22 - https://support.sonos.com/s/article/3517?language=en_US

[93] Voicebot.ai, *New Samsung Smart Fridge Comes Built With Alexa*, Accessed Feb 22 - https://voicebot.ai/2021/07/26/new-samsung-smart-fridge-comes-built-with-alexa/

[94] In addition to the industry led initiatives, the European Parliament's recent proposed amendments to the DMA (see Section 5.2.1) included adding virtual assistants[94], as a "core platform service" which means that ex-ante regulation could be imposed on voice assistant providers. Should this amendment been kept in the final Act it means that increased interoperability requirements would be imposed on voice assistant providers.

[95] The Open Voice Network (OVN) also aims to improve interoperability with voice assistants, but its main aim is to increase user trust in voice services.

[96] The Verge, *A year later, Amazon's voice assistant alliance still hasn't attracted any of its rivals*, Accessed Feb 22 - https://www.theverge.com/2020/9/9/21429893/amazon-voice-interoperability-initiative-alexa-apple-google-samsung

[97] Protocol, *OK Google, meet Alexa: Interoperability emerges as a key antitrust issue,* Accessed Feb 22 - https://www.protocol.com/google-alexa-sonos-antitrust

application. For example, you are able to install Amazon's Alexa onto an Apple or Android smartphone. However, not all voice assistants can be accessed from all devices. Apple has allowed some third-party devices to respond directly to Siri commands, but only if the third-party devices are also connected to an Apple HomePod Mini device, Siri cannot be directly installed on non-Apple devices.[98]

7.2 SMART HOME

A smart home device is an electronic consumer device found in the home that connects to other devices or networks via wireless protocols to form a smart home system. The connected device can be controlled and monitored, providing data and information that can be processed and stored in the cloud. Smart home devices include household appliances, home entertainment devices, comfort and lighting devices and security devices.

The market for smart home devices has grown substantially over recent years. It is predicted to further grow from an estimated $60.5 billion in 2020 to over $178.5 billion by 2025.[99] In Q3 of 2021, there were over 220 million smart home devices shipped, a 10% increase from Q3 2020.[100] Video entertainment devices (such as smart TVs) had the largest volume of these shipments (35%), followed by security devices (20%) and smart speakers (14%). The US and China represented the top two countries in terms of shipments.

The penetration of smart home devices varies across regions. In developed economies such as the US or the UK penetration is higher. For example, eMarketer estimated that in 2021, 42% of US households used a smart home device.[101] Penetration in less economically developed nations is lower. A Google investigation into the Asia Pacific region found that (excluding Smart TVs) smart home device penetration was below 10% of households in India, Indonesia and Thailand.[102] Finally, certain smart home devices are used more than others. A 2021 UK survey found that, ownership of Smart TVs (58%) and speakers (38%) was much higher than for smart lighting (12%) or smart plugs (11%).[103]

There are many different ways for users to control their devices. The European Commission and Tech UK both estimate that first and third-party applications downloaded onto smartphones are the most popular interface across all smart home devices.[104] However, the available and popular user interfaces often vary by

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[98] BGR, *Every non-Apple device with Siri built into it: Get Siri anywhere*, Accessed Feb 22 - https://bgr.com/guides/every-third-party-device-with-siri/

[99] Omdia, *Omdia report finds purpose-driven smart homes will lead to a market size of $178bn in 2025,* Accessed Feb 22 - https://omdia.tech.informa.com/pr/2021-sep/omdia-report-finds-purposedriven-smart-homes-will-lead-to-a-market-size-of-178bn-in-2025

[100] IDC, *Worldwide Smart Home Devices Market Grew 10.3% in Third Quarter 2021, Says IDC,* Accessed Feb 22 - https://www.idc.com/getdoc.jsp?containerId=prUS48502821

[101] eMarketer, *Smart Home Forecast 2021,* Accessed Feb 22 - https://www.emarketer.com/content/smart-home-forecast-2021

[102] Google, *The Rise of the Connected Home in APAC,* Accessed Feb 22 - https://www.thinkwithgoogle.com/_qs/documents/10517/The_Rise_of_the_Connected_Home_in_APAC_2020.pdf

[103] TechUK, *The state of the Connected Home 2021: a year like no other,* Accessed Feb 22 - https://spark.adobe.com/page/LCRPh1X14fjDM/

[104] See European Commission, 2022, page 16 *"Across all types of smart home devices, based on the total number of the monthly active users (MAUs), smart home applications emerge as the most popular user interface".* Also see TechUK *"Mobile phones remain the*

device and use case. Voice assistants as an interface are used more widely for some devices (such as smart speakers) than others.[105] . In other cases remote controls, keypads, PCs or direct controls on the device function as the user interface. Usually, each smart home device can be operated via more than one interface often including the manufacturer's first-party interface and other third-party interfaces.

The make-up and market shares of leading smart home manufacturers varies significantly by device type. With a wide range of firms represented, the market for smart home products has been described as "fragmented".[106] For example, for Smart TVs, in the US, Samsung holds a 32% market share of sales, leading TCL with 14%.[107] For smart doorbells, Strategy Analytics estimated that based on units sold globally in 2020, Amazon's Ring has the largest market share (17.9%), followed by SkyBell (10.3%) and Google Nest (6.9%), Other smart home markets have different groups of market-leading firms.[108]

7.2.1 CURRENT STATE OF INTEROPERABILITY

The smart home device market is complex. There are a many manufacturers using different technical specifications and standards, providing devices that interoperate with different IoT platforms. In this context a consumer IoT platform is a platform for smart home devices, consumers and IoT services (i.e. where consumers can control multiple different smart devices and associated IoT services). Examples of IoT platforms include voice assistants, smart hubs or certain smart device operating systems.[109] [110] Leading smart home IoT platform providers include Apple, Google and Amazon.

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number one method to control other smart home devices" in, *The state of the Connected Home 2021: a year like no other,* Accessed Feb 22 - https://spark.adobe.com/page/LCRPh1X14fjDM/

[105] In 2020, Voicebot.ai noted that 35% of US adults owned smart speakers and 28% were active users of voice assistants on smart speakers. However, while 49% of US adults owned non-speaker smart home devices, only 27% of adults were active users of voice assistants on these devices.

[106] As noted by Stuart Sikes of Interpret Market Research *"Despite the large percentage of people owning smart home products, the market remains extremely fragmented. This is one of the few spaces in consumer technology in which one dominant player does not own a majority of customers. Google, Apple, Amazon, and Samsung are all megabrands that dominate consumer electronics, yet no one has carved out a large share of the smart home market."* Accessed Feb 22 - https://interpret.la/smart-home-fragmentation-is-holding-back-industry-growth/

[107] NextTV, *Samsung maintains US market share lead in Smart TV at 32%,* Accessed Feb 22 - https://www.nexttv.com/news/samsung-maintains-us-market-share-lead-in-smart-tv-at-32

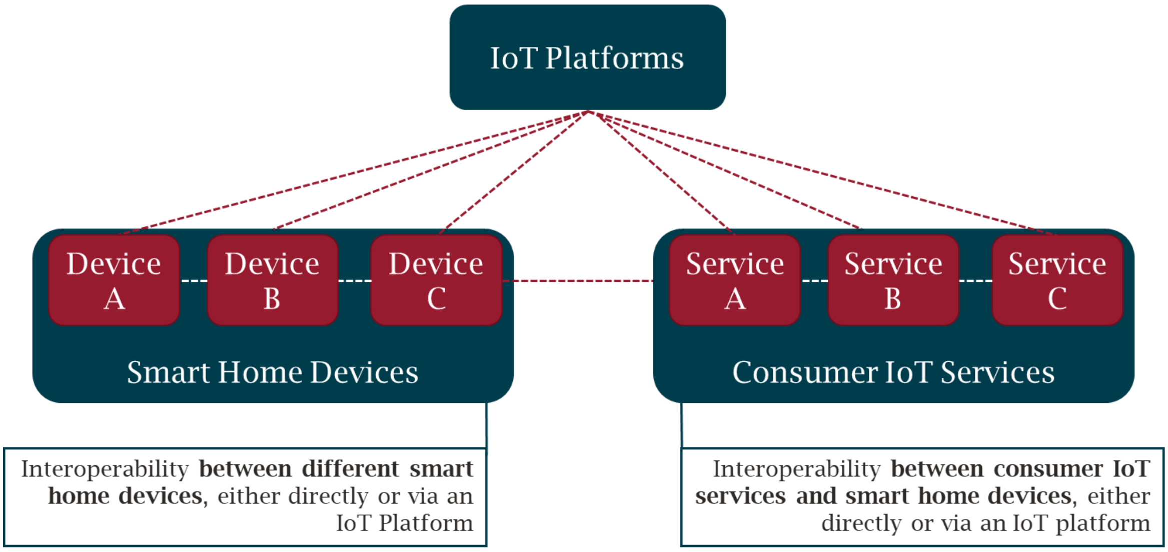
[108] For example, in smart fridges (Samsung, Electrolux, Haier, Whirlpool, LG, Panasonic, Hisense), smart lighting (Acuity, Signify , Honeywell and others) and smart speakers (Amazon, Google, Baidu, Alibaba) . See Fortune Business Insights, *Smart Fridge Market Research Report,* Accessed Feb 2022 - https://www.fortunebusinessinsights.com/smart-fridge-market-104431 and Grand View Research, *Smart Lighting Market Size (2021 – 2028),* Accessed Feb 22 - https://www.grandviewresearch.com/industry-analysis/global-smart-lighting-market?

[109] Smart hubs or, gateways, as defined by the European Commission are *"Pieces of hardware or software that connects devices on a home automation network and controls communication among them. There are standalone dedicated hub or gateway devices, but they might also be integrated into smart home devices such as smart speakers"* (European Commission, 2021, p. 57)

[110] While this report considers IoT platforms as such in the context of interoperability, it must be recognised that voice assistants, smart hubs and operating systems do also fundamentally differ. As noted in Amazon's response to the European Commission's public consultation, operating systems control and manage all applications on a device and are exclusive (i.e. devices usually only run on one operating system which cannot be changed). On the other hand, while voice assistants do allow users to control smart devices and IoT services, they are applications that run on device operating systems and as discussed previously are not always exclusive. Amazon, *Amazon observations on the European Commission's preliminary report from the Consumer Internet of Things Sector Inquiry,* Accessed Feb 22 - https://ec.europa.eu/competition-policy/public-consultations/2021-internet-things_en

The widespread use of IoT platforms creates a number of dimensions when considering interoperability for smart home devices and services. These include the vertical interoperability between smart home devices, IoT platforms and consumer IoT services and are displayed in Figure 16 Figure 16 below.

FIGURE 16 ASPECTS OF VERTICAL INTEROPERABILITY IN SMART HOME ENVIRONMENTS



Source: Frontier Economics

Interoperability between consumer IoT services and smart home devices

In general, consumer IoT services interoperate with smart home devices in two ways. The first is directly via the smart home device and its first-party app/operating system. For example, audio-visual content providers develop applications that run directly on the operating systems of smart TVs.[111] The second is via a third-party IoT platform such as a voice assistant. For example, Samsung Family Hub smart refrigerators have built-in integrations with Bixby and Alexa voice assistants which can be used to access third-party IoT services such as the streaming app Spotify.[112] Similarly, certain smart TVs, such as the Toshiba 4K Farfield, have built-in integrations with Amazon's Fire OS, which acts as an IoT platform and allows users to access apps such as Netflix which integrate with Fire OS.[113]

Interoperability between different smart home devices

There are technical barriers which can limit scope for interoperability between different smart home devices. Smart home devices currently use a variety of communications protocols and standards including Zigbee, Z-Wave, Bluetooth, and WiFi. The protocols have different characteristics, and use of one over another can bring trade-offs.[114]

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[111] Samsung, *Samsung Developers – Smart TV,* accessed Feb 22 - https://developer.samsung.com/smarttv/develop

[112] Samsung, *Family Hub refrigerator,* Accessed Feb 22 - https://www.samsung.com/us/explore/family-hub-refrigerator/features/

[113] Amazon, *Fire OS Overview,* Accessed Feb 22 - https://developer.amazon.com/docs/fire-tv/fire-os-overview.html

[114] For example, WiFi can facilitate quicker data transfer than Bluetooth but it has high power requirements for battery-powered devices. Zigbee and Z-Wave protocols, while having relatively low power requirement, require dedicated hubs which can be a single point of failure. When developing devices, manufacturers select which, and how many, protocols to incorporate based on device feature requirements including security, power, memory and cost.

Often, the range of communications protocols being used means that smart home devices using different protocols may not be able to communicate with each other. For example, according to the European Commission, the two most prominent communications protocols, Zigbee and Z-Wave, do not allow for interoperability among devices using one or the other (European Commission, 2022a). Furthermore, devices and sensors (such as smart bulbs) that use non-IP based networks (such as Bluetooth, Zigbee or Z-wave) cannot communicate through the internet. Therefore, IoT platforms are often necessary to facilitate interconnection and exchange of data between devices that do not run compatible communication protocols or between non-IP devices and the cloud.

How interoperability is achieved in practice

Interoperability in the smart home context, between devices, IoT platforms and consumer IoT services is achieved in a similar way to the process outlined in Figure 15for Voice Assistants. For smart home device manufacturers and consumer IoT service providers seeking to integrate with IoT platforms, they use APIs , SDKs and technical specifications published by the platform before going through a certification process.[115][116] For consumer IoT service providers wishing to integrate with a smart home device directly or via its first-party operating system, again a similar process occurs. Manufacturers of smart home devices make their operating system's API and technical specifications available to service providers, who develop and test the integration. The integration is then reviewed and certified by the manufacturer.[117]

7.2.2 CURRENT EFFORTS TO PROMOTE INTEROPERABILITY

As noted, the relatively fragmented smart home sector can add costs and complexity to suppliers and users. However, there is anticipation that industry-wide collaboration around a new standard ("Matter") will significantly improve interoperability, benefitting developers, consumers and the leading IoT platforms.[118]

Matter (Formerly named the Connected Hope over IP or CHIP project), set to be introduced in 2022, is a new smart home connectivity standard developed by the Connectivity Standards Alliance (CSA).[119] The CSA is supported by the majority of the smart home industry with over 400 companies as members (210 directly involved in the Matter working group) including each of the leading IoT digital platforms (Apple, Amazon and Google). The working group, under the previously named Zigbee Alliance, was established to develop and promote the adoption of a new royalty-free standard, designed to improve interoperability amongst smart home products. The goal of Matter is to simplify development for device manufacturers and service providers and increase compatibility for consumers.

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[115] For example, see the process for integration with the Apple Homekit platform. Apple, *Homekit,* Accessed Feb 22 - https://developer.apple.com/homekit/

[116] For integrations with third party operating systems see for example the process for integrating with Amazon's FireOS for Smart TVs, Accessed Feb 22 - https://developer.amazon.com/docs/fire-tv/getting-started-developing-apps-and-games.html. Once service providers develop an application based on the Amazon's technical specification it must pass through an approval process in the following link, Accessed Feb 22 - https://developer.amazon.com/docs/app-submission/viewing-app-submission-status.html

[117] See for example the process for developing applications for the Samsung Smart TV, Accessed Feb 22 - https://developer.samsung.com/smarttv/develop

[118] Note, that alongside the widely supported Matter standard, there are also other initiatives which promote interoperability that are relevant to the smart home market. For example, the One Data Model (OneDM) is an initiative to create an interoperability framework between existing IoT data model standards (see One Data Model, Overview, Accessed Feb 22 - https://onedm.org/overview/)

[119] Matter, *Build with Matter,* Accessed Feb 22 - https://buildwithmatter.com/

Matter was developed via an open-source approach and will act as an application layer on top of existing IP based communication technologies including ethernet, WiFi, Thread and Bluetooth. All Matter certified devices, platforms and services will be able to communicate with each other over this standardized protocol regardless of the manufacturer or platform being used. To control their smart devices users will need a Matter controller, this can be a smartphone, tablet or device that works with their preferred smart home ecosystem (e.g. an Amazon Echo speaker).

The introduction of the widely supported standard is likely to have significant implications for interoperability. Service providers and device manufacturers will be able to work to standardised technical requirements to integrate with other Matter devices, platforms (which will include the leading voice assistants) and services. This will reduce costs and complexity of developing integrations, removing the need to customize products to platform or manufacturer specific APIs and SDKs. With compatible products carrying a Matter logo, the standard will remove consumer uncertainty on whether devices will work together and allow buyers to choose flexibly from a wider range of services. This could lead to increased smart home product adoption. Furthermore, as stated by the CSA, the adoption of Matter will mean that companies will no longer compete on connectivity and interoperability.[120] This could spur innovation and competition over features as developers and platforms seek to differentiate their offerings beyond the standard Matter functionality.

7.3 AUTOMOTIVE INFOTAINMENT

A connected car is a vehicle that is capable of connecting to other devices or vehicles over wireless networks, becoming essentially another IoT device. With the increasing availability of high-speed networks, the level IoT functionality in the automotive sector is set to rise and consumers will be able to access a wide range of IoT services through their cars[121].

Automotive infotainment systems are integrated, usually touchscreen, displays that are most commonly mounted into or on the dashboard in the centre of the car.[122] These systems can have a range of functionalities but usually operate audio entertainment, satellite navigation, access to third-party applications, Bluetooth connectivity to a smart phone (or other device) and often provide access to vehicle information such as service intervals, tyre pressure and more. Infotainment displays interact with a range of systems, including both walled-off proprietary on-board diagnostics data as well as third-party services.

Infotainment systems can be broadly split into three main types:

- **Built-in Manufacturer Systems –** Most automotive manufacturers have developed their own proprietary infotainment systems such as BMW's iDrive, Audi's MMI or Mercedes' MBUX. These proprietary infotainment systems are primarily based on underlying QNX, Microsoft, Linux or "forked" Android operating systems and developed in-house[123]. Along with the physical

[120] Michelle Mindala-Freeman, Head of Marketing at CSA in The Verge, *Matter's Plan to Save the Smart Home,* Accessed Feb 22 - https://www.theverge.com/22787729/matter-smart-home-standard-apple-amazon-google

[121] A growing area of automotive IoT is so called vehicle-to-everything (V2X) connectivity, which includes a range of communication modes which can improve road safety, reduce congestion and facilitate Cooperative Intelligent Transport Systems (C-ITS). However, this section focuses specifically on infotainment systems as the key automotive IoT area from the consumer perspective today.

[122] Motors, *What is Infotainment,* Accessed Feb 22 - https://news.motors.co.uk/what-is-infotainment-car-infotainment-explained/

[123] "Forked" Android operating systems refer to infotainment systems that use Google's open source codebase but require automakers to *"do a lot more of the software work when integrating these older Android-powered infotainment setups, which were*

infotainment consoles in each vehicle, manufacturers also develop accompanying apps which can be used on smartphones and tablets.[124]

- **Built-in Third-Party Systems –** These are third-party built-in operating systems that function as the predominant infotainment system in place of a manufacturer developed system. A leading example is Google's Android Automotive OS (AAOS). AAOS has been recently used in Volvo vehicles and is set to be introduced as the primary system in future Ford, GM, Stellantis (Dodge, RAM, Jeep, Fiat, Chrysler Peugeot, Opel etc), Renault-Nissan-Mitsubishi and Honda vehicles.[125] Manufacturers build their infotainment system based on Google's software and specifications and develop their own user interfaces on top of AAOS to reflect their own brand. Car makers can choose the applications that are embedded as standard, potentially contracting with Google Automotive Services (GAS) to provide Google apps such as Maps, Play Store, Assistant etc.[126]

- **Non Built-in Third-Party Systems –** These are systems including Apple's CarPlay and Google's Android Auto "mirroring" systems or Huawei's HiCar[127]. They are platforms running on users' smartphones that project the smartphone's operating system user experience onto an existing compatible in-vehicle infotainment system over a USB or Bluetooth connection. They are not built-in to the vehicle itself and are used as an additional layer on top of the native infotainment system. These in-car mirroring systems have proven very popular. In 2020 over 80% of new cars sold supported Apple CarPlay and the Android Auto application had been downloaded an estimated 100 million times. [128] [129] In a 2018 survey of US drivers, Strategy Analytics found, that when users have both CarPlay and a built-in system, 34% said they only use CarPlay in their car and a further 33% said they mostly used CarPlay.[130] Only 4% said they used the embedded system over CarPlay.

Network connectivity for infotainment systems is usually achieved in two main ways, embedded connectivity or connectivity via smartphone. In recent years, many new vehicles have embedded SIM

typically forked off of older versions of the operating system. That meant they couldn't be easily be updated or offer the same kind of access to Android Auto-approved apps via the Play Store" - The Verge, *"GM will use Google's embedded Android Automotive OS in cars starting in 2020",* Accessed Feb 22 - https://www.theverge.com/2019/9/5/20851021/general-motors-android-auto-google-infotainment. Note that these "forked" operating systems are distinct from Google's Android Automotive OS, which is specifically designed as an embedded infotainment system.

[124] These apps, such as "My BMW" and "myAudi", allow drivers to access some aspects of infotainment functionality away from their vehicles. BMW, *My BMW App,* Accessed Feb 22 - https://www.bmw.co.uk/en/topics/owners/bmw-apps/my-bmw-app-overview.html? Audi, *Connect Infotainment,* Accessed Feb 22 - https://www.audi.co.uk/uk/web/en/owners/my-audi/connect-infotainment.html

[125] Google Design for Driving, *Automotive OS,* Accessed Feb 22 - https://developers.google.com/cars/design/automotive-os

[126] Forbes, *Ford, Google Teaming Up On Cloud, Next-Gen Automotive Infotainment,* Feb 22 - https://www.forbes.com/sites/samabuelsamid/2021/02/01/ford-picks-google-for-cloud-next-gen-android-automotive-infotainment/?sh=7d918b656a9d

[127] Note, there are different versions of Huawei HiCar. These range from mirroring systems to full built-in operating systems similar to AAOS.

[128] CNBC, *Apple's massive success with CarPlay paves the way for automotive ambitions,* Accessed Feb 22 - https://www.cnbc.com/2021/05/29/apple-carplay-massive-success-paves-way-for-automotive-entry.html

[129] Android Police, *Android Auto app hits 100 million downloads in the Play Store,* Accessed Feb 22- https://www.androidpolice.com/2020/01/13/android-auto-app-hits-100-million-downloads-in-the-play-store/

[130] CNBC, *Apple's massive success with CarPlay paves the way for automotive ambitions,* Accessed Feb 22 - https://www.cnbc.com/2021/05/29/apple-carplay-massive-success-paves-way-for-automotive-entry.html

connectivity[131]. In 2020, ABI Research estimated that there were 30 million new vehicles sold with embedded connectivity that year.[132] This amounted to, based on IEA data, roughly 41% of sales worldwide.[133][134] With embedded SIM connectivity, in most cases, the car manufacturer has entered into an agreement with a connectivity provider to allow users to access internet services.[135] The second way of achieving network connectivity on infotainment systems is via a connection with the user's smartphone. Through the user's smartphone data plan, the user can use compatible services on their infotainment system, for example streaming music via Spotify or using mirroring solutions such as Apple CarPlay or Android Auto via a Bluetooth connection.

Infotainment systems are primarily controlled via in-car touch screen displays, connected smart devices and, increasingly, through voice assistants. In 2020, a US survey found that 51% of adults had used a voice assistant in their car and 33% were monthly active users.[136] The most frequent in-car VA use cases for survey respondents were (in order) making phone calls, navigation, sending texts and controlling audio. Vehicle manufacturers often have their own built-in voice assistants but also often allow users to access the leading voice assistant platforms, Apple (Siri), Google (Google Assistant) and Amazon (Alexa) via integrations with infotainment systems.[137] Voicebot.ai found that 33% of US adults had used their vehicle's embedded voice assistant and 30% had used the VA from their smartphones via Bluetooth. Siri and Google Assistant had both been used by 26.7% of adults while using Apple CarPlay and Android Auto.[138]

7.3.1 CURRENT STATE OF INTEROPERABILITY

Among the types of infotainment systems described it is helpful to distinguish first, vertical interoperability between the connected car, built-in infotainment system and consumer IoT services;

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[131] In Europe, the recent increase in embedded connectivity is in part due to the European Union mandating that all new vehicles sold must have embedded technology to enable connectivity to the eCall automated emergency call system. See ETSC, *Automated emergency calling 9eCall) now mandatory on new car models,* Accessed Feb 22 - https://etsc.eu/automated-emergency-calling-ecall-now-mandatory-on-new-car-models

[132] ABI Research, *The connected car market will endure a 15% shipment decline, flat revenues in 2020; Sales return on trend early 2022,* Accessed Feb 22 - https://www.prnewswire.com/news-releases/the-connected-car-market-will-endure-a-15-shipment-decline-flat-revenues-in-2020-sales-return-on-trend-early-2022-301100761.html

[133] ABI Research, *The connected car market will endure a 15% shipment decline, flat revenues in 2020; Sales return on trend early 2022,* Accessed Feb 22 - https://www.prnewswire.com/news-releases/the-connected-car-market-will-endure-a-15-shipment-decline-flat-revenues-in-2020-sales-return-on-trend-early-2022-301100761.html

[134] IEA, *Global car sales by key markets, 2005-2020.* Accessed Feb 22 - https://www.iea.org/data-and-statistics/charts/global-car-sales-by-key-markets-2005-2020

[135] For example, see Audi's partnership with Cubic Telecom at Audi Centre, *Online without borders,* Accessed Feb 22 - https://www.audicentre.ie/en/about-us/news/online-without-borders.html, or BMW's partnership with Vodafone at BMW, *BMW Group and Vodafone integrate 5F and personal eSIM networking into a vehicle for the first time,* Accessed Feb 22 - https://www.press.bmwgroup.com/global/article/detail/T0341435EN/bmw-group-and-vodafone-integrate-5g-and-personal-esim-networking-into-a-vehicle-for-the-first-time?language=en

[136] Voicebot.ai, *In-car voice assistant consumer adoption report 2020*, Accessed Feb 22 - https://voicebot.ai/wp-content/uploads/2020/02/in_car_voice_assistant_consumer_adoption_report_2020_voicebot.pdf

[137] Manufacturers' proprietary voice assistants rely on underlying third-party software. Two of the largest third-party providers are Cerence, used by BMW and Audi (Cerence, Accessed Feb 22 - https://cerence.com/) and SoundHound, used by Mercedes, Honda, Hyundai and PSA (SoundHound, Accessed Feb 22 - https://www.soundhound.com/automotive)

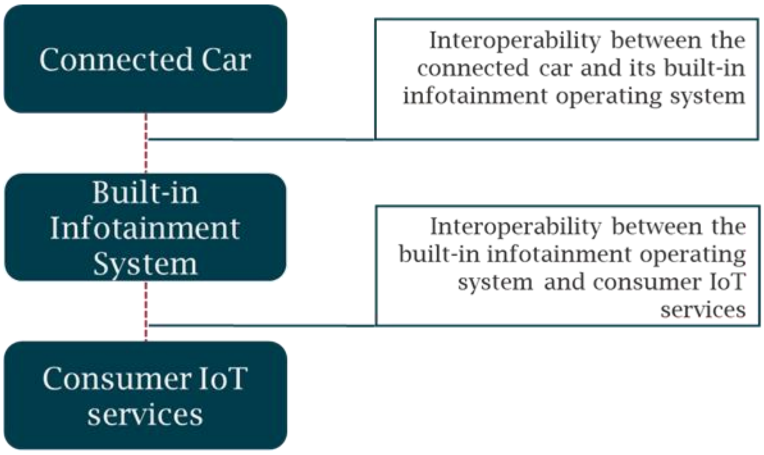
[138] Voicebot.ai, *In-car voice assistant consumer adoption report 2020*, Accessed Feb 22 - https://voicebot.ai/wp-content/uploads/2020/02/in_car_voice_assistant_consumer_adoption_report_2020_voicebot.pdf

second, (horizontal) interoperability required to enable users to choose between the built-in infotainment system and non-built-in third party systems.

VERTICAL INTEROPERABILITY

There are two main aspects of vertical interoperability to consider: the interoperability between cars and built-in infotainment systems, and the interoperability between infotainment systems and consumer IoT services (both are depicted in Figure 17).

FIGURE 17 MAIN ASPECTS OF VERTICAL INTEROPERABILITY IN AUTOMOTIVE INFOTAINMENT SYSTEMS



Source: Frontier Economics

Interoperability between connected cars and built-in infotainment systems

Until recently manufacturers developed their own infotainment systems and sought to maintain sole control of the market and accompanying data. This has changed over the last five years with manufacturers recognising the seamless user experience that can be achieved by embedding leading digital platforms and voice assistants into third-party built-in infotainment systems that link to user's profiles across devices. Entering into these agreements allow car-makers access to these companies' mature developer platforms and third-party app ecosystems while also eliminating the significant cost of building in-house solutions. With the growing use of Google's AAOS for example, these systems are expected to become more commonplace.

Interoperability between infotainment systems and consumer IoT services[139]

The second aspect of vertical interoperability is between infotainment systems and consumer IoT services or platforms. Consumer IoT services such as music streaming (e.g. Spotify or Apple Music), VoD (e.g. Netflix or Hulu), mapping apps (e.g. Google Maps or Waze) or leading voice assistants platforms are able to integrate with infotainment systems to varying degrees. This can be through built-in integrations with the

[139] A further aspect of vertical interoperability is between automotive infotainment systems and other IoT devices (such as those in the smart home). A number of infotainment systems have integrated consumer IoT services that offer consumers the ability to control aspects of their smart home ecosystems from their vehicles by linking user accounts across devices. For example, the Samsung SmartThings application has integrations with Mercedes' MBUX infotainment systems and Android Auto, letting driver control certain integrated smart home devices remotely. Similarly, Volvo recently announced an integration with Google Home into its AAOS infotainment system and a number of manufacturers have announced integrations between their infotainment systems and Amazon's FireTV services.

embedded infotainment system (for example Spotify's integration with BMW's iDrive or Netflix's integration with the Tesla infotainment system) or through mirroring solutions such as Android Auto or Apple CarPlay where users can project a version of the service from their mobile devices onto the existing infotainment system.[140][141] For connected cars with third-party infotainment operating systems such as AAOS, these services can similarly be integrated directly into the infotainment system or accessed via mirroring solutions. Whether or not an IoT service (or device) can interoperate with a car's infotainment system depends on the specific car model, compatibility with mirroring solutions and the agreements in place between the car manufacturer, infotainment system developer and IoT service providers.

How interoperability is achieved in practice

When car manufacturers install their own proprietary infotainment systems, vertical integration between the car and the infotainment operating system is relatively straightforward to achieve, taking place during the in-house development process. However, when the manufacturer wishes to use a third-party infotainment system, such as AAOS, a number of agreements and ongoing collaboration with the system provider is necessary to ensure interoperability. When adopting AAOS manufacturers build their infotainment system based on Google's specifications, accepting what Google calls the "core tenets" of the Android platform with respect to consumers and developers, while fulfilling certain compatibility requirements.[142]

Vertical interoperability between infotainment systems and third-party consumer IoT services or applications is achieved in different ways depending on the type of infotainment system. For cars with proprietary built-in infotainment systems, integration is usually achieved through direct agreements with large commercial service providers (such as Spotify) or via the car-maker's own developer platform. These platforms provide developers with standardized APIs and SDKs for the cars infotainment system allowing them to develop applications which the manufacturer would then need to approve. Examples include Mercedes Benz or GM's developer platforms.[143] [144] In some cases a large consumer IoT service provider might provide APIs or SDKs to the car-maker for it to integrate the service into the infotainment system itself, before the provider reviews and certifies the solution.[145]

HORIZONTAL INTEROPERABILITY

At this time there is limited horizontal interoperability between different infotainment systems. Users cannot choose which built-in operating system and user interface to have installed in their vehicle or switch between systems. Vehicles that come with a specific infotainment system built-in, whether that be manufacturer developed or third-party, cannot have it removed and there is no exchange of data between

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[140] Spotify, *Car Audio,* Accessed Feb 22 - https://explore.spotify.com/uk/collections/car-audio

[141] Variety, *Tesla adds Spotify, Netflix, YouTube and Hulu Support,* Feb 22 - https://variety.com/2019/digital/news/tesla-spotify-netflix-youtube-hulu-1203350885/

[142] The Verge, *The head of Android Auto on how Google will power the car of the near future*, Accessed Feb 22 - https://www.theverge.com/2019/1/25/18196234/google-android-auto-in-car-systems-apple-carplay-interview

[143] Mercedes-Benz, *Developers Homepage,* Accessed Feb 22 - https://developer.mercedes-benz.com/

[144] GM, *Build in-vehicle apps,* Accessed Feb 22 - https://developer.gm.com/

[145] An example of this are integrations of Amazon's Alexa voice assistant into car infotainment systems. Amazon provides the Alexa Auto Software Development Kit which sets out the guidelines for manufacturers to integrate Alexa into their vehicles. Amazon, *Alexa Auto Software Development Kit,* Accessed Feb 22 - https://developer.amazon.com/en-US/alexa/devices/alexa-built-in/development-resources/auto-sdk

competing infotainment systems. Rather, users can choose to use compatible mirroring solutions such as Android Auto or Apple CarPlay, which sit on top of the existing infotainment system and project the interface and applications from a user's smartphone (in this sense the different systems can be considered compatible in that they coexist together). These solutions are usually not direct substitutes for infotainment systems. For example, in most cases, these mirroring solutions do not allow users to control the physical components or 'hardware' of the car such as temperature control.[146]

7.3.2 CURRENT EFFORTS TO PROMOTE INTEROPERABILITY

In recent years, digital platforms such as Apple and Google have increased interoperability in the automotive sector by enabling integrations between infotainment systems and third-party consumer IoT services through their developer platforms for products such as Apple CarPlay, Android Auto and Android Automotive OS (AAOS).

Over the last decade there have been a number of organizations promoting interoperability in different ways. For example, the Connected Vehicles Systems Alliance (COVESA), is a cross-industry alliance, with members including BMW, Ford and Hyundai, focused on the development of open standards and technologies that accelerate innovation for connected vehicle systems.[147] COVESA's active projects include supporting automakers interested in adopting Google's AAOS infotainment system as well as launching the Common Vehicle Interface Initiative, which attempts to address need for industry standards to efficiently collect and manage vehicle data.

Other organizations include Automotive Grade Linux (AGL) and the Open Automotive Alliance (OAA), which are alliances made of automakers, suppliers and technology companies, designed to bring Linux and Android based infotainment systems to cars.[148][149] Both AGL and OAA promote the use of open, common development platforms for vehicles to enable the rapid development of new features.[150]

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[146] A notable exception to this is Huawei's HiCar solution, which, through a deeper integration with the car manufacturer at the hardware level, allows users to control physical aspects of the car such as climate control and window operation. See Huawei Central, *Huawei Smart Car Technologies*, Feb 22 - https://www.huaweicentral.com/huawei-smart-car-technologies-harmonyos-hicar-in-car-smart-screen-car-app/ and Mobile Geeks, *Huawei's HiCar is more ambitious than you think*, Feb 22 - https://www.mobilegeeks.com/article/huaweis-hicar-is-more-ambitious-than-you-think/

[147] COVESA, *About COVESA,* Accessed Feb 22 - https://www.covesa.global/about-covesa

[148] Automotive Grade Linux, *What is Automotive Grade Linux,* Accessed Feb 22 - https://www.automotivelinux.org/

[149] Open Automotive Alliance, *About,* Accessed Feb 22 - https://www.openautoalliance.net/#about

[150] The Car Connectivity Consortium (CCC) is another cross-industry organization that in 2012 introduced MirrorLink which, pre-dating Apple CarPlay and Android Auto, is an open source standard for "mirroring" smartphone handsets onto the vehicle's built-in infotainment system, enabling interoperability between a wide range of smartphones and cars. However, in recent years some phone manufacturers, including Samsung, have ended support for MirrorLink, and the CCC itself has announced that it will terminate all MirrorLink operations by 2023. The CCC are currently focusing on developing its new open standard Digital Key, a standardized ecosystem allowing consumers to unlock and lock their vehicles with their smartphones. Another project called Car Data seeks to create an ecosystem to link vehicle data to authorized data usage, such as pay-how-you-drive insurance, road monitoring, and fleet management. Car Connectivity Consortium, *Homepage*, Accessed Feb 22 - https://carconnectivity.org/

8 CONCLUSION AND RECOMMENDATIONS

Consumer IoT is a transformative technology that will bring new services, devices and applications to be used across all aspects of daily life. Data collected and processed from a plethora of devices have the potential to unlock welfare and efficiency benefits throughout society: enabling firms to reach consumers better, supporting the development of new and innovative products, and bringing benefits of choice and competition to consumers. It is thus heralded as a potentially transformative technology which will shape industry and society.

The value created by consumer IoT is partly enabled by the ability of IoT devices and services to interoperate and share data. Interoperability is the function which facilitates coordination between many different parties in supplying an economic activity. It enables new services to be designed and supplied by exploiting complementarities between different systems.

The benefits of interoperability can be significant as the value from complementary products are realised; or the benefits of network effects are created and shared; or competition is enhanced (for example by reducing lock-in); or environmental benefits are realised. However, interoperability involves costs and trade-offs that are context specific and depend on the precise nature and maturity of competition.

In this context, there are a number of factors that could guide policy makers when considering interoperability as a policy instrument in consumer IoT markets:

1. **Be clear on the rationale for intervention as this will drive the form of interoperability that is chosen.**
2. **Carefully consider the costs and trade-offs involved in different forms of interoperability**.
3. **Policy makers should support the process of defining the precise location, layer and degree of interoperability required**.

8.1 BE CLEAR ON THE RATIONALE FOR INTERVENTION AS THIS WILL DRIVE THE FORM OF INTEROPERABILITY THAT IS CHOSEN

Firms often face strong (unilateral) incentives to interoperate since it can bring benefits to all parties. In many circumstances there is no need for policy makers to intervene since firms will actively seek to agree the appropriate form of interoperability and its technical design.

However, there can be a number of instances where policy makers may wish to intervene to promote positive outcomes. Policy makers should carefully consider the rationale for intervention. It is important to recognise that interoperability as a policy tool is not an end in itself, but a means to an end: to promote the welfare effects of competition, or to promote social goals such as environmental goals. The rationale and objective for intervention will directly relate to the precise form of intervention that is proposed or adopted. The rationale for intervention can include three distinct reasons: to secure public and social welfare benefits, mitigate competition concerns and to overcome coordination problems.

PUBLIC AND EXTERNALITY BENEFITS

Public and social benefits can be a justification for requiring interoperability. This implies that policy makers mandate that different firms must interoperate (or at least be able to interoperate) where absent such regulation they would not, in order to achieve a specific public or social goal. There are many examples, such as the interconnection obligations for telephone networks; or in relation to digital markets EU legislation to promote limited form of interoperability (compatibility) between chargers and electronic devices to support environmental goals. In these cases the wider gain to society of promoting interoperability is considered to outweigh the costs involved. Here the form of intervention should be proportionate to the objective, and be the minimum required to meet the objective.

COMPETITION RATIONALE FOR INTERVENTION

Competition-related interventions aim to remedy deficiencies in the competitive process which result in harms to consumers or to the competitive outcomes (for example foreclosure). As set out in Section 5.2 there are a number of precedents where a lack of interoperability was a feature of the competition problems that were assessed in ex-post investigations. In some cases behavioural remedies have been imposed which mandate forms of interoperability to remedy the specific observed harms. One example of this is the Microsoft vs Commission decision after which a duty to license interoperability information was imposed on Microsoft (Section 4.2.1 for more detail). In these cases, the examination of the competitive problem and the remedy is focussed on the specific issue and relates only to behaviour of dominant firms or mergers which result in a substantial lessening of competition. The resulting remedy is, by design, proportionate to what is required to mitigate the observed competition concern since ex-post competition remedies are legally required to be proportionate to the harm identified. Furthermore, the specific form of interoperability is often clearly specified after a careful review of the market context, including an assessment of potential costs of its imposition.

More recently, UK, EU and member state legislators have proposed targeted forms of *ex ante* regulation to remedy competition problems in digital markets which are not necessarily related to dominance but can relate to features of digital markets which can restrict the operation of markets. The draft DMA required limited forms of interoperability and in the UK the CMA proposed the creation of a Digital Markets Unit that will examine competition in this specific context. In Germany, the revised Competition Act (Section 19a) now allows the Bundeskartellamt to impose interoperability obligations on so-called Undertakings of Paramount Significance for Competition Across Markets.[151] Competition authorities should be cautious when considering interoperability in the context of ex-ante regulation. Interoperability is not a one size fits all tool and it imposes costs and trade-offs that need to be carefully considered. Therefore the specific market context needs to be assessed in detail before ex-ante requirements are imposed. Furthermore, to the extent that the competition problem identified is a strong asymmetry in bargaining power between two parties wishing to interoperate, it is not clear that a simple blanket interoperability obligation will mitigate this concern: the bargaining asymmetry will remain as parties attempt to agree the form of any interoperability.

OVERCOMING COORDINATION PROBLEMS

While interoperability can be welfare enhancing, and the benefits of interoperability to parties wishing to interoperate are often clear, coordinating the precise form of interoperability to achieve these benefits is complex. Different suppliers wishing to interoperate will have a mix of, sometimes opposing, incentives to interoperate and will have to consider the costs and benefits of different forms of interoperability. This can create a barrier to the implementation of interoperability.

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[151] Federal Ministry of Justice, *Act against Restraints of Competition,* Accessed Feb 22 - https://www.gesetze-im-internet.de/englisch_gwb/englisch_gwb.html#p0071

For these reasons policy makers should in the first instance encourage and support positive industry efforts to coordinate, such as in the examples set out in Section 7 in relation to consumer IoT markets. Where industry efforts do not overcome coordination problems, industry cooperation can be achieved via government or regulatory ("standards") involvement from Standard Setting Organisations (SSO). Supporting the pooling of Intellectual Property (IP) associated with interoperability can further help to align the incentives on an ongoing basis. For example when agreeing the USB standard several industry firms which included some competitors agreed to pool their relevant IP, this made it easier for firms to align their incentives, since the interoperability standard would not necessarily benefit their competitors.

8.2 CAREFULLY CONSIDER THE COSTS AND TRADE-OFFS INVOLVED IN DIFFERENT FORMS OF INTEROPERABILITY

Whatever form of interoperability is adopted, it will also incur costs. Simple data porting might incur fewer costs than full protocol interoperability which would require on going agreement on how standards are developed and how data is shared. There can be transaction costs to set up interoperability. Firms compete to offer security, privacy and user functionality, and all these dimensions of competition become more complex where different parties interoperate with each other. For example Section 7 sets out that the processes designed to ensure interoperability between different consumer IoT parties can involve certification and testing processes. The costs that different parties will face in supporting and promoting interoperability will vary significantly. Platforms may have a much greater incentive to protect the value of their investment in their platform and will therefore incur greater costs in ensuring that complementary services are consistent with security, privacy and user functionality standards. Therefore policy makers need to carefully consider the costs of different proposed options where interoperability is considered.

Interoperability also involves trade-offs since it changes the incentives of providers to compete and innovate. Horizontal interoperability and to a lesser degree vertical interoperability can soften incentives for different systems to compete. Interoperability between different systems means that each system faces lower returns to investment to differentiate their service (since interoperability means consumers can access some of the benefits of any investment from a rival's system). However, these trade-offs will be context specific and depend on the precise nature and maturity of competition.

Ultimately this requires policy makers to make a judgement of the likelihood of different forms of innovation, compared to the benefits of different forms of interoperability. Where innovation benefits are concentrated within the platform itself, then it is likely that competing platforms will facilitate and promote disruptive innovation. In this case, mandating forms of vertical interoperability could soften competition between platforms at the expense of such disruptive innovation. This may improve outcomes in the short term, as mandated interoperability could reduce practices which support the central platform such as self-preferencing or otherwise encourage customer loyalty to the platform. However, unless there are specific competition related concerns (i.e. related to the exercise of market power), then there is a risk that intervention to require interoperability will blunt incentives to invest and differentiate, leaving consumers worse off in the longer term. Whereas where innovation is concentrated in the complementary services and devices, there may be a greater justification for interoperability.

8.3 POLICY MAKERS SHOULD SUPPORT THE PROCESS OF DEFINING THE PRECISE LOCATION, LAYER AND DEGREE OF INTEROPERABILITY REQUIRED

The application of interoperability in the consumer IoT "system of systems" is complex. This is because the precise form of interoperability that takes place between different systems will be specific to the individual context of the two parties wishing to interoperate.

Therefore, to the extent that regulation is imposed that requires forms of interoperability it should be focused on a specific context and objective in mind. Where interoperability remedies have been required as part of a competition or merger case they have been designed for the particular competition issue being examined. Whereas blanket ex-ante requirements for an unspecified form of interoperability will not identify the optimal trade-off and hence the appropriate form of interoperability. Hence, where policy makers wish to impose interoperability they should be ready to participate in the process of agreeing the detailed definition (layer, location and degree).

It is only having agreed on the optimal form (layer, location and degree) of interoperability that different parties can then agree the specific technical design of the process for creating and maintaining interoperability. Parties will have to agree many factors such as detailed technical specifications; the content and format of data flows; the approach to resolving disagreements; any payment flows; the approach to privacy, security, user functionality; or how the services can be developed while maintaining interoperability. While it has been argued that this task can be delegated to an industry committee, in practice where interoperability has been mandated it is difficult to see how design of the form and type of interoperability could be fully delegated for industry participants to agree. [152] Of course, it would be essential for industry participants to be involved, but without government or SSOs involvement (acting is independent third parties without "skin in the game") industry participants may struggle to coordinate over the technical and commercial terms of interoperability given the differing costs, benefits and trade-offs involved for different market participants. By illustration, it took over a decade to agree common standards for the shipping container, which was a stackable metal box. A significant degree of regulatory intervention may be required on an ongoing basis to support interoperability standards.

[152] Morton et al. suggested that the task of determining the specific technical design process for interoperability could be delegated to an industry committee *"After a dominant digital platform has been identified, there is an additional step of determining the most effective location for the interface, followed by determining its design and functionality. These tasks can be carried out in different ways. The staff of the regulator could do both. Another option, proposed in legislation in the United States, allows the regulator to establish and oversee a technical committee including industry participants that would carry out the work. If this approach is chosen, the project does not burden the regulator with a responsibility to engage in interface design: it can evolve flexibly with technological trends to meet the needs of the industry"* (Morton, et al., 2021, p. 7).

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