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Who wants interoperability?

Compatibility and regulation in digital markets

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Abstract

The forthcoming Digital Markets Act (DMA) in the EU will likely contain provisions regarding interoperability in digital markets. Interoperability is viewed by certain stakeholders as a tool to reduce market concentration and increase competitive pressure on dominant firms. This master's thesis investigates the role and effect of protocol interoperability in digital markets based on the theory of industrial organization. I use a theoretical model to evaluate incentives to interoperate at firm level, assess the effect of interoperability on competition and market structures, and define conditions under which mandating or encouraging interoperability may be a sound policy option. I complement this with an analysis of important submissions to EU consultations conducted in 2020 in preparation for the DMA. I find that interoperability may be an interesting policy tool in some markets. Policymakers should be most concerned about highly concentrated markets with personalization and multihoming. When it comes to policy instruments, standardization is not always the best way of achieving interoperability.

Key words

Industrial organization, interoperability, DMA, competition policy, network economics, network effects

À la mémoire de mes grands-parents, Louis et Elisabeth Beley.

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Contents

Why should I read this research?

With the advent of modern tech giants, antitrust (and one might add, regulation) is "sexy again", in the words of Carl Shapiro (2018, p. 714). The COVID-19 pandemic, which is a boon for dominant tech companies, is reinforcing the view that competitive pressure is lacking in certain (digital) markets such as social media, e-commerce, and interpersonal messaging. This unease has been exacerbated by widespread concerns surrounding privacy and data protection. With policymakers, regulators, and antitrust authorities facing mounting pressure to act, it is increasingly important to base public intervention on evidence. When faced with calls to "break up Big Tech" or to "regulate" these firms, one should always ask the following question: would consumers be better off? In this work, I echo voices which have pointed out that it may be more judicious to "break open" dominant tech companies rather than break them up. This is the case *inter alia* because certain characteristics of digital markets, primarily network effects, mean that these markets would most likely lapse back into a state of high concentration in the long term if today's dominant firms were "broken up". In this context, encouraging interoperability might be a wiser path for public authorities who want to tackle structural competition issues in digital industries. My work builds on the industrial organization literature on compatibility, pioneered in the 1980s and 1990s, to investigate the effect of interoperability on digital markets. Hopefully, my research can shed light on an issue that has come to the fore in many democratic debates. Behind a seemingly arcane discussion, a more fundamental question lurks: "What kind of networks do we want?". I hope that my work can help policymakers and citizens to answer this question.

1. Introduction

Digitalization is affecting our economies and societies in unprecedented ways. Online platforms have transformed our social interactions, accelerated innovation, and are changing the way business is conducted. These evolutions have had largely positive effects in terms of ease of communication, access to information, and consumer choice. Yet concerns have arisen that only a handful of firms may be reaping the benefits on the supply side, sometimes at the expense of consumer welfare. This is the case due to specific characteristics of digital industries, such as extreme returns to scale, network effects, switching costs, and the role played by data (Crémer, et al., 2019). In addition, there is evidence that dominant digital platforms may be engaging in potentially anti-competitive practices such as *leveraging* (when a firm uses its market power in an adjacent market) and *self-preferencing* (a specific form of leveraging where firms give preferential treatment to their product on a platform that they control) – see Crémer et al. (2019). This comes on top of other exclusionary practices such as abusive tying and bundling, unjustified denial of access or restricting data portability and compatibility (European Parliament, 2020). These practices have the potential to cement dominant players' market power, thus softening competition, hampering entry, and leaving consumers vulnerable to further abusive practices.

While competition law remains the main means of addressing anti-competitive practices, there may also be room for *ex ante* regulation in digital markets. In the EU, Article 101 addresses anti-competitive agreements and concerted practices, while Article 102 TFEU addresses abuses of dominant positions. In the past sixty years, these provisions have proved incredibly flexible and apt to tackle a wide variety of anti-competitive practices, including in the digital economy. But there are concerns that antitrust procedures may sometimes be too slow and costly, especially in fast-moving digital markets. In addition, designing and enforcing appropriate remedies in cases of monopolization/abuse of dominant position is typically a highly complex endeavor, as illustrated by cases such as *Microsoft* (2001 in the United States, 2007 in the European Union) – see Shapiro (2009) – or *Google Shopping* (2017).[1] Consequently, a balance must be struck between *ex post* enforcement and *ex ante* rules. In cases where infringements are systematic or structural, it may be warranted to introduce a new regulatory regime.

It is against this backdrop that the European Commission proposed to revise the regulatory framework for digital platforms in 2020. Two separate legislative initiatives are on the table, namely the Digital Services Act (DSA) and the Digital Markets Act (DMA).[2] Both proposals were presented on 15 December 2020 and are being discussed in the European Parliament and the Council under the ordinary legislative procedure (as of April 2021). While the DSA seeks to revise the 2000 e-Commerce Directive, especially when it comes to the liability of platforms for the

[1] *United States v. Microsoft Corporation*, 253 F.3d 34 (D.C. Cir. 2001), *Microsoft Corp. v. Commission* (Case T-201/04), and *Google LLC and Alphabet Inc. v. European Commission* (Case T-612/17).

[2] Proposal for a Regulation of the European Parliament and of the Council on a Single Market For Digital Services (Digital Services Act) and amending Directive 2000/31/EC, COM/2020/825 final, and Proposal for a Regulation of the European Parliament and of the Council on contestable and fair markets in the digital sector (Digital Markets Act), COM/2020/842 final.

content which they host, the DMA is of key interest here because it aims to lay down new *ex ante* rules to increase competition in digital markets.[3] As part of the DMA, several regulatory tools are being discussed, including *ex ante* prohibitions and obligations for so-called "gatekeeper platforms". A key area of focus in this context is promoting data portability and interoperability (European Parliament, 2020).[4] The right to data portability, which is enshrined in the General Data Protection Regulation (GDPR), allows users to take their data with them as they switch services and has the potential to decrease switching costs and barriers to entry (Gans, 2018).[5] Interoperability, for its part, is the ability of systems to work together. Interoperability can take several forms, as distinguished in Crémer et al. (2019, pp. 83-85):

- *Data interoperability* is a sort of real-time data portability allowing third parties acting on data subjects' behalf to access their data, most often through Application Programming Interfaces (APIs). To achieve this, data formats must be standardized, so that services are able to "understand" and process the data. This would allow users to delegate content curation on social media to third-party services, for instance.
- With *protocol interoperability*, users of two systems (e.g., communication services) can communicate with one another directly, because the two systems have been made compatible. This can be achieved through standardization (firms agree on a set of technical standards) or by contract (e.g., two firms decide to interoperate) – see Faulhaber (2002). In the case of social media, protocol interoperability can take the form of cross-posting, where content posted on one platform can simultaneously be posted on another platform (Brown, 2020).[6]

This master's thesis focuses mainly on the second form of interoperability. Based on seminal literature on network externalities and compatibility, I look at interoperability from a microeconomic perspective, with the aim to evaluate incentives to interoperate at firm level, assess the effect of interoperability on competition, and finally suggest conditions under which encouraging or mandating interoperability may indeed be a sound policy option. Interoperability has become a "buzzword" in EU digital policy circles, but the link with academic work on compatibility is too seldom made. Conversely, more work needs to be done on compatibility in "modern" digital industries (two-sided platforms, markets with data monetization, etc.). This master's thesis attempts to bridge these gaps. My work is structured as follows. Section 2 comprises a review of the literature on competition in network markets (2.1). It also discusses compatibility from an economic, legal, and regulatory perspective (2.2). Section 3 lays out my approach in the theoretical model and the methodology used to analyze submissions to the

[3] Directive 2000/31/EC of the European Parliament and of the Council of 8 June 2000 on certain legal aspects of information society services, in particular electronic commerce, in the Internal Market ('Directive on electronic commerce').
[4] For examples of obligations related to interoperability, see Article 6(c) and Article 6(f) in the DMA proposal.
[5] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC.
[6] Unless otherwise specified, "interoperability" henceforth refers to protocol interoperability.

DSA/DMA and New Competition Tool (NCT) consultations. In section 4, I present a model of interoperability in network markets with data collection and personalization (4.1). I also develop extensions of the baseline model (4.2), a model of policy intervention (4.3) and several practical case studies (4.4). With the results of this theoretical model in mind, I go through important submissions to the DSA/DMA and NCT public consultations which took place between June and September 2020 (4.5). Finally, I draw policy implications from this analysis in section 5 and conclude in section 6.

2. Interdisciplinary state of knowledge

2.1. Network strategies

Networks are ubiquitous in the modern economy. Classical examples of networks include railroads, power lines or communications networks. What is a network? A network is a set of nodes which are connected by links (Economides, 1996). In certain networks, all the nodes are connected or have the potential to be connected with one another. In these networks, the number of links grows quadratically with the number of nodes: there are $\frac{n(n-1)}{2}$ links between a network of n nodes.[7] This has important implications for the economics of networks because users benefit from *network externalities* which are responsible for market-wide *network effects*. These network effects can bind a consumer to a seller, create coordination problems, and lead consumers to value compatibility. In this, they resemble switching costs, which are also characteristic of network industries (Farrell & Klemperer, 2007). Both features of network industries (network effects and switching costs) imply specific strategies and market structures.

2.1.1. Network effects

The utility a user derives from joining a network depends on the number of users currently in the network. When signing up to a social network, my utility is increasing in the number of people I can interact with. This is what is termed *network benefits* or *network externalities*.[8] These benefits are externalities in the sense that they are not fully internalized in prices charged to consumers (Farrell & Klemperer, 2007, p. 1975).[9] Markets where consumers benefit from network externalities are said to exhibit *network effects*. The literature has distinguished between two effects, namely the *total effect* – one user's adoption benefits other current members of the network – and the *marginal effect* – the adoption increases others' incentives to join (Farrell & Klemperer, 2007, p. 2007). Formally, network effects are analogous to classic economies of scale. Given a coalition composed of a seller and n buyers, per-buyer surplus is increasing in n. Beyond this analogy, the implications of network effects in terms of contracting and coordination are much more complex (Farrell & Klemperer, 2007, p. 1974).

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[7] This result is sometimes known as "Metcalfe's law" in the field of telecommunications.

[8] Early literature on network effects calls them external economies in consumption (Rohlfs, 1974) or positive adoption externalities (Katz & Shapiro, 1994).

[9] Some authors have challenged the extent to which these benefits are *always* externalities, pointing to different ways in which they are in fact internalized (Liebowitz & Margolis, 1994).

Since the 1980s, the literature has developed a distinction between direct network effects and indirect network effects, which carry different economic implications (Katz & Shapiro, 1985; Katz & Shapiro, 1994). Direct network effects are typical of physical networks such as e-mail or telephone networks, where benefits are directly linked to the number of individuals a user can interact with. By contrast, indirect or virtual network effects arise in settings where consumers can buy goods that are complementary (Katz & Shapiro, 1985, p. 424), or where two or more groups of users create network benefits for each other (Rochet & Tirole, 2003). A classic example of markets with indirect network effects is so-called hardware/software systems, such as computer operating systems and compatible software. As the pool of compatible software grows, an operating system becomes more valuable to consumers (Katz & Shapiro, 1985).[10]

The theory of network effects is clear, but what is the empirical evidence? Quantitative studies of network effects have mainly adopted two approaches, namely estimating network effects empirically, and evaluating the market outcomes predicted by the theory (Farrell & Klemperer, 2007, p. 2015). Researchers who adopt a quantitative approach to network effects run into a significant challenge: according to the theory, benefits result from consumption, leading to higher demand, which in turn leads to more consumption. The positive feedback involved creates an empirical conundrum, because demand for a good or service cannot be used as a statistical predictor for itself (Farrell & Klemperer, 2007, p. 2015). Consequently, many studies posit that there is some inertia in network size and use previous sales or installed bases as a proxy for network effects (Farrell & Klemperer, 2007, p. 2015). Using this method or similar methods, empirical support for network effects has been found in the field of spreadsheets (Brynjolfsson & Kemerer, 1996), PCs (Goolsbee & Klenow, 2002), DVDs (Dranove & Gandal, 2003; Karaca-Mandic, 2011), and video games (Shankar & Bayus, 2003), for instance.

We saw earlier that the number of links between n nodes is quadratic in n, implying that the utility for an individual adopter is a linear function of network size. There is a consensus in the empirical literature, however, that network benefits are not quadratic or even homogenous. This is due to consumers belonging to communities of interest. New adoptions will not increase a user's utility if the user can already interact with all the members of her community of interest, implying that utility is not a linear function of network size (Rohlfs, 1974; Swann, 2002). For tractability, most theoretical models nonetheless maintain the assumption of linear network benefits, which is standard in the literature (Belleflamme & Peitz, 2015, p. 588).

From a modelling perspective, network effects are inherently tied to the notion of *expectations*. A rational consumer making a purchasing decision in period t will anticipate other consumers' actions and will thereby form expectations about network size in period $t + 1$. This expected network size will determine expected network benefits, which will enter the consumer's maximization of utility. For example, if I want to join an interpersonal messaging application, I will look at the size of the existing network as an indicator of the number of users I will be able to

[10] The hardware/software pair (Katz & Shapiro, 1994) can also be seen as a two-sided platform in the terminology introduced by Rochet & Tirole (2003), whereby operating systems, for instance, are intermediaries which bring together application developers and clients.

communicate with, and so of the network benefits involved. Here there are two main approaches in the literature, namely *myopic expectations* and *fulfilled expectations* (Matutes & Regibeau, 1996). With *fulfilled expectations*, consumers base their purchasing decisions on future network sizes (Belleflamme & Peitz, 2015, pp. 587-588). With *myopic expectations*, consumers join a network based only on current network sizes (Belleflamme & Peitz, 2015, p. 597). Models with network effects often have multiple equilibria (see 2.1.3), and for tractability the set of equilibria is generally restricted to those where consumers' expectations are correct (Gandal, 2002, p. 82).

2.1.2. Switching costs

Network effects and network markets are closely related to the concept of *switching costs*. A customer faces a switching cost – or a substitution cost, as it was called in the earlier literature (von Weizsäcker, 1984) – between two sellers when an investment that she made when purchasing from the current seller must be duplicated for the new seller (Farrell & Klemperer, 2007, p. 1977). Traditional contractual relationships where switching costs arise are those between doctor and patient, lawyer and client, consultant and customer, landlord and tenant, or banker and client, for instance (von Weizsäcker, 1984, p. 1088). Klemperer (1987, pp. 375-376) distinguishes between three types of switching costs, namely transaction costs (e.g., the paperwork involved in closing a bank account and opening one with a competitor), learning costs (e.g., when a user learns to use software that is compatible with their operating system), and artificial costs which are put in place at the firm's discretion (e.g., frequent-flyer programs or supermarket coupons).

Switching costs are a prominent feature of network industries (Chen, 2018; Shy, 2001). They arise when shifting from one operating system to another (learning costs) or when changing mobile networks, for example if it is impossible to keep one's phone number (transaction costs). In his discussion of the market for instant messaging, Faulhaber (2002, p. 328) also mentions the cost of "migrating" one's contacts to another service, a point that can easily be applied to interpersonal messaging and social media today – see also Gans (2018) on "identity portability". In fact, switching costs can also be thought of as a generalization of network effects: some authors speak of network effects as "collective switching costs" (Farrell & Klemperer, 2007, p. 2052). This is because in the presence of network externalities, consumers must coordinate to be able to switch from one seller to another without losing their network benefits. Network effects and switching costs link together trades that are not part of the same contract. Network effects bind buyers' trades together, insofar as customers must coordinate to reap maximal network benefits, while switching costs bind current trades with future trades, insofar as customers cannot switch to another seller (Farrell & Klemperer, 2007, p. 2055). As a result, both switching costs and network effects can confer an advantage on incumbents with larger installed bases.

Empirical studies of switching costs are more recent than the theoretical literature, in part due to the difficulty of accessing micro-data on consumers' purchasing histories and to the impossibility of measuring switching costs directly (Farrell & Klemperer, 2007, p. 1980). A leitmotiv in the empirical literature is the challenge of controlling for unobserved consumer heterogeneity – see Goldfarb (2006). Nonetheless, there is some empirical support for the existence of switching costs in a variety of industries (including network industries), for instance bank credit cards (Ausubel, 1991), computer software (Larkin, 2004), telecommunications (Knittel, 1997; Shi, et al., 2006; Lee, et al., 2006), or electricity suppliers (Waterson, 2003).[11]

2.1.3. Lock-in and competition for the market

Both network effects and switching costs bind consumers to sellers. As a result, consumers' initial purchasing decisions in network markets become analogous to long-term commitments (Farrell & Klemperer, 2007, p. 1976). This has implications for firms' strategies and for market structures. Recall that when there are network externalities, social marginal benefits exceed private marginal benefits (Katz & Shapiro, 1994, p. 96). This has an intuitive effect on market structures: in the monopoly setting, equilibrium network size is smaller than the socially optimal network size (Katz & Shapiro, 1994, p. 96; Economides, 1996, p. 683). Another key result is that network industries often exhibit multiple equilibria for a given price level (Rohlfs, 1974; Katz & Shapiro, 1994; Farrell & Klemperer, 2007). This is due to the coordination problems at play: when network effects are strong, consumers' network benefits outweigh their individual preferences, so that they prefer to do whatever other consumers do (Farrell & Klemperer, 2007, p. 2018). Due to this, "no adoption" is always a possible equilibrium at any price level if consumers do not expect their peers to join, illustrating the so-called "chicken-and-egg problem" (Leibenstein, 1950).[12] This underlines a crucial feature of network industries, namely the role played by expectations and coordination (Katz & Shapiro, 1994).

In the setting where several networks compete for unattached customers, a long strand of literature starting from David (1985) and Arthur (1989) contends that self-reinforcement creates "tipping" (the market becomes dominated by a single network good) and consumer "lock-in".[13] David (1985) famously studies the example of the QWERTY keyboard, which according to him became the *de facto* standard despite being inferior to other keyboard layouts, such as Dvorak. Lock-in is due to an accidental initial advantage and to coordination failure between consumers, who are unable to switch to a better option.[14] This theory is still controversial, and some economists are notably more optimistic when it comes to coordination and the level of competition in network markets (Liebowitz & Margolis, 1995; Liebowitz & Margolis, 2013). Nonetheless, there seems to be some level of empirical support for occurrences of tipping and temporary lock-in in certain markets – as surveyed by Farrell & Klemperer (2007, pp. 2038, 2052) – such as high-definition

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[11] For a more extensive review of the empirical literature on switching costs, see Farrell & Klemperer (2007, pp. 1980-1981).

[12] Katz & Shapiro (1994, p. 97) give the following example: "Sticking with the example of fax machines, clearly no consumer would value owning the only fax machine in existence. If each consumer supposes that no other consumer purchases a fax machine, then no one will purchase it, and there is a fulfilled expectations equilibrium with no sales." This problem rests on the simplifying assumption that all consumers make purchasing decisions simultaneously.

[13] Tipping is closely related to the existence of multiple equilibria in static models, including often multiple corner equilibria where one network dominates the market (Katz & Shapiro, 1994, p. 106). For a stylized model of market tipping based on the baseline model laid out below, see the extension in 4.2.1.

[14] Farrell & Klemperer (2007, p. 2052) describe David and Arthur as "pessimists" when it comes to the ability of consumers to coordinate on the best network.

television (Farrell & Shapiro, 1992), telecommunications (Economides & Himmelberg, 1995), and the computer industry (Bresnahan & Greenstein, 1999). Because firms know that a first-period advantage can create long-term dominance, competition in network markets tends to be fierce in the early stages, and first-mover advantage is strong (Katz & Shapiro, 1994, p. 107). As such, firms compete "for" the market as opposed to "in" the market. Network effects make entry more difficult: coordination failures may create "excess inertia" which prevents users from switching to an entrant's network even though they would be (collectively) better off (Belleflamme & Peitz, 2015, pp. 600-601).

Under certain conditions, switching costs may create similar dynamics. A simple and intuitive consequence of switching costs is that they can give firms a certain degree of market power over their existing customers (Klemperer, 1995, p. 519). Indeed, in the absence of long-term contracts, opportunistic sellers can raise their price above competitors' prices by an amount that is almost equal to the switching cost faced by their buyers (Farrell & Shapiro, 1988, p. 123). Like with network effects, competition is stronger in the early stages of market formation (*ex ante*), because in the first period, firms enter in competition over market shares that will largely predict future profits (*ex post*) (Klemperer, 1995, p. 521). Simple two-period models show that in the first period firms produce excessive output (Klemperer, 1987, p. 390) and price aggressively to gain market share (Klemperer, 1995, p. 523), sometimes adopting "bargain-then-rip-off" price patterns (Farrell & Klemperer, 2007, pp. 1981-1982). A key finding in the literature is that firms face a tradeoff between charging high prices to locked-in customers ("harvesting" these customers) and setting a low price to attract new customers, which can consolidate the firm's market share ("investing") (Klemperer, 1995, p. 525).[15]

Despite the perceived wisdom that lowering switching costs necessarily benefits consumers (Belleflamme & Peitz, 2015, p. 181), there is no consensus in the literature as to the effect of switching costs on competition. The consequences of switching costs crucially depend on which of the two strategies (*harvesting* v. *investing*) takes precedence in each market. Some authors find that the first strategy tends to dominate in many markets, leading – at least temporarily – to higher prices and profits (Klemperer, 1987; Klemperer, 1995; Farrell & Klemperer, 2007).[16] However, there is some evidence from dynamic models that switching costs may lead to less market concentration in the long term because they can facilitate entry (Beggs & Klemperer, 1992). On the one hand, small-scale entry focused on unattached consumers may be too easy in markets with switching costs when incumbents focus on "harvesting" their current customers, acting as harmless "fat cats" (Fudenberg & Tirole, 1984). On the other hand, competition for locked-in customers is very difficult (Farrell & Shapiro, 1988; Klemperer, 1987; Farrell & Klemperer, 2007). As a result, when markets experience rapid growth or high turnover (i.e., when there is a high

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[15] A key assumption here is that there can be no price discrimination between old and new customers, and that switching costs are homogenous across the population. The latter assumption is relaxed in more recent work by Biglaiser et al. (2013).

[16] An important question here is whether customers are on the losing end over multiple periods. If firms give all of their *ex post* rents to customers *ex ante* (through aggressive pricing, for example), then customers are not worse-off overall. There are reasons to believe that this is not always the case (Farrell & Klemperer, 2007, pp. 2005-2006).

number of unattached customers in each period), switching costs do not tend to hinder entry (Klemperer, 1987; Klemperer, 1995). By contrast, mature markets with high switching costs may be more problematic in terms of competition. In more recent literature, several authors show, *contra* earlier findings, that small switching costs can lead to lower prices and profits (Cabral, 2009; Dubé, et al., 2009). Finally, recent work by Chen (2016) shows that switching costs may make network advantages longer lasting, but conversely that if switching costs are stronger than network externalities, markets may be stable.[17]

2.2. Interoperability in network markets

When a network, say a telephone network, is owned by a monopolist, all the nodes can be linked: in theory, a given customer can call any other customer. Research on these kinds of networks has mainly focused on their topology (their shape) and on efficient cost allocation (Economides, 1996; Sharkey, 1995). Conversely, when a market is composed of more than one network belonging to different firms, questions of interconnection, compatibility and interoperability arise. Indeed, it is no longer a given that users of different networks will be able to connect with one another. These questions were extensively studied in the 1980s when telecommunications monopolies such as AT&T were broken up (Katz & Shapiro, 1985; Farrell & Saloner, 1985). More recently, they re-emerged with the commercialization of the Internet (Crémer, et al., 2000) and with the rise of multi-sided platforms in the digital economy (Riley, 2020).

2.2.1. Choosing how to compete

In the previous section, I discussed network externalities and switching costs while maintaining an important assumption, namely that networks are privately owned and incompatible. An alternative is to imagine that networks *are* in fact compatible in a given market, i.e., that competing services are interoperable. This can be the case either because firms choose compatible competition, or because it is enforced by a regulator or court. This change in competition has important effects on market structure and welfare.

Compatibility is defined by Economides (1996, p. 686) in the broadest sense as the feature of goods or services that function together and can be combined without cost.[18] When networks are compatible, the services at hand are said to be *interoperable*. In network industries, compatibility has an important consequence, namely that consumers get full network benefits even if they do not all patronize the same firm (Farrell & Klemperer, 2007, pp. 1975-1976). If there are several telecommunications operators, each with a telephone network, and all of them are compatible, I can patronize any of the operators and derive benefits from the full network size. Because of this, the choice of compatibility or incompatibility is of paramount importance in

[17] Faulhaber (2002) provides an example of early work on the interaction between switching costs and network externalities. See also Farrell & Klemperer (2007) and Suleymanova & Wey (2011).

[18] Here I mainly discuss literature on compatibility in markets with direct network effects and with firms selling a single good. Another approach has been adopted in the so-called “mix and match” literature, which looks at compatibility in markets without network effects and with multi-product firms, and whose findings are quite different (Matutes & Regibeau, 1988).

network markets (Katz & Shapiro, 1985; Katz & Shapiro, 1994; Chen, 2018). There are several ways to achieve two-way compatibility in network markets, the main approaches being (1) interoperability by contract (>2 firms agree to interoperate) and (2) interoperability following standardization (firms agree on a set of technical standards, sometimes aided by a standard-setting organization) – see Faulhaber (2002) and Chen (2018).[19]

An important strand of the literature seeks to define the conditions under which interoperability will emerge endogenously (without public intervention). Several authors using static models find that compatibility will emerge when firms in a given market are comparable in size (Katz & Shapiro, 1985; Crémer, et al., 2000; Malueg & Schwartz, 2006). This intuitive result is easily understood when one considers one of the principal effects of compatibility, namely *levelling*: compatibility neutralizes the competitive advantage of firms with a larger installed base, preventing market tipping in the long term (Farrell & Klemperer, 2007, p. 2048). As such, network size becomes a public good (Kristiansen & Thum, 1997), and firms enter in competition "in" the market as opposed to "for" the market. A key corollary of this result is that dominant firms generally have low incentives to interoperate. On the contrary, they have incentives to refuse to contract with their competitors and to block attempts at standardization. Generally, the coordination problem involved in standardization has been studied extensively through the lens of game theory (Farrell & Klemperer, 2007, pp. 2026-2027).

Absent consensus, another strategy remains for smaller competitors who want to reap the benefits of a larger network, namely *one-way*, or *adversarial* interoperability: firms market a service that is compatible with the dominant player's service without the latter's consent. This form of compatibility by imitation or reverse engineering can be parried by dominant firms with the help of intellectual property rights (e.g., patents, or more recently, terms of service), by invoking secrecy, by changing technologies frequently (Besen & Farrell, 1994, p. 127), or in the case of communication networks, simply by refusing to interconnect (Economides, 1996, p. 677; Farrell & Klemperer, 2007, p. 1976). Finally, some of the literature looks at the incentives to engage in side payments in order to increase the willingness to interoperate. The classical literature on compatibility also studies markets for converters/adapters, which can create compatibility without changing the design of the original goods or services (Katz & Shapiro, 1985).

2.2.2. Interoperability and antitrust

Compatibility and interconnection have been important themes in landmark US antitrust cases such as *Carterfone* (1968) and *U.S. v. AT&T* (1982) – both related to telecommunications – as well as, more recently, *U.S. v. Microsoft* (2001) and its EU counterpart *Microsoft Corp. v. Commission* (2007) in the field of computer software.[20] A brief overview of the facts follows, with emphasis

[19] Katz & Shapiro (1986, pp. 823-824) also mention *de facto* standardization, i.e., having all consumers purchase the same technology following a standards war. This would typically be an example of market tipping. Consumers do get full network benefits, but they lose the option to switch networks, and are liable to be exploited by the monopolist. See also Belleflamme & Peitz (2015, p. 633).

[20] *In re* Use of the Carterfone device in Message Toll Telephone Service, 13 F.C.C.2d 420 (1968) and *United States v. AT&T*, 552 F. Supp. 131 (D.D.C. 1982). See also footnote 1 on the *Microsoft* cases.

on showing how antitrust has approached the issue of compatibility through the prism of monopolization and access. All of the rulings mentioned above led to some form of interoperability mandate being put in place following a finding of monopolization (Section 2 of the Sherman Act) or abuse of dominant position (Article 102 TFEU). As a preliminary comment, it should be noted that most systems of competition law do not recognize a duty to deal with competitors, and so no duty to interconnect. This could seem to be contradicted by rulings such as *Aspen Skiing* (1985) in the United States, but these have been treated as exceptional in the case law that followed (see *Verizon v. Trinko*), and some academics argue that any "duty to deal" doctrine expressed in *Aspen Skiing* has effectively been overruled (Weiser, 2009).[21]

In *Carterfone*, the telephone monopolist AT&T warned Thomas Carter's customers that they had breached FCC Tariff No. 132 on the prohibition of "interconnecting devices" (Johnson, 2008). Carter had been selling radio transceivers which allowed customers to call conventional telephone users remotely, a service that was particularly useful to oil field workers. It used the public telephone network but relied on its own electricity supply. Carter sued AT&T, contending that AT&T's warnings against its customers violated the Sherman Act. In 1968 the Federal Communications Commission (FCC) overturned the ban on "interconnecting devices" and provided that these devices would be allowed insofar as they did not damage the network. This decision paved the way for the notion "net neutrality" (Wu, 2003) and shows an early case of a dominant player's anti-compatibility strategy being struck down.

After the war, AT&T had total control of long-distance and local telephony, but also (through its subsidiary Western Electric) on the manufacturing of equipment (Solymar, 1999, p. 233). Despite some minor concessions in the 1950s and despite *Carterfone*, this situation remained largely unchanged until the 1970s. *U.S. v. AT&T* originated in a private company, MCI, setting up private lines between public exchanges to undercut AT&T's prices in long-distance telephony. This was facilitated by the spread of microwave transmission, a relatively new technology at the time. It was also related to the fact that AT&T's universal service pricing meant that long-distance callers between urban areas subsidized rural long-distance callers, and so it was easy to undercut these prices (Solymar, 1999, p. 234). AT&T refused to interconnect but MCI ended up winning the dispute that ensued, and a consent decree was signed in 1982, providing both a structural remedy (long-distance and local telephony were separated) and rules enforcing equal access to the network (Weiser, 2009). The pattern in this case resembles *Carterfone*, with a dominant player resisting interconnection with a third-party service, only to be forced to interconnect by law. The equal access rules which ensued spurred innovation and transformed communications in the long term (Weiser, 2009, pp. 275-276), to such an extent that some academics have argued that these rules would have sufficed to generate a competitive telephony market (Crandall, 2001).

The two Microsoft cases (in the United States and in the European Union) bring us closer to the digital economy. In 1998, the US government brought suit against Microsoft for having allegedly engaged in exclusionary behavior (including several agreements with ISPs,

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[21] *Aspen Skiing Co. v. Aspen Highlands Skiing Corp*., 472 U.S. 585 (1985) and *Verizon Commc'ns Inc. v. Law Offices of Curtis V. Trinko*, LLP, 540 U.S. 398, 409 (2004).

manufacturers, and content providers to promote Internet Explorer) and predatory conduct (including pricing Internet Explorer below cost, tying the browser with the operating system, and promoting a Windows-specific version of the programming language Java to reduce portability) – see Gilbert & Katz (2001). Efficiency arguments for most of these practices were rejected in court, but there were strong disagreements on the remedies to be put in place, going from divestiture to softer behavioral remedies (Weiser, 2009, pp. 282-284). In the end, a consent decree which was signed in 2001 required Microsoft *inter alia* to maintain APIs which would allow third-party software developers to develop applications for other platforms, but which would be compatible with Windows (Weiser, 2009, p. 284). The European Commission took a similar view when it obliged Windows to supply "interoperability information" to competitors in 2004 as part of the *Microsoft Corp. v. Commission* case (Moldén, 2008).[22]

2.2.3. The regulator's point of view

We saw that firms in network markets may agree to interoperate, and that in rare cases of monopolization, courts may put remedial interoperability mandates in place. But, as recognized in *Trinko*, courts should not "assume the day-to-day controls characteristic of a regulatory agency" (Weiser, 2009, p. 483). Considering this observation, what is the place of public intervention in the field of compatibility? Doganoglu & Wright (2006, p. 46) define the "compatibility problem" as the situation in which firms do not make their networks compatible even though doing so is socially desirable. Katz & Shapiro (1985, p. 684), for their part, speak of a market failure when the fixed cost of interoperability is larger than the increase in profits for some firms, while this cost is lower than the increase in total surplus. When faced with such a market failure, regulators may consider enforcing interoperability, for example via sectorial regulation. Generally, two distinct questions must be answered from the regulator's point of view, namely (1) when do the benefits of interoperability outweigh the costs? and (2) what is the best way to intervene? I discuss these two issues in turn below.

Generally, economists disagree on how efficient competition between incompatible networks is (Farrell & Klemperer, 2007, p. 2052). This means that pro-compatibility policies are bound to be controversial. We saw earlier that firms with comparable market shares are likely to want to interoperate (Katz & Shapiro, 1985; Crémer, et al., 2000; Malueg & Schwartz, 2006). Conversely, interoperability is unlikely to emerge endogenously in markets that are highly asymmetric. This is because dominant firms are unlikely to be willing to relinquish the competitive advantage they derive from their proprietary network, especially if no side payments are made. Indeed, denial of compatibility is often a profitable strategy for dominant firms (Farrell & Klemperer, 2007, p. 2054), as is targeted degradation of interconnection (Crémer, et al., 2000). Given that industrywide compatibility brings clear benefits for consumers, this might warrant intervention in certain markets. Furthermore, the presence of multihoming should not be taken as

[22] Although not directly related to antitrust, the *Google LLC v. Oracle America, Inc.* case is also interesting. It concerns the applicability of copyright to APIs, which are crucial for the development of compatible software (Gratz & Lemley, 2018). A more general discussion of the issue of intellectual property and interfaces is provided by Farrell & Katz (1998). On the related issue of the legality of reverse engineering, see Samuelson & Scotchmer (2002).

evidence that compatibility is not needed. Indeed, while multihoming gives consumers greater network benefits, it creates costs for consumer, leading to higher prices and profits, and reduces firms' incentives to interoperate. Due to this, regulators should probably be more concerned about compatibility when multihoming is present (Doganoglu & Wright, 2006). Data portability, for its part, reduces switching costs, but does not solve the compatibility problem either. In fact, there is empirical evidence from the telecommunications sector that data portability can make compatibility less desirable at firm level (Shi, et al., 2006).

What are the effects of compatibility on consumer welfare, and what might be the social costs of compatibility? While compatibility clearly presents advantages for consumers, who get full network benefits, a lower risk of market tipping, and lower prices, some authors have pointed to the risk of loss of variety (Farrell & Saloner, 1986). When it comes to innovation, Kristiansen & Thum (1997) underline the risk of over- or underinvestment, a point which has been made repeatedly in the current debates surrounding the DMA. When compatibility takes the form of standardization, public authorities are often inexpert, and consumers could get "trapped" in an inferior standard if there is imperfect information (Farrell & Saloner, 1985). The fact that public authorities require private information to achieve standardization also increases the risk of capture (David, 1987, pp. 219-220). Finally, compatibility is liable to diminish competition in nascent markets, because it reduces *ex ante* incentives to acquire a large installed base before one's competitors (Katz & Shapiro, 1986, p. 148). Hence most of the literature finds that the case for pro-compatibility policies is strongest when technological progress is unlikely (Farrell & Klemperer, 2007, p. 2054) and/or when markets are relatively mature.

The question of policy levers remains. This has been comparatively less studied in the literature, but Farrell & Klemperer (2007) express a general preference for policies which *facilitate* rather than *require* compatibility, based on the risks of government failure seen above. A rich strand of the literature looks at public intervention in the field of publicly mediated standardization – see Farrell & Saloner (1985) and David (1987) for early work on this topic – but standardization is only one of the possible policy tools at governments' disposal when they want to achieve compatibility. Going back to the current debates surrounding the DMA, three main policy levers deserve mention here:

- A general interoperability mandate modelled on the obligation to interconnect in telecommunications.[23] The EU could require the concerned firms (gatekeepers) to adopt existing technical specifications (standards) or ask them to agree on new ones.
- A prohibition of intellectual property rights (IPR) and/or secrecy arrangements whose sole purpose is to maintain incompatibility. This could facilitate the emergence of compatibility

[23] In telecommunications, compatibility is to a large extent compulsory in the EU and in the United States, but a fee is often charged for interconnection (Laffont, et al., 1998). This interconnection mandate is often mentioned by stakeholders as an example of what could be put in place in digital markets (see 4.5. below), even though it is understood that compatibility would not be conditional on the payment of a fee – probably because the cost of interconnection has decreased tremendously with the digitalization of communication networks.

by contract or by standardization without requiring it, particularly in markets where one dominant player is inefficiently imposing incompatibility.

- A promotion of adaptors and converters to encourage compatibility. Adaptors (e.g., third party applications which would access social media platforms on users' behalf) would require some level of data interoperability, open interfaces (APIs), and permissive intellectual property.[24]

3. Data, sources, methodology

The approach adopted here to investigate interoperability and competition in digital markets is twofold. First, I develop a microeconomic model of competition in network markets. The baseline model is a simple duopoly which draws on previous literature on network effects and compatibility (Katz & Shapiro, 1985; Crémer, et al., 2000), with the important addition of literature on competition with data collection and disclosure (Casadesus-Masanell & Hervas-Drane, 2015). I also develop four extensions of the baseline model. The model helps to flesh out hypotheses about the conditions under which interoperability is likely to emerge endogenously in markets such as social media and interpersonal messaging. It also helps to conceptualize public intervention in this area. I then calibrate the theoretical model in two separate case studies to see how it reacts in stylized scenarios. Second, I study important submissions to the DMA/DSA consultations in the European Union to confront the theoretical results with firms' views on interoperability. Below, I develop the main assumptions made in the theoretical model (3.1), and my approach to filtering and analyzing the submissions to the DMA/DSA and NCT consultations (3.2).

3.1. Theoretical background for the model

The model is based on the theory of industrial organization (IO), itself a subfield of microeconomics. Industrial organization is the study of the interaction between firms as sellers and consumers as buyers. This interaction results in a market allocation which has various welfare properties (Belleflamme & Peitz, 2015, p. 3). To study this interaction and the resulting market allocation, the IO literature makes certain assumptions, *inter alia* (1) that firms may have market power, i.e., competition may be imperfect and (2) that market players interact strategically. The first assumption is a relaxation of the perfect competition paradigm, which posits that firms do not have price-setting power (firms cannot increase prices without lessening the demand for their products). Assuming that competition is perfect is warranted in markets where many small firms compete, and where barriers to entry are low (Belleflamme & Peitz, 2015, p. 4). By contrast, it is often inadequate when studying digital and/or network markets such as the ones which I study here. The second assumption means that firms and consumers anticipate each other's actions. The

[24] Two other means of achieving compatibility, namely side payments and reducing the cost of interoperability, are discussed in the literature – see Katz & Shapiro (1985) – but are not mentioned here. Indeed, side payments can resemble concerted practices, and in many cases would not survive antitrust scrutiny. Meanwhile, digitization has drastically reduced the cost of interconnection, which means that cost reduction is not as relevant a policy lever as it used to be.

study of decision-making in situations where agents interact strategically forms part of what is known as game theory.

In addition to these two general assumptions on which IO is based, three more assumptions are made in the model I develop below. First, I assume that actors in the model are rational, namely firms are profit-maximizing and consumers are utility-maximizing. This is not always the best approximation of real-life behavior, as readily recognized by IO economists. However, profit maximization is a useful standard against which to measure firm behavior and is particularly pertinent if we assume that firms have market power (Belleflamme & Peitz, 2015, pp. 15-16). The utility-maximization hypothesis is not unproblematic either, given that consumers can make occasional errors or even be more systematically biased, but this hypothesis remains standard in the literature. Despite its limitations, it provides a useful benchmark for studying real-life behavior. Second, I assume that there is complete information: all the sellers and buyers in the game have full information about prices, utilities, payoffs, strategies, and previous decisions. A final assumption made in the model is that consumers' expectations about network sizes are fulfilled (Katz & Shapiro, 1985, p. 425). Namely, I assume that consumers decide to patronize a firm based on expectations about other consumers' behavior (joining the firm where expected network benefits are highest, for instance), and that these expectations turn out to be true (Belleflamme & Peitz, 2015, pp. 587-588).[25]

The study of strategic interaction between rational decision-makers falls within the ambit of game theory. To predict market allocation using game theory, we need a rule which can predict the way in which the game will be played. This type of rule is known as a solution concept (Belleflamme & Peitz, 2015, pp. 7-8, 720-728). The solution concept used here is the Cournot-Nash equilibrium. When we suppose that there is perfect information, a sequential game can be solved using backward induction, provided it is finite. In practice, we start from the last action taken in the game and move up the game tree until the first action is reached, assuming at every step that the actors maximize their profit or utility. When using backward induction, we know that the resulting Nash equilibria are subgame perfect (Belleflamme & Peitz, 2015, pp. 720-728). Optimization is conducted analytically using partial differentiation.

3.2. Studying the DMA/DSA and NCT consultations

Proposals for the Digital Services Act (DSA) and the Digital Markets Act (DMA) regulations (henceforth DSA/DMA) were presented by the European Commission on 15 December 2020. These proposed pieces of legislation are components of the European digital strategy. The legislative packages are being discussed by the European Parliament and the Council under the ordinary legislative procedure (as of April 2021). The DSA mainly aims to update the e-Commerce Directive, including a revision of the liability of intermediaries for online content, while the DMA is designed to lay down obligations and prohibitions for online platforms that play a "gatekeeper" role, with the objective of preventing anti-competitive practices which are systematic. With regards to the second objective, several stakeholders have called for the new regulations to contain,

[25] Both Katz & Shapiro (1985) and Crémer et al. (2000) adopt a fulfilled expectations approach.

inter alia, interoperability requirements. These could take the form of obligations to interoperate, or prohibitions of practices or arrangements that limit interoperability.

As part of the process leading up to the proposed pieces of legislation, stakeholders were asked to give their say on the new rules as part of a single consultation, which ran between June and September 2020. I call this consultation the DSA/DMA consultation. Various stakeholders were consulted, and the European Commission received 2862 responses (European Commission, 2020). The DSA/DMA questionnaire contains six different modules and a total of 359 questions. Users were given the option to answer all or only a subset of the six modules, which concern (1) user safety, (2) liability regimes, (3) online gatekeepers, (4) advertising and smart contracts, (5) the self-employed, and (6) governance. The questionnaire is a mix of open-ended questions (free text of varying length) and close-ended questions (radio buttons, checkboxes, and Likert scales). Only one question specifically mentions interoperability: in module 3, respondents are asked to what extent they agree with the statement "There is sufficient level of interoperability between services of different online platform companies." Most of the responses mentioning interoperability are part of module 3 on "online gatekeepers".

In parallel, another consultation on a so-called "New Competition Tool" (henceforth NCT) ran during the same period, gathering responses from 188 stakeholders, who answered a total of 219 questions (European Commission, 2020). Given that the NCT consultation attracted far fewer responses, I mainly consider the DSA/DMA consultation below, but some of the analysis contains elements from the NCT consultation. One question in the NCT consultation specifically pertains to data/protocol interoperability and structural competition problems. It should be noted that the NCT was later merged with the DMA, given significant redundancies between the two initiatives. The submissions to the consultations provide an empirical means of analyzing firms' incentives to interoperate given the theoretical results from the model. To find responses pertaining to interoperability more efficiently and systematically, I used regular expressions (regex) to search through all the free text responses in both consultations (DSA/DMA and NCT). This allowed me to filter out responses mentioning "interoperability" or related terms, while also accounting for possible spelling mistakes in the submissions.[26] The responses are grouped by type of respondent and exported as text documents for qualitative analysis.

4. Analysis and findings

4.1. The baseline model

Drawing on Crémer, Rey & Tirole (2000), Katz & Shapiro (1985) and Casadesus-Masanell & Hervas-Drane (2015), it is possible to construct a model of interoperability and competition between networked services.[27] The model is a Cournot duopoly: there are two firms competing on

[26] The source code which filters the submissions and produces the documents is available on GitHub. See https://github.com/julesbeley/Sciences-Po-Who-wants-interoperability.

[27] The model developed here draws extensively on the network economics literature, as opposed to the literature on multi-sided platforms – see Rochet & Tirole (2003) – and so it does not, for example, elaborate on indirect network

quantities for unattached customers.[28] The two firms have two sources of revenue, namely prices charged to consumers and disclosure of personal data collected during use, in line with Casadesus-Masanell and Hervas-Drane (2015). There are two steps in the model, namely (1) firms simultaneously set prices p_i and data analytics input z_i, and (2) consumers patronizing either of the firms decide how much personal information y_i to provide. The baseline model is not tailored to a specific industry. Rather it is apt to describe the incentives to interoperate of any digital service competing with direct network effects, including most notably social media networks and interpersonal messaging applications.

4.1.1. Demand side

There are two firms providing networked services and a large number of customers. Firm $i = 1,2$ has an installed base of customers $\beta_i \geq 0$ with $\beta_1 \geq \beta_2$: firm 1 benefits from a larger installed base of customers than firm 2. In line with Crémer et al. (2000), customers in the installed bases are locked into their services, i.e., they cannot switch.[29] The two firms compete for unattached customers. Unattached customers are heterogenous, reflecting different types of adopters of the service, e.g., early adopters and so-called laggards. This is standard in the literature on technology adoption (Mansfield, 1961). The demand curve is linear, i.e., the stand-alone benefit τ is uniformly distributed between 0 and 1. Customer of type $\tau \in [0,1]$ obtains net utility from subscribing to firm i at price p_i equal to:

$$u_i = \tau + s_i - p_i,$$

where s_i represents the quality of firm i's service.[30] With $i = 1,2 \neq j$, s_i can be written as:[31]

$$s_i = v\Big([1 + \rho y_i(1 - y_i - d_i)](\beta_i + q_i) + \theta\big(\beta_j + q_j\big)\Big).$$

In this equation, q_i is firm i's capacity for market expansion, and so $\beta_i + q_i$ is the total number of consumers patronizing firm i once the unattached customers have made their purchasing decisions. A consumer's utility when joining firm i's network (u_i) is composed of a standalone benefit τ

effects or more complex questions of price structure arising in platform markets. As such, it is apt to describe only one "side" of multi-sided platforms. Underpinning this is the assumption that the two "sides" of a multi-sided platform are analytically separable. This is a admittedly a simplification, but one that is useful – see Rochet & Tirole (2003, p. 993): "To make progress, … [the network economics] literature has ignored multisidedness and the price allocation question".

[28] It is important to note that this type of model can describe two different kinds of situations. The most obvious situation is that in which there actually are new consumers entering the market. Alternatively, we can think of unattached consumers as being customers who reconsider their decision to patronize one of the two services.

[29] In a more elaborate multi-period model, we could imagine introducing switching costs in addition to network effects. Faulhaber (2004) provides an example of such a model. For simplicity I assume switching costs are infinite here.

[30] Note that the price p_i is not necessarily monetary, as customers rarely pay a "price" in the conventional sense of the term for modern digital services. Rather, price here can also be seen as "payment" made by the customer with attention or personal data, in line with the assumptions usually made when studying digital services.

[31] I maintain the notation $i = 1,2 \neq j$ throughout this section.

which captures heterogeneity in demand, and a network benefit $f(n)$ with n the expected size of firm i's network and $f' > 0$. This is the standard approach to modelling demand for network goods and services, as we saw above. It is important to note that the network effects in the model are direct: up to the personalization of firm i's service $\rho y_i(1 - y_i - d_i)$, the quality of the service is directly proportional to network size $\beta_i + q_i + \theta(\beta_j + q_j)$. Unattached consumers make their purchasing decisions based not only on the number of existing customers β_i, but also on the expected number of new customers q_i. I assume that these expectations turn out to be correct, in keeping with the fulfilled expectations approach adopted by Katz & Shapiro (1985) and Crémer et al. (2000).

Like in the model developed in Crémer et al. (2000), there is an exogenous interoperability parameter θ. Crémer et al. (2000) have a continuous parameter denoting the quality of interconnection $\theta \in [0,1]$. This is the case because the firms studied in their model (Internet backbones) can increase or degrade the quality of interconnection – typically, the speed of interconnection. By contrast, here I assume that when two networks are interoperable, interconnection is perfect ($\theta = 1$), so that the two services can work together without loss or delay. Hence the parameter here is discrete: there are two different states – interoperability ($\theta = 1$) and no interoperability ($\theta = 0$). The parameter θ can be set either by the firms involved (two firms agreeing to interoperate by contract) or by a regulator (in the case of firms being required adopt a standard, for instance). In the baseline model, I assume that θ is industrywide: following the maxim that "it takes two to tango", interoperability cannot be put in place unilaterally (Crémer, et al., 2000, pp. 434-435). This assumption is relaxed in the case studies (see 4.4). When there is interoperability ($\theta = 1$), the two networks are interconnected, and so up to benefits derived from personalization, the network benefits are the same for customers of both firms: s_i increases with the number of consumers patronizing firm i but also the number of customers patronizing the competitor (firm j), given that we have:

$$s_i = v\Big([1 + \rho y_i(1 - y_i - d_i)](\beta_i + q_i) + (\beta_j + q_j)\Big).$$

Following Casadesus-Masanell & Hervas-Drane (2015), consumers benefit from personalization of their service when they provide personal data (y_i), but they incur a disutility from disclosure of these data (d_i). I add $\rho \in [0,1]$, which is a parameter that captures the importance of personalization, and which is assumed to be market-wide in the baseline model. Note that even when $\theta = 1$, benefits from personalization are not "shared": firm i collects data from its own customers, and only its customers benefit from the resulting personalization. The quality of service is proportional to $v > 0$, which represents the importance of connectivity, and ensures the existence of a stable equilibrium, like in Crémer et al. (2000).[32] To simplify the baseline model,

[32] Unlike in Crémer et al. (2000), it is difficult to describe the valid parameter space analytically. Nonetheless, I have observed tipping effects and instability with values of v above 0.35, and use values of v for which $v \leq 0.3$ in the case studies below.

we can assume that all the personal data provided by consumers are disclosed by the firms, namely $d_i = y_i$ (this assumption is lifted in one of the extensions below – see 4.2.2). The total population of new customers is normalized to 1. It is easy to show that there is an optimal level of information provision $y_i^* = \frac{1}{4}$ (see Appendix A for proof). From this result, we can see that all customers provide the same amount of personal information. Plugging y_i^* into s_i and writing:

$$\alpha = \rho y_i^*(1 - 2y_i^*) = \frac{8+\rho}{8},$$

we have:

$$s_i = v\left[\alpha(\beta_i + q_i) + \theta\left(\beta_j + q_j\right)\right].$$

4.1.2. Supply side

Following Katz & Shapiro (1985), the two firms choose capacities for market expansion simultaneously, and prices adjust at levels such that customers are indifferent between the two firms and demand is equal to supply (Crémer, et al., 2000, p. 449). Given that unattached customers view the two services as perfect substitutes, the quality-adjusted prices (also known as hedonic prices) are the same, namely we can write:

$$p_1 - s_1 = p_2 - s_2 = \hat{p}.$$

Consumers join a network when their utility is positive, and the marginal customer (who is indifferent between signing up to one of the services and not signing up, i.e., $u_i = 0$) has valuation:

$$\tau = p_i - s_i = \hat{p}.$$

From the assumption that τ is uniformly distributed, we know that the expected total number of customers is equal to the mass of consumers with a larger valuation than $\hat{p}$. Seeing as the total population of new customers is normalized to 1, there are $\hat{p}$ consumers with a valuation smaller than $\hat{p}$, and $1 - \hat{p}$ consumers with a valuation larger than $\hat{p}$. Given fulfilled expectations, we have:

$$q_1 + q_2 = 1 - \hat{p}.$$

We know that $\hat{p} = p_i - s_i$. Rearranging the terms and plugging in our definition of quality of service s_i yields the optimal price for firm i as a function of capacities and installed bases. We have:

$$p_i^* = 1 - (1 - \alpha v)q_i - (1 - v\theta)q_j + \alpha v\beta_i + v\theta\beta_j.$$

Prices are increasing in the size of the installed base but decreasing in the number of new customers. Given prices, firms set quantities to maximize gross profits. Firms have two sources of revenue, namely price and disclosure of personal information. I posit that marginal cost c is constant and identical for both firms. Casadesus-Masanell & Hervas-Drane (2015) assume that all personal data are disclosed to third parties at the price of 1. In fact, firms collecting data from their customers tend to perform data analytics, which increases their value. With this in mind, we can write firm i's gross profits as:

$$\pi_i(\theta) = \left(p_i^* + (1+z_i)^2 y_i^* d_i - c - c(z_i)\right)q_i - F(\theta),$$

with $z_i \in [0,1]$ the data analytics input and $c(z_i)$ the marginal cost of data analytics for firm i. We can write the marginal cost of data analytics as $c(z_i) = \frac{1}{2}(z_i)^2$. Recalling the full disclosure assumption $d_i = y_i$, we can show that π_i is concave in z_i, and that the optimal data analytics input is $z_i^* = \frac{1}{7}$ (see Appendix A for proof). In the above equation, $F(\theta)$ is the cost of interoperability for the firm, with $F(0) = 0$ and $F(1) = F > 0$, i.e., I assume the cost of interoperability to be fixed, in line with Katz & Shapiro (1985). Plugging z_i^* in our expression of profits and optimizing for q_i, we can write q_i^* as a function of q_j^*. Taking advantage of the fact that $q_i^* = \frac{1}{2}\left(\left[q_i^* + q_j^*\right] + \left[q_i^* - q_j^*\right]\right)$, firm i's equilibrium capacity can be written as a function of the installed bases (see Appendix A for proof):[33]

$$q_i^*(\theta) = \frac{1}{2}\left(\frac{(\alpha+\theta)v\left(\beta_i+\beta_j\right) + \frac{15}{7} - 2c}{2(1-\alpha v) + (1-v\theta)} + \frac{(\alpha-\theta)v\left(\beta_i-\beta_j\right)}{2(1-\alpha v) - (1-v\theta)}\right).$$

4.1.3. Demand expansion and levelling

From the result above, we can see the effect of interoperability on market outcomes and study the associated welfare properties. Note that the sum of the two firms' capacities is increasing in the sum of the installed bases $\beta_i + \beta_j$, and similarly that the difference between the capacities is increasing in the difference between firm i and firm j's installed bases $\beta_i - \beta_j$. This reflects the fact that unattached customers are attracted to larger installed bases, and that, absent interoperability, the installed base advantage allows firm 1 to attract a larger proportion of new customers. Generally, two effects can be observed from the equation above, namely *demand expansion* (Crémer, et al., 2000, p. 451) and *levelling* (Farrell & Klemperer, 2007, pp. 2047-2048). The left-hand side of the expression in parentheses, $q_i^* + q_j^*$, is larger when there is interoperability

[33] For ease of notation, I sometimes write equilibrium capacities $q_i^*(\theta)$ as q_i^*.

($\theta = 1$) given that both v and $\beta_i + \beta_j$ are positive and that the denominator is positive and smaller when $\theta = 1$. This means that a larger proportion of unattached customers join either of the networks when there is interoperability: we have *demand expansion*.[34] The second effect (*levelling*) can be observed by looking at the influence of θ on the right-hand side of the expression. When $\beta_i - \beta_j$ is positive, $q_i^* - q_j^*$ is smaller with $\theta = 1$. By construction we have $\beta_1 - \beta_2 > 0$, and so $q_1^* - q_2^*$ is smaller when $\theta = 1$. Interoperability means that network benefits are shared, and so the larger firm's competitive advantage fades. This is the *levelling* effect.

In Crémer et al. (2000, p. 451), equilibrium capacities are symmetric when $\theta = 1$, because quality of service depends solely on network benefits in their model.[35] This is not the case here: with $\theta = 1$ and when there is personalization ($\alpha > 1$) the larger firm (firm 1) obtains a larger share of unattached customers than the smaller firm: $\alpha - \theta > 0$, and so $q_1^* - q_2^* > 0$. This reflects the fact that personalization allows the firms to maintain part of their network effects proprietary even with interoperability (recall that personalization only ever applies to the firm's own network, regardless of the value of θ). $q_1^* - q_2^*$ is directly proportional to the difference between the installed bases and increases with α and so with the importance of personalization ρ.

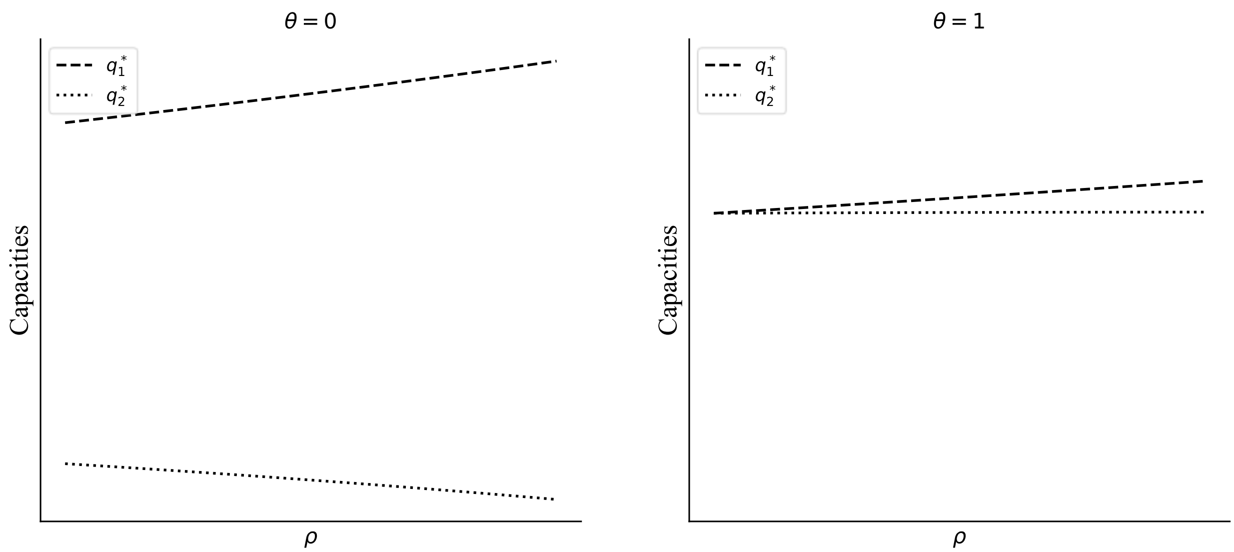

Figure 1. Equilibrium capacities as function of personalization: numerical example in a highly asymmetric market.

Figure 1 shows how equilibrium capacities diverge when the importance of personalization ρ increases. I set $\beta_1 = 0.85$, $\beta_2 = 0.1$, $v = 0.25$ and $c = 0.4$. Note how the difference between the

[34] The notion of *demand expansion* could justifiably be met with skepticism given that many of the markets at hand here are characterized by high coverage. The "demand expansion" narrative is more apt to describe the first scenario mentioned above (see footnote 28), i.e., the scenario where new consumers really do enter a nascent market. Alternatively, we can think of demand expansion as a higher share of customers staying in the market after reconsidering their purchasing decisions.

[35] The model in Crémer et al. (2000) can be viewed as a special case of the present model where $\rho = 0$.

capacities is increasing in the importance of personalization, and how the large firm stands to lose from the move to interoperability. In this case, firm 1 has no incentives to interoperate with firm 2, regardless of the level of personalization ρ. Note also how the capacities are equal when personalization is unimportant and there is interoperability (r.h.s.). Visually, we can surmise that the average of the capacities is higher with interoperability than without for any level of personalization ρ. This is indeed borne out by the model: $q_1^* + q_2^*$ is larger when $\theta = 1$.

Generally, when firm 1's installed base advantage is strong, interoperability benefits firm 2, whose capacity q_2^* increases, but it penalizes firm 1: we have $q_1^*(1) < q_1^*(0)$. We can see that the equilibrium capacities are equal when there is no personalization ($\rho = 0$) and $\theta = 1$, as demonstrated above: in this case, firm 1 and firm 2 get an equal share of unattached customers, because quality of service is the same for both firms, at $s_i = v([\beta_1 + q_1] + [\beta_2 + q_2])$, like in Crémer, Rey & Tirole (2000). These results are consistent with the literature: absent compatibility, network effects mean that the larger firm can attract a larger share of the unattached customers. When the two networks are interoperable and when there is no personalization, the network externalities are equally distributed between the two services, which means that the equilibrium capacities are symmetric.

4.1.4. Welfare and incentives to interoperate

To study the welfare properties of interoperability, it is necessary to write out consumer surplus and profits as a function of θ. In line with Katz & Shapiro (1985), consumer surplus can be written as the utility for an individual consumer integrated over the range of customers who join either network (i.e., consumers for whom $\tau > \hat{p}$; recall also that the population of unattached consumers is normalized to 1). Thus, consumer surplus $CS(\theta)$ can be written as (see Appendix B for proof):

$$CS(\theta) = \int_{\hat{p}}^{1} (\sigma + s_i - p_i)\, d\sigma = \frac{[q_1^*(\theta) + q_2^*(\theta)]^2}{2}.$$

From this result, we can see that consumer surplus is maximal when the sum of capacities $q_1^* + q_2^*$ is maximal, i.e., when the largest number of unattached consumers joins the two networks. We saw above that we have:

$$q_1^*(\theta) + q_2^*(\theta) = \frac{(\alpha + \theta)v(\beta_i + \beta_j) + \frac{15}{7} - 2c}{2(1 - \alpha v) + (1 - v\theta)}.$$

Clearly $q_1^*(1) + q_2^*(1) > q_1^*(0) + q_2^*(0)$. This means that we have $CS(1) > CS(0)$: consumers always benefit from the move to interoperability, regardless of the respective sizes of the installed bases β_1 and β_2.

What are the private incentives to interoperate? Plugging optimal capacities into our definition of $\pi_i^*(\theta)$, we can rewrite gross profits as $\pi_i^*(\theta) = (1 - \alpha v)[q_i^*(\theta)]^2 - F(\theta)$ (see

Appendix B for proof). From this equation, we can see that firm i's profits vary with q_i^* and with the fixed cost of interoperability F. For now we can assume that firm i's willingness to interoperate depends only on the profitability of interoperability (in keeping with the profit-maximization assumption, firms are not concerned with other market properties such as variety or consumer surplus).[36] I introduce firm i's willingness to interoperate φ_i, which is equal to the profitability of interoperability, namely: $\pi_i^*(1) - \pi_i^*(0)$.[37] Thus we can assume that firm i is willing to interoperate when $\varphi_i = \pi_i^*(1) - \pi_i^*(0)$ is positive, i.e., when $\pi_i^*(1) > \pi_i^*(0)$.

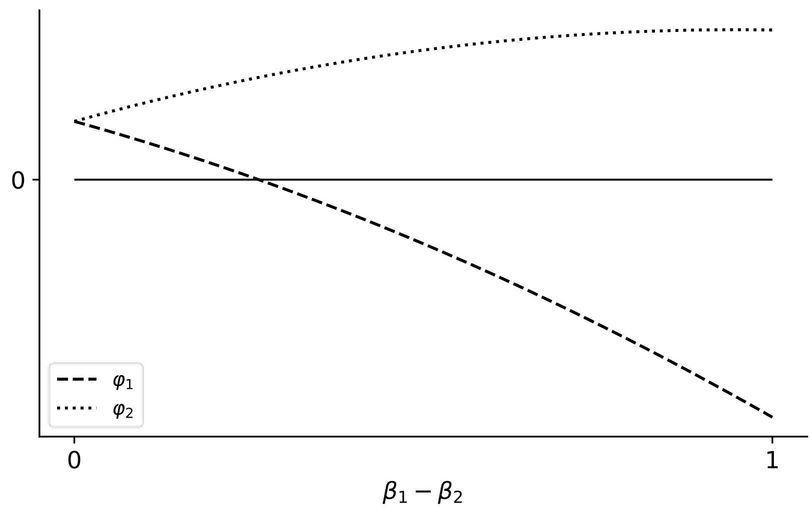

Figure 2. Willingness to interoperate as a function of the difference between the installed bases: a numerical example.

Figure 2 shows a numerical example. I keep the sum of installed bases fixed at $\beta = 1$, and the other parameters are set to $\rho = 1$; $v = 0.25$; $c = 0.4$, and $F = 0.01$. In this case, when the difference between the installed bases satisfies $\beta_1 - \beta_2 > 0.25$ (approximately), firm 1 is no longer willing to interoperate. Indeed, we have $\varphi_1 < 0$. We can see that the smaller firm always has incentives to interoperate, whereas firm 1's willingness to interoperate is decreasing in its installed base advantage, and negative when this advantage becomes important. Writing φ_i as $(1 - \alpha v)[q_i^*(1) + q_i^*(0)][q_i^*(1) - q_i^*(0)] - F$, it is clear that the sign of $\varphi_i + F$ depends on the sign of $q_i^*(1) - q_i^*(0)$, i.e., on the difference between equilibrium capacities with and without interoperability – note that $1 - \alpha v$ and $q_i^*(1) + q_i^*(0)$ are always positive. We know that $q_2^*(1) > q_2^*(0)$, given that this is the case for both $q_2^*(\theta) + q_1^*(\theta)$ and $q_2^*(\theta) - q_1^*(\theta)$. Thus $\varphi_2 + F$ is always positive: up to the cost of interoperability the smaller firm is always willing to interoperate

[36] When firms can unilaterally decide to make their network compatible, interoperability becomes highly strategic: firms must consider not only the profitability of interoperability *ceteris paribus*, but also other firms' decisions. This is illustrated in the case study on adversarial interoperability below (see 4.4.2).

[37] Willingness to interoperate could also be relative, i.e., $\varphi_i = \frac{\pi_i^*(1) - \pi_i^*(0)}{\pi_i^*(0)}$. This would make comparisons with different values for the parameters more rigorous, but it makes the expressions more complex. Note that the roots are the same regardless of which definition is chosen.

in this setup. Note that if the cost of interoperability is insignificant or null ($F \approx 0$), the smaller firm is always willing to interoperate with its larger competitor ($\varphi_2 > 0$).

The large firm, for its part, may or may not be willing to interoperate, depending on whether it can benefit more from the *demand expansion* effect than it loses from the *levelling* effect. This is more likely to happen when the installed bases are similar in size. As the installed base advantage $\beta_1 - \beta_2$ tends to 0, the capacities advantage $q_1^*(\theta) - q_2^*(\theta)$, which is smaller when $\theta = 1$, also tends to 0. There is a value of $\beta_1 - \beta_2$ for which the *demand expansion* effect becomes stronger than the loss incurred for firm 1 due to the *levelling* effect (see Figure 2 for an illustration). In this case, both firms have incentives to interoperate. Figure 3 shows a numerical example where the installed bases are very close in size, and the firms' capacities both increase with interoperability. I set $\beta_1 = 0.5$ and $\beta_2 = 0.45$. Like in the example in Figure 1, we have $v = 0.25$ and $c = 0.4$. Note how here both firms benefit from interoperating: equilibrium capacities increase significantly for firm 1 and firm 2. In this case, and up to the cost of interoperability F, both firms would be willing to interoperate. Here, private incentives would be sufficient for compatibility to emerge endogenously, provided the cost of interoperability is not too high.

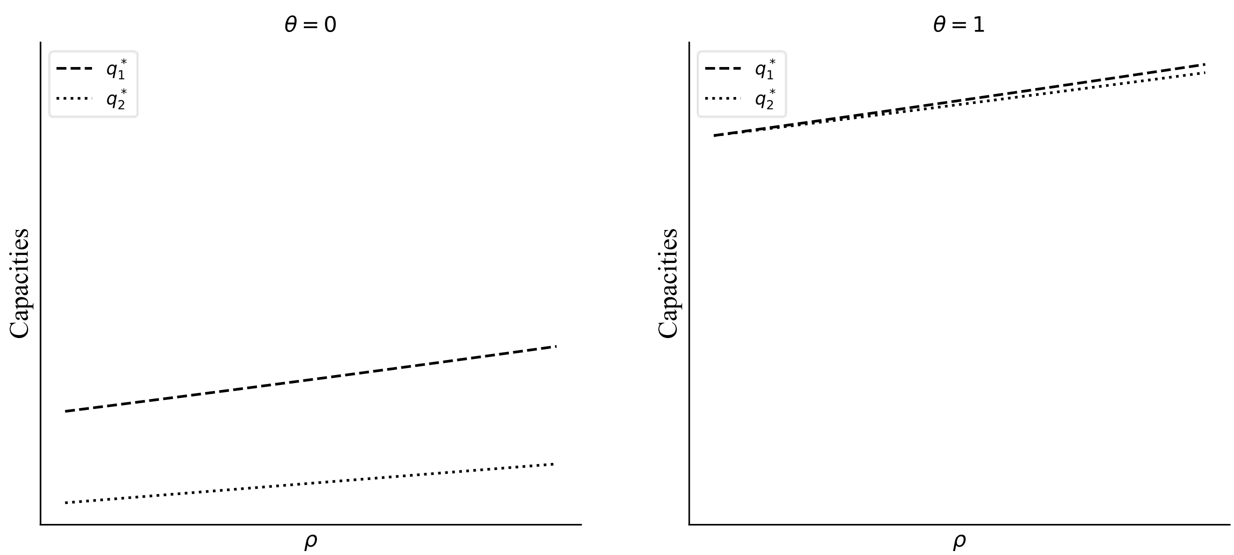

Figure 3. Equilibrium capacities as a function of personalization: numerical example with near-equal installed bases.

Who decides on interoperability when the two competitors disagree? In the baseline model, I assume that interoperability must be reciprocal, i.e., firms cannot unilaterally decide to interoperate.[38] Given this assumption, whether interoperability arises endogenously or not will depend on what the firm that is least willing to interoperate wants. We can introduce φ, defined as

[38] This assumption is suspended in one of the case studies below (see 4.4.2). The definition of joint willingness to interoperate here is analogous to the joint quality of interconnection in Crémer et al. (2000) defined as $\theta = \min\{\theta_1, \theta_2\}$ (2000, pp. 449-450). Crémer et al. (2000, pp. 450, see footnote 23) also discuss an alternative means of determining θ, namely bargaining, but for simplicity I assume that there can be no bargaining or side payments.

the joint willingness to interoperate, with $\varphi = \min\{\varphi_1, \varphi_2\}$. In this framework, the two firms only agree to interoperate when $\varphi > 0$. Given that $\varphi_2 + F$ is always positive, the sign of φ depends on the sign of φ_1, up to the cost of interoperability F. If F is not too high, the smaller firm will always be willing to interoperate, and so interoperability will only emerge endogenously if firm 1 benefits from *demand expansion* more than it loses from *levelling*. Thus firm 1's incentives determine whether compatibility will emerge endogenously or not.

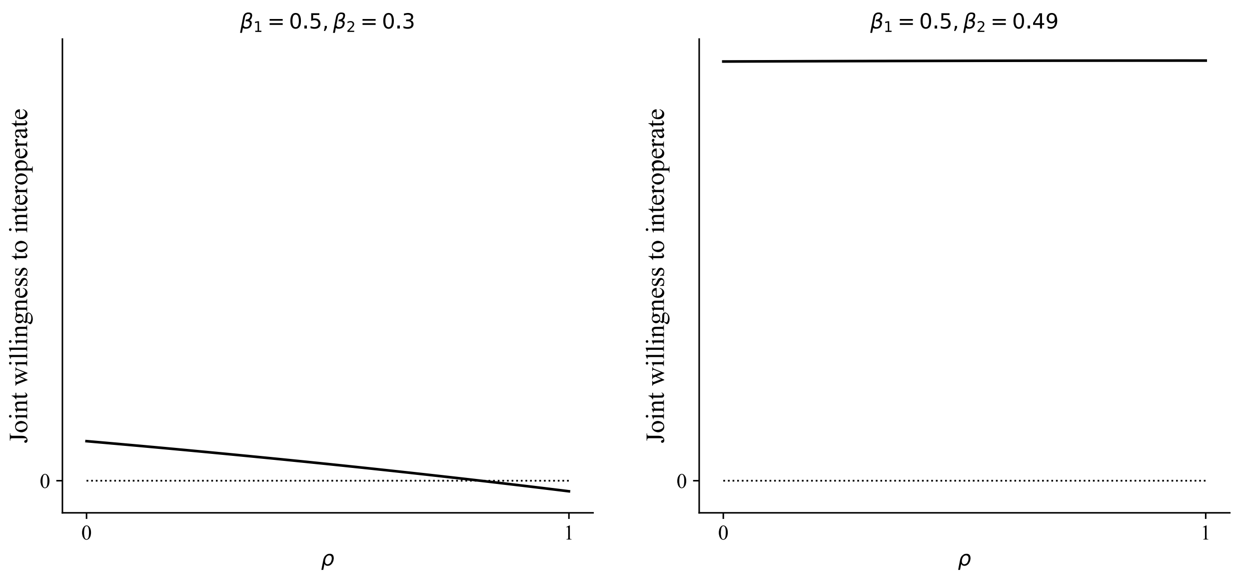

Figure 4. Joint willingness to interoperate as a function of personalization.

It can be shown that φ is decreasing in the level of personalization ρ when the installed bases are sufficiently different in size (i.e., when firm 1 has a large installed base advantage).[39] This is because the dominant firm disproportionately benefits from personalization when there is no interoperability. Indeed, in this scenario q_1^* is larger than q_2^* and personalization only applies to the firm's own network $\beta_i + q_i$. Given that the dominant firm wants to keep this advantage in quality of service, it is less willing to interoperate when there is more personalization.[40] Conversely, when the two firms are similar in size ($\beta_i \approx \beta_j$), φ is increasing in ρ, i.e., a higher level of personalization reinforces the joint willingness to interoperate. Generally, we can draw the conclusion that personalization accentuates the effect of the installed bases on the willingness to interoperate. This is illustrated in Figure 4. The model is calibrated with $v = 0.3$, $c = 0.3$, and $F = 0.01$. The joint willingness to interoperate is weakly increasing in the level of personalization in the example on

[39] Again, writing willingness to interoperate as the relative change in gross profits would admittedly be more rigorous here than computing the simple difference (see footnote 37). For simplicity I keep the definition introduced above. Tests conducted with the "relative" willingness to interoperate show that the results found here are robust.

[40] Recall that quality of service is written as $s_i = v\left([1 + \rho y_i(1 - y_i - d_i)](\beta_i + q_i) + \theta(\beta_j + q_j)\right)$.

the right (the dotted lines mark $\varphi = 0$). From this result, we can represent the willingness to interoperate as a function of (1) the difference between the installed bases and (2) personalization (see Table 1).

Table 1. Joint willingness to interoperate as a function of personalization and installed base advantage.

	Low level of personalization	High level of personalization
Small difference between installed bases (low market concentration)	High	Highest
Large difference between installed bases (high market concentration)	Low	Lowest

4.2. Extensions of the baseline model

For the sake of simplicity, the baseline model makes certain assumptions regarding periodicity, disclosure of personal data, the number of firms in the market, and consumer behavior that can be relaxed here to generalize certain findings. In this section, I look at various extensions which provide further insights on competition and the incentives to interoperate. In particular, the extensions tackle the issues of market tipping, incomplete disclosure of personal data, competition between n firms, and consumer multihoming.

4.2.1. A stylized model of market tipping

Using the baseline model, it is easy to create a stylized model of market tipping in a market with two incompatible networks ($\theta = 0$) and no switching.[41] We saw earlier that the literature expects incompatible competition in markets with network effects to lead to market tipping (Arthur, 1989; Belleflamme & Peitz, 2015, pp. 597-598; Farrell & Klemperer, 2007). This result can easily be reproduced here. To do this, we imagine that the game from the baseline model is repeated over T periods, and that in every period, unattached customers join the market and may decide (or not) to patronize one of the two firms. Like in the baseline model, the population of unattached customers is normalized to 1 in every period. Maintaining the assumption that consumers cannot switch networks once they have made their purchasing decision, firm i's equilibrium capacity in period $t = 0,1,2,\dots,T$ is given by:

$$q_i^*(t) = \frac{1}{2}\left(\frac{\alpha v[\beta_i(t) + \beta_j(t)] + \frac{15}{7} - 2c}{2(1-\alpha v) + 1} + \frac{\alpha v[\beta_i(t) - \beta_j(t)]}{2(1-\alpha v) - 1}\right),$$

[41] We can imagine for example that switching costs are infinite.

where firm i's installed base in period $\beta_i(t)$ is defined by:

$$\begin{cases} \beta_i(0) = \beta_i \\ \beta_i(t+1) = \beta_i(t) + q_i^*(t). \end{cases}$$

β_i denotes the initial installed base and in every period the installed base corresponds to the installed base in the previous period added to the equilibrium capacity in that same period.

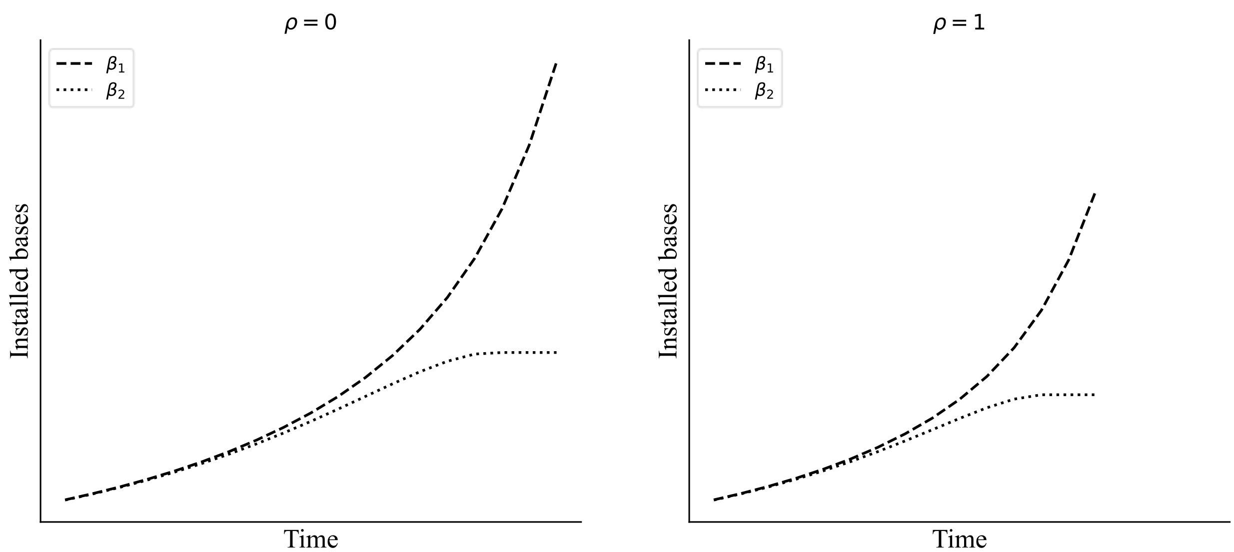

Figure 5. A numerical example of tipping in a duopoly with incompatible competition.

Using numerical examples like the one presented above (see Figure 5), it is easy to show that even with small differences between the initial installed bases, the market will eventually tip in favor of the largest firm. This is in line with the literature on incompatible competition.[42] In Figure 5 the parameters are set at $v = 0.25$, $c = 0.4$. A very small initial advantage is given to firm 1, namely $\beta_1 = 0.11$ and $\beta_2 = 0.1$. The simulation stops 2 periods after firm 2's equilibrium capacity q_2^* has reached 0. When $q_2^* < 0$, the market is considered to have tipped and I write $q_2^* = 0$. The axes are identical in the two figures. Note how with more personalization ($\rho = 1$), tipping occurs sooner (r.h.s.), because the larger firm enjoys a larger installed base advantage. Using the same model but setting $\theta = 1$ (compatible competition), we have:

[42] Arthur's (1989) model is slightly more elaborate in that consumers are randomly assigned types, which determine which firm they prefer. Arthur shows that the sequence of differences between the installed bases $\delta(t) = \beta_i(t) - \beta_j(t)$ is non-ergodic (the long run is determined by small historical events) and path-dependent (it is impossible to predict which firm will dominate) – see Belleflamme & Peitz (2015, pp. 597-598).

$$q_i^*(t) = \frac{1}{2}\left(\frac{(\alpha+1)v[\beta_i(t)+\beta_j(t)]+\frac{15}{7}-2c}{2(1-\alpha v)+(1-v)} + \frac{(\alpha-1)v[\beta_i(t)-\beta_j(t)]}{2(1-\alpha v)-(1-v)}\right),$$

with $\beta_i(t)$ defined like above. Numerical examples show that in this case and with any level of personalization (α), the two firms compete "for" the market and there is no tipping: the market is symmetric in the long run, regardless of firm 1's initial installed base advantage.

4.2.2. Variable disclosure

In the baseline model, I assumed that there was full disclosure of personal data after collection. This means that firms sell all the data they collect from their users. In line with Casadesus-Masanell & Hervas-Drane (2015), we can relax this assumption here, writing disclosure d_i as $d_i = \mu y_i$ with $\mu \in [0,1]$ – recall that in the baseline model we have $d_i = y_i$, i.e., $\mu = 1$. With this new parameter, quality of service can be written as:

$$s_i = v\left([1+\rho y_i(1-y_i-\mu y_i)](\beta_i+q_i)+\theta(\beta_j+q_j)\right).$$

Using this specification, we can write optimal provision of personal information on the demand side as $y_i^* = \frac{1}{2(1+\mu)}$. Provision of personal information is homogenous and decreasing in the level of disclosure because consumers incur disutility from disclosure. For simplicity, I assume that firms do not conduct data analytics, i.e., we have $z_i = 0$ and so we write gross profits as:

$$\pi_i(\theta) = (p_i^* + \mu(y_i^*)^2 - c)q_i - F(\theta).$$

It can be shown that the difference between the equilibrium capacities is given by (see Appendix C for proof):

$$q_i^*(\theta) - q_j^*(\theta) = \frac{\left(1+\frac{1}{2}\rho y_i^* - \theta\right)v(\beta_i-\beta_j)}{2\left(1-\left(1+\frac{1}{2}\rho y_i^*\right)v\right)-(1-v\theta)}.$$

Given that y^* is decreasing in μ, the difference between the capacities $q_i^* - q_j^*$ is clearly decreasing in μ and is smaller when $\theta = 1$. This means that while personalization creates an advantage for the largest firm, the advantage is higher when disclosure is low. When disclosure is high, customers will provide less information, which will reduce the value of personalization as shown by Casadesus-Masanell & Hervas-Drane (2015). As we saw earlier, a higher level of personalization favors the larger firm. With higher disclosure, this advantage fades. Hence disclosure has a levelling effect here. Due to the form of $\pi_i^*(\mu)$, it is difficult to optimize μ analytically. An interesting question for future work is whether the optimal level of disclosure μ^* is lower when

$\theta = 1$.[43] Indeed, it would be interesting to investigate the effect of interoperability on privacy. Numerical simulations I have conducted do not give a clear answer to this question.

4.2.3. Generalizing to n firms

It can be shown that the *demand expansion* and the *levelling* effect hold for any number of firms n. Instead of having a duopoly, we can model an oligopoly, much like in Katz & Shapiro (1985). There are n firms which are viewed as perfect substitutes by consumers. They enter in competition over a population of unattached customers which is normalized to 1. I posit that firms may either not interoperate at all or may all interoperate, forming a large network (θ is industry-wide and equal to 0 or 1, whereby firms cannot form compatible coalitions). This assumption may seem unrealistic but is justified in the case where interoperability is achieved through industrywide standardization, for example. In the interest of simplifying notation, the full disclosure assumption is maintained ($d_i = y_i$), without loss of generality. Quality of service can be written as:

$$s_i = v\left([1 + \rho y_i(1 - 2y_i)](\beta_i + q_i) + \theta \sum_{j \neq i} (\beta_j + q_j)\right).$$

Writing prices and gross profits and optimizing, it is possible to express equilibrium capacities like in the baseline model (see Appendix C). With $\alpha = \frac{8+\rho}{8}$, the sum of capacities is given by:

$$\sum_{e=1}^{n} q_e^* = \frac{(\alpha + (n-1)\theta)v\beta + \frac{15}{14}n - nc}{2(1 - \alpha v) + (n-1)(1 - v\theta)},$$

with $\beta = \sum_{e=1}^{n} \beta_e$ the sum of installed bases. The sum of capacities is clearly larger when $\theta = 1$, and so we have a *demand expansion* effect like in the duopoly setting. Consumer surplus CS can be shown to be equal to $CS = \frac{1}{2}(\sum_{e=1}^{n} q_e^*)^2$. In this context, consumers benefit from a decision to interoperate between any number of firms n, as long as all of the firms interoperate.[44] It can also be shown that the sum of the differences between q_i^* and the capacities of the other $n - 1$ firms is:

$$\sum_{j \neq i} (q_i^* - q_j^*) = \frac{(\alpha - \theta)v}{2(1 - \alpha v) - (1 - v\theta)} \sum_{j \neq i} (\beta_i - \beta_j).$$

[43] In Casadesus-Masanell & Hervas-Drane (2015), disclosure is endogenous. Firms commit to a level of disclosure before setting prices. The same approach could be adopted here to look at the effect of interoperability on privacy.
[44] Welfare and surplus are much more complex when firms can build compatibility "coalitions" spanning less than the entire market, as first introduced by Rohlfs (1974). Katz & Shapiro (1985, p. 436) show that private incentives to standardize may be too high when the standard leads to less-than-industrywide compatibility. This topic is also tackled by Economides & Flyer (1995). See also the case study in 4.4.1 below.

When $\sum_{j\neq i}(\beta_i - \beta_j)$ is positive, $\sum_{j\neq i}(q_i^* - q_j^*)$ is smaller when $\theta = 1$. Solving $\sum_{j\neq i}(\beta_i - \beta_j) > 0$ for β_i, we find that this condition amounts to $\beta_i > \overline{\beta_{j\neq i}}$ where $\overline{\beta_{j\neq i}}$ is the arithmetic mean of the installed bases of all of firm i's competitors, i.e., the average size of the other firms. This means that when firm i's installed base is larger than the average installed base of its competitors, it will lose ground relative to these competitors if all firms decide to interoperate, due to the *levelling* effect seen above in the duopoly setting. Under certain conditions, it may successfully balance this loss against the benefits derived from the *demand expansion* effect. Like in the duopoly setting, it is easy to write firm i's equilibrium capacity as follows (See Appendix C for proof), and so we can express equilibrium capacities as a function of the installed bases:

$$q_i^* = \frac{1}{n}\left(\sum_{e=1}^{n} q_e^* + \sum_{j\neq i}(q_i^* - q_j^*)\right).$$

Note that when all installed bases are equal, i.e., we have $\beta_i = \frac{\beta}{n}$ for all $i = 1,2, \dots n$, all the firms attract the same share of unattached customers: the market is strictly symmetric. Indeed, we have $\sum_{j\neq i}(\beta_i - \beta_j) = 0$ for all i and so $\sum_{j\neq i}(q_i^* - q_j^*) = 0$, which means that we can write equilibrium capacities as $q_i^* = \frac{1}{n}(\sum_{e=1}^{n} q_e^*)$, i.e., the unattached customers are indifferent between the networks. As we saw above, the sum of capacities increases when firms decide to interoperate, and so given that $\pi_i^*(\theta) = (1 - \alpha v)[q_i^*(\theta)]^2 - F(\theta)$, it is profitable for the firms to agree to interoperate, provided the cost of interoperability $F(1) = F$ is not too high. This means that when the market is symmetric, there is no *levelling* effect, and so all the firms benefit from interoperating. Up to the fixed cost of interoperability, the crucial predictor of joint willingness to interoperate is market concentration. Indeed, when a market is concentrated, there will be at least one firm for which $\sum_{j\neq i}(\beta_i - \beta_j)$ is high, and so from the definition of $\sum_{j\neq i}(q_i^* - q_j^*)$, at least one firm will stand to lose from interoperating with its competitors due to the *levelling* effect. Hence, they would prevent any joint industry effort to do so, given that in this set-up all firms must cooperate for consumers to benefit from interoperability.

4.2.4. Multihoming

Instead of assuming that customers in the installed base exclusively patronize either of the firms, we can assume that some of these customers multihome, in the language introduced by Rochet & Tirole (2003) and Caillaud & Jullien (2003). Formally, and going back to our duopoly framework, I assume that there is a fraction of multihomers ω that patronizes both firms, and that for $i = 1,2$, there are $\beta_i - \frac{\omega}{2}$ customers attached solely to firm i (Crémer, et al., 2000, p. 464). From this specification, we can write quality of service as:

$$s_i = v\left([1 + \rho y_i(1 - 2y_i)]\left(\beta_i - \frac{\omega}{2} + q_i\right) + \theta\left(\beta_j - \frac{\omega}{2} + q_j\right) + [1 + \rho y_i(1 - 2y_i)]\omega\right),$$

while still maintaining the full disclosure assumption ($d_i = y_i$). Note that the total installed base can still be written as $\beta_1 + \beta_2$ and that firm i's installed base advantage $\beta_i - \beta_j$ remains unchanged. Note also that by construction both firms collect data from the group of multihoming customers, which is why we have $[1 + \rho y_i(1 - 2y_i)]\omega$ in s_i. After factorizing, quality of service can be written as:

$$s_i = v\left([1 + \rho y_i(1 - 2y_i)]\left(\beta_i + \frac{\omega}{2} + q_i\right) + \theta\left(\beta_j - \frac{\omega}{2} + q_j\right)\right).$$

Once we have optimized data provision on the consumer side ($y_i^* = \frac{1}{4}$), we can write equilibrium prices p_i^* like in the baseline model (see Appendix E for proof). Firms conduct data analytics z_i like above, and have two sources of revenue, namely disclosure of personal information and price charged to consumers. Optimizing gross profits, which are written as:

$$\pi_i = \left(p_i^* + (1 + z_i)^2 y_i^* d_i - c - \frac{1}{2}(z_i)^2\right) q_i,$$

for z_i and then for q_i, we can write $q_i^* + q_j^*$ and express equilibrium capacities as a function of ω and θ (see Appendix E):

$$q_i^*(\omega, \theta) = q_i^*(0, \theta) + \frac{\omega}{2}\left(1 - \frac{3(1 - \alpha v)}{3 - v(2\alpha + \theta)}\right),$$

where $q_i^*(0, \theta)$ is firm i's equilibrium capacity when $\omega = 0$ (i.e., there is no multihoming – see Appendix E for proof). Given that $q_i^*(\omega, \theta) - q_j^*(\omega, \theta) = q_i^*(0, \theta) - q_j^*(0, \theta)$, multihoming does not affect the difference between the two firms' capacities in equilibrium. Indeed, the multihoming advantage is symmetric. Note that when $\alpha = \theta = 1$, we have:

$$\frac{\omega}{2}\left(1 - \frac{3(1 - \alpha v)}{3 - v(2\alpha + \theta)}\right) = 0,$$

which means that the multihoming advantage is null. In fact, $q_i^*(\omega, \theta) > q_i^*(0, \theta)$ is equivalent to $\alpha > \theta$. This condition is satisfied for any values of θ and α except $\theta = 1$ and $\alpha = 1$, i.e., there is no personalization but there is interoperability. Except in this scenario, multihoming increases equilibrium capacities. Note also that the advantage derived from multihoming is smaller with $\theta = 0$. Hence multihoming reduces the incentives to interoperate, as found in earlier literature such as Doganoglu & Wright (2006). Indeed, holding other parameters constant, a higher level of multihoming ω means that a firm will lose more from the move to interoperability. Note that consumer surplus is the same as in the baseline model here (see 4.1.4): consumers always benefit from interoperability thanks to the *demand expansion* effect.

4.3. Modelling public intervention

We saw that interoperability always increases consumer welfare in the short term because it leads to demand expansion, thus increasing market coverage. However, in some markets, imposing interoperability can incur significant costs on firms who have invested heavily in acquiring a large customer base when the market was nascent. In turn, this might reduce future entrants' incentives to make those investments. A firm anticipating interoperability requirements would have no incentive to acquire a large market share, which could *in fine* harm consumers due to unmet demand. Hence, while it is often the standard for competition authorities, consumer welfare is not the best measure to look at from a regulatory point of view. Instead, total welfare may be more relevant in this context. In order to model public intervention in the most general case, I use the oligopoly extension presented above. Following Katz & Shapiro (1985), we can write total welfare in the oligopoly setting as $W(\theta) = \pi^*(\theta) + CS(\theta)$, where $\pi^*(\theta)$ denotes aggregate profits in equilibrium (the sum of the n firms' gross profits) and $CS(\theta)$ is consumer surplus. From this definition, we can write total welfare as (see Appendix B for proof):

$$W(\theta) = (1 - \alpha v)\left(\sum_{e=1}^{n} (q_e^*)^2\right) + \frac{1}{2}\left(\sum_{e=1}^{n} q_e^*\right)^2 - nF(\theta),$$

with $F(\theta)$ the fixed cost of interoperability ($F(0) = 0$ and $F(1) = F > 0$). In our model, the problem for a regulator is to set θ to maximize $W(\theta)$.[45] Intervention is warranted when firms set a value for θ which is not efficient from a social perspective: this is the "compatibility problem" seen above (Doganoglu & Wright, 2006, p. 46). Note here that policy intervention takes place after the markets have formed and could be described as *ex post*: unattached customers have already made their purchasing decisions when the hypothetical regulator intervenes.[46] Setting θ as a regulator is analogous to choosing between competition "for" and "in" the market: with incompatible competition ($\theta = 0$), there is competition "for" the market, at least in the early phases of market formation; with compatible competition ($\theta = 1$), firms compete "in" the market. The

[45] A regulator may be more interested in setting $\theta = 1$ only for the dominant firms or for the "gatekeepers". Reflecting this concern, a more asymmetrical approach would be to set a size threshold β_t so that the subset of the n firms for which $\beta_i > \beta_t$ are required to interoperate with their $n - 1$ competitors, while firms that fall beneath this threshold do not have interoperate with the largest firms but are however free to access the dominant players' networks. This type of intervention is not developed further here, but the possibility of non-reciprocal interoperability is analyzed below in the second case study on adversarial interoperability. See also 4.5.

[46] The denomination *ex post* clashes with the common understanding that competition law/policy are *ex post* (they apply after a given situation which needs intervention has arisen) while regulation is *ex ante* (it applies to a set of future situations which require intervention). Here I write that public intervention is *ex post* from an IO perspective because markets have already formed when public authorities decide (or not) to encourage interoperability.

above definition of total welfare is used below in the case studies (see Appendix G and Appendix H).

4.4. Case studies

The baseline model can be expanded and calibrated to study incentives to interoperate between heterogeneous firms (see Appendix F for the methodology used). Two case studies are presented below. One is a three-firm problem based on Facebook's acquisition of WhatsApp, and the other is a simulation of adversarial interoperability in the duopoly setting. The case studies show how the model reacts in practical settings and allows me to study the welfare properties of various stylized scenarios. As such, it is a valuable means of drawing policy implications, even if the results developed here are not as general as the results found above.

4.4.1. The Facebook/WhatsApp acquisition

In 2014, Facebook acquired WhatsApp, after the transaction was cleared by the European Commission and the US Federal Trade Commission (Giannino, 2016). Since then, Facebook has declared it is considering making WhatsApp, Facebook Messenger and another subsidiary, Instagram, interoperable, allowing users from the three messaging applications to communicate with each other without having to switch platforms. For simplicity, I consider Facebook Messenger and WhatsApp in this section, along with an unnamed hypothetical competitor. Even though the acquisition was cleared unconditionally, a key point of controversy following the merger has been data sharing between Facebook and WhatsApp (see Case M.8228 in the EU). The European Commission accused Facebook of having supplied misleading information as part of the merger review, especially concerning the feasibility of integrating personal data collected from the two services. With this point in mind, we can imagine various scenarios:

1. In the original state, all the services are separate and there is no interoperability.
2. In a moderate form of interoperability, we have $\theta = 1$ between Messenger and WhatsApp, i.e., the users of these services can communicate with each other, but users of the third service do not have access to these two services' networks. Here Messenger and WhatsApp form a sort of "coalition" following the acquisition, but the competitor's network remains incompatible.
3. In the highest level of integration, not only would $\theta = 1$ between Messenger and WhatsApp like in Scenario 2, but the two services also share users' personal data, so that personalization applies to the large "integrated" network.
4. Finally, we imagine in the fourth scenario that following standardization or mandated interoperability, compatibility is imposed on the entire market (θ is industrywide and set to 1). In this scenario, customers from all three services can communicate with each other.

Using the model presented above, it is possible to compare the four market outcomes and their welfare properties. To do this, we must calibrate the model with values for the different parameters, as shown in Table 2, and analyze equilibrium capacities, gross profits, and consumer surplus.

Based on the 2020 user bases (1.3 billion for Facebook Messenger and 2 billion for WhatsApp), we can write $\beta_f = 0.3$ and $\beta_w = 0.4$, where β_f and β_w are Facebook Messenger's and WhatsApp's respective installed bases. For simplicity I return to the full disclosure assumption made in the baseline model ($\mu = 1$). Personalization on WhatsApp is very low, but personal data (especially metadata such as activity, contacts, and device information) are most likely monetized.[47] By contrast, users accessing Messenger via Facebook have a relatively high level of personalization, mostly through the recommendation system and targeted advertisement. We can set $\rho_f = 0.8$, $\rho_w = 0$ and $\rho_c = 0.2$.[48] The importance of connectivity v can be assumed to be homogenous. To ensure the existence of a stable equilibrium, I set $v = 0.2$. Given the size of the platforms, we can posit that the marginal cost is homogenous and low at $c = 0.3$. Using the multihoming extension seen above, we can consider that a share of Messenger and WhatsApp users are in fact multihomers, with $\omega = 0.2$. This means that around half of the users of either platform use both platforms. Consequently, there are $\beta_f - \frac{\omega}{2}$ sole Facebook Messenger users, and $\beta_w - \frac{\omega}{2}$ sole WhatsApp users (see Appendix G for the exact model specifications). Finally, the cost of interoperability F is assumed to be low. I set it at $F = 0.05$. Note that in Scenario 1 and 4, θ is industrywide, like in the baseline model and the n-firm extension. By contrast, in Scenario 2 and 3, θ is not industrywide: only Facebook Messenger and WhatsApp have access to each other's network, and only they pay the fixed cost of interoperability F.

Table 2. Values chosen for the parameters in the Facebook/WhatsApp model.

	Description	Facebook Messenger (f)	WhatsApp (w)	Competitor (c)
β_i	Installed base	0.3	0.4	0.3
ρ_i	Level of personalization	0.8	0	0.2
μ	Level of disclosure	1	1	1
v	Importance of connectivity	0.2	0.2	0.2
c	Marginal cost	0.3	0.3	0.3
F	Cost of interoperating	0.05	0.05	0.05

With this set of parameters, we can write equilibrium capacities in the different scenarios described above (we have a linear system of equations – see Appendix G). For each scenario, I also calculate total welfare. The results are presented in Table 3.

[47] Before 2016, WhatsApp charged a subscription fee. I disregard this here, focusing instead on its current business practices.

[48] When $\rho_w = 0$, the value that customers set for y_i (the amount of information they provide) has no effect on their utility. Strictly speaking, an infinite number of values y_i allow consumers to maximize u_i. For consistency with the rest of the model, I nonetheless keep $y_i^* = \frac{1}{4}$ here for WhatsApp (see Appendix G), and disclosure of personal data enters the definition of the firm's gross profits.

Table 3. Equilibrium capacities in the Facebook/WhatsApp case study, in the different scenarios.

	q_f^*	q_w^*	q_c^*	W
1.	0.257	0.260	0.199	0.393
2.	0.363	0.335	0.085	0.405
3.	0.370	0.334	0.081	0.409
4.	0.322	0.296	0.301	0.495

The similarity between the firms' installed base means that in Scenario 1 (no interoperability), each service gets a similar share of unattached consumers. By contrast, when Messenger and WhatsApp interoperate, the competitor attracts fewer customers ($q_c^* = 0.085$), because customers benefit from stronger network benefits by joining either Messenger or WhatsApp. After the acquisition, data sharing (Scenario 3) does not significantly increase the number of customers who join Messenger and WhatsApp. It is interesting to note that WhatsApp does not benefit from data sharing in this scenario ($q_w^* \approx 0.34$ in Scenarios 2 and 3) because the firm does not offer any personalization to its customers. By contrast, Facebook Messenger benefits slightly from data sharing with WhatsApp, because its personalization applies to a larger network following the acquisition (see Appendix G). With this specification, data sharing between the two services confers a far less important advantage than the decision to interoperate or merge. This suggests that network effects contribute more to market concentration than personalization and data sharing. This result may be partly specific to the model at hand. If, for instance, both firms pooled users' data in such a way that both could disclose data from the other service, we can imagine that data sharing would play a larger role. Here, each firm discloses its own users' data (see Appendix G).[49]

Finally, full interoperability between the three services means the firms set near-equal capacities in equilibrium ($q_i \approx 0.3$). Equilibrium profits increase for all three firms when going from Scenario 1 (no interoperability) to Scenario 4 (industrywide interoperability), and so it would be profitable for the three firms to decide to interoperate. However, it is more profitable for Facebook and WhatsApp to "team up" against the competing firm (Scenario 2 and 3). We can see that total welfare is highest with full interoperability (Scenario 4) and is not affected much by data sharing (Scenario 3). This suggests, in line with previous research, that incentives to achieve less-than-industrywide compatibility may sometimes be too high from a social perspective (Katz & Shapiro, 1985, p. 436). This crucially depends on the cost of interoperability and on the size of the installed bases: when the cost of interoperability is too high compared to the installed base of the smallest firm, this firm will not be able to interoperate (recall that firm i's gross profits are written

[49] In addition, we could assume that the value of the data (and so the price charged during disclosure) does not increase linearly in the total volume of data. The literature on synergies in horizontal mergers (Belleflamme & Peitz, 2015, pp. 397-402) is relevant here. If we accounted for this phenomenon in the current model, it can reasonably be assumed the advantage derived from data sharing would be more important.

as $\pi_i^*(\theta) = (1 - \alpha_i v)[q_i^*(\theta)]^2 - F(\theta)$). Here the firms have similar installed bases, and welfare clearly increases with the decision to interoperate.

4.4.2. Adversarial interoperability

In the baseline model and in the previous case study, I posited that interoperability is consensual and reciprocal. The two firms must agree to interoperate, and if firm 1's customers have access to firm 2's network, the converse is also true. This kind of approach is useful in two situations: when the two firms cooperate with one another because they have common interests (typically, as we saw, when they have similar characteristics and sizes), or when interoperability is enforced by a regulator. In this case study, I lift these assumptions to analyze a third type of situation, namely adversarial and non-reciprocal interoperability.[50] I extend the model seen above with different parameters for the two firms, making the interoperability variable θ firm-specific (θ_i) and endogenous, i.e., firms decide unilaterally whether to interoperate or not, and interoperability can be partial. In this way, a consumer's utility in joining firm i can be written as:

$$u_i = \tau + v_i\left([1 + \rho_i y_i^*(1 - y_i^* - \mu_i y_i^*)](\beta_i + q_i) + \theta_i\left(\beta_j + q_j\right)\right) - p_i.$$

The rest of the model is solved as above (see Appendix F). Up to the fixed cost of interoperability F, the most basic way to analyze incentives to interoperate would be to write $\theta_i^* = 0$ if $\varphi_i < 0$ and $\theta_i^* = 1$ if $\varphi_i > 0$, where φ_i is the willingness to interoperate defined as $\varphi_i = \pi_i^*(1) - \pi_i^*(0)$. But this approach has an important shortcoming: firm i does not anticipate firm j's decision. Yet one of the key assumptions underlying the model used here is that firms do in fact act strategically. In some cases, firm i's decision to interoperate will depend on whether its competitor decides to do so or not, i.e., both firms anticipate each other's actions. Hence φ_i is not sufficient to describe incentives to interoperate when firms can act unilaterally.

Making the interoperability variable firm-specific (θ_i) allows us to study smaller players' incentives to "hack" dominant firms' networks, and relatedly, the latter's incentives to guard against this. Let there be two social media platforms, named d for "dominant" and c for "competitor" and let firm d's installed base be twice the size of firm c's installed base, i.e., $\beta_d = 2\beta_c = 0.6$. We can imagine that the dominant firm is well-installed and that it has extensive personalization and disclosure in place (I set $\rho_d = 0.5$ and $\mu_d = 0.7$). The competitor, by contrast, is privacy-oriented, i.e., it has low personalization and low disclosure ($\rho_c = 0.1$ and $\mu_c = 0$). Marginal costs are the same for both competitors and set at $c = 0.4$, and I choose a setting where the cost of interoperability is low, for instance because there is an open standard which firms can choose to adopt ($F = 0.01$). The parameters chosen for this case study are summarized in Table 4. Here interoperability means that cross-posting is possible: when $\theta_i = 1$, firm i's customers can

[50] Adversarial interoperability is closely related to the study of what some authors call 'partial compatibility' (Belleflamme & Peitz, 2015, p. 605). The European Commission's aim to impose an obligation to interoperate only on gatekeeper firms is also related to adversarial interoperability. In both cases compatibility is one-sided. See also footnote 45 above.

cross-post their content on the competitor's platform, so that they have access to the full network. Meanwhile, the competitor's customers benefit from the additional content, but they cannot post content on firm j's platform.[51] I only consider the network benefits derived from having access to a greater audience here, so that with adversarial interoperability we have $\theta_i = 1$ and $\theta_j = 0$.

Table 4. Values chosen for the parameters in the adversarial interoperability model.

	Description	Firm d	Firm c
β_i	Installed base	0.6	0.3
ρ_i	Level of personalization	0.5	0.1
μ_i	Level of disclosure	0.7	0
v	Importance of connectivity	0.25	0.25
c	Marginal cost	0.4	0.4
F	Cost of interoperating	0.01	0.01

Here we have two scenarios, namely the default scenario (Scenario 1) where the two firms compete with an industrywide parameter $\theta = 0$ and the adversarial interoperability scenario (Scenario 2). In Scenario 2, the competitor makes its service compatible with the dominant firm's service without the latter's consent, for example through reverse engineering. As a result, the competitor's customers can share content on the dominant firm's platform, but the reverse is not true.

Table 5. Equilibrium capacities in the two chosen scenarios.

	q_d^*	q_c^*	W
1.	0.474	0.136	0.364
2.	0.286	0.412	0.419

The results are presented in Table 5. With this setup and without interoperability (Scenario 1), almost half of the unattached customers join the dominant firm ($q_d^* = 0.474$) while a much lower proportion of customers join the new privacy-oriented firm ($q_c^* = 0.136$). If the firms had to cooperate to achieve interoperability, they would most probably not do so, and the market would likely become highly concentrated in the long term. This is because firm d enjoys a significant installed base advantage which it is unwilling to relinquish.

Alternatively, firm c can deliberately make its service compatible with the dominant player's service without the latter's consent (Scenario 2). We saw earlier that this was a common phenomenon in the telecommunications industry (e.g., *Carterfone*), often leading to protracted

[51] A more elaborate model would also consider the utility derived from accessing a greater amount of content, whereby firm j's customers in this example would also experience an increase in network benefits. The interaction between multi-homing and cross-posting would also be interesting to study here, but I leave this for future research.

battles in court (see 2.2.2).[52] By doing this the entrant increases the value of its service, erasing part of the advantage that the dominant firm derives from its installed base. Any of firm c's customers can post content on firm d's platform but the converse is not true. Setting the interoperability parameters to $\theta_c = 1$ and $\theta_d = 0$, I find $q_d^* = 0.286$ and $q_c^* = 0.412$. By "hacking" the incumbent firm's network, the competitor attracts more unattached customers than firm d in equilibrium. This is the case because network effects are now much stronger for customers of firm c, and because customers no longer have to trade off some privacy for strong network benefits by patronizing firm d. It is interesting to note that this form of interoperability is welfare-increasing, thanks to the demand expansion effect and to the low cost of interoperability F. Given these results, it becomes clear that the incumbent should prevent adversarial interoperability to maintain its dominance, for example by suing the entrant or by putting restrictive intellectual property in place.

If the dominant firm cannot prevent the competitor from making its service compatible, the most profitable strategy for firm d is also to choose compatibility. Indeed, if the competitor's service is compatible ($\theta_c = 1$), firm d's capacity q_d is greater when its service is also compatible ($\theta_d = 1$). It is easy to show that the dominant strategy for both firms in this setup is to interoperate, and so the dominant strategy equilibrium is $\{\theta_c^* = 1, \theta_d^* = 1\}$. This result is summarized in Table 6 below, with gross profits in equilibrium presented as a function of the different values of θ_i. It is interesting to note that the result seen here can easily be generalized to any situation where two firms $i = 1,2$ compete with network effects, provided that the cost of interoperability F is not too high. This is particularly clear when the fixed cost of interoperating is null, i.e., $F \approx 0$. In this case, we know from the baseline model that the smaller firm always has an incentive to interoperate, even when interoperability is reciprocal. The larger firm, for its part, anticipates the threat of adversarial interoperability, and so the dominant strategy is always $\{\theta_1^* = 1, \theta_2^* = 1\}$.[53] This explains why dominant firms make efforts to erect barriers against adversarial interoperability.[54] It also suggests that without these barriers, interoperability could emerge endogenously in certain markets when the fixed cost of interoperability is low.[55]

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[52] In *Carterfone*, the interoperability was adversarial, but it was reciprocal: clients of AT&T could also reach Carterfone users (Johnson, 2008). Here, interoperability is adversarial and non-reciprocal. Another example of non-reciprocal/partial compatibility is file formats: Microsoft Word only offers partial support for the OpenDocument (.odt) file format, while free word processing software offers full support for Office Open XML (.docx) documents. In such a case we could write that interoperability is imperfect, i.e., $0 < \theta_i < 1$.

[53] This result will not be proved here but it is intuitive. Simulations of duopolies with random parameters and $F = 0$ suggest that the dominant strategy is always to interoperate. Incentives for adversarial interoperability when $n > 2$ are more complex and are not analyzed further here. It seems reasonable to assume that when the fixed cost of interoperability is null, the dominant strategy is to interoperate for any number of firms n, but this remains to be explored given the complex dynamics arising in settings where firms can form coalitions.

[54] This result naturally extends to settings where interoperability is adversarial but reciprocal, i.e., where a small firm unilaterally makes its service compatible with a dominant firms' (e.g., *Carterfone*) and both consumer groups derive full network benefits.

[55] Note that this case study does not apply to interpersonal messaging: the competitor's consumers would not derive any benefits from being able to send text messages to consumers from the dominant service if the latter could not answer them. It could however apply to placing telephone calls, whereby only the competitor's customers could call

Table 6. Adversarial/non-reciprocal interoperability as a cooperation game: normal form representation of gross profits π_i^* as a function of firms' decisions to interoperate. The dominant strategy is underlined.

		Firm c	
		$\theta_c = 0$	$\theta_c = 1$
Firm d	$\theta_d = 0$	(0.164,0.014)	(0.060,0.116)
	$\theta_d = 1$	(0.243,0.003)	$(\underline{0.138}, \underline{0.071})$

4.5. Insights from EU consultations

With the findings from the theoretical model in mind, we can analyze the responses to the open consultation for the DSA/DMA package, as well as the NCT consultation. This will enable us to evaluate some elements of the model based on different stakeholders' views. It can also shed light on some aspects of interoperability that could be missing from the model, pointing to further refinements that could be made in future research. We saw that one of the main predictors of a firm's incentives to interoperate was the relative size of the firm's installed base, i.e., its market share. In practice, we can expect incumbents and dominant firms to be reluctant to interoperate, because they would lose ground to their smaller competitors, in particular entrants. Consequently, we can also expect them to want to pressure public authorities not to put any wide-ranging interoperability requirements in place. Given that consumers are expected to benefit from interoperability in the model, we can also predict that consumer organizations and non-governmental organizations (NGOs) will pressure policymakers to put interoperability requirements in place.

As a preliminary comment, we can point out that in the DSA/DMA consultation, almost half of the respondent firms (44.9% with $n = 69$) "Fully disagree" with the statement "There is sufficient level of interoperability between services of different online platform companies", and that this result is relatively homogenous across the different size classes (micro-firms, small, medium-sized, and large firms) – see European Commission (2020). The NCT consultation specifically asks respondents to what extent they consider various market scenarios to constitute "structural competition problems", where the scenarios include "restricting content/service interoperability" and "limited data portability due to lack of interoperability" (European

the dominant firm's customers – this can be thought of as a non-reciprocal version of *Carterfone*. Note also that the dominant strategy would still be $\{\theta_c^* = 1, \theta_d^* = 1\}$ even if customers of the firm being "hacked" drew partial network benefits (e.g., $\theta_i^* = 0.5$), along the lines of the extension suggested in footnote 51.

Commission, 2020). Free-text responses to the questionnaires allow firms to justify their position on the topic, which makes these responses more interesting than either Likert scale.[56]

Generally, two different kinds of interoperability are referred to by respondents, namely protocol interoperability and data interoperability. The former is the principal focus of my work, but I also discuss the latter below, especially as it relates to data portability. Firms which mention "interoperability" in at least one of their responses to the two questionnaires fall mainly within two groups, namely tech companies and telecommunications operators. Besides the private sector, many consumer organizations and NGOs responded to the DSA/DMA and NCT questionnaires. In the sections that follow, I review the responses of tech companies, telecoms, and consumer organizations/NGOs respectively, with specific attention to the arguments used by stakeholders to support or argue against interoperability requirements. Generally, questions related to competition pertain to 5 different themes, namely (1) prohibitions for gatekeeper platforms, (2) obligations for gatekeeper platforms, (3) case-by-case remedies when intervention is firm-specific, (4) governance arrangements to enforce new rules, and (5) criteria to establish firms' gatekeeper status.

4.5.1. Tech companies

Several tech companies mention interoperability in their answers to the questionnaires, including Google (United States), IBM (United States), Open-Xchange (Germany), Oracle (United States), Spotify (Sweden), Twitter (United States), Yelp (United States), and Zalando (Germany). Most of these companies are open to more data sharing and data portability. They warn against wide-ranging obligations applied to all firms, but most agree that "gatekeeper platforms" should face more stringent regulation, including in the way of interoperability. There is disagreement, of course, on what constitutes a "gatekeeper platform". It is interesting to note that several firms mention *prohibiting* obstacles to interoperability as opposed to putting in place an *obligation* to interoperate. This is in line with the findings of the second case study above, which shows that entrants have an incentive to "hack" dominant firms' networks, and consequently that dominant firms have an interest in limiting interoperability to enhance their dominance. It is also consistent with the policy approach favored by Farrell & Klemperer (2007), i.e., facilitating rather than requiring compatibility.

Discrimination is mentioned by several firms as the key issue when dealing with "gatekeepers" and as the problem which interoperability could solve (see Zalando's submission, for instance). Answering question 1 on "unfair practices" by "very large online platform companies", Spotify mentions the obstacles to interoperability that Apple allegedly put in place, and which are currently under investigation at the EU level (as of February 2021 – see Case 40437 Apple - App Store Practices). As a result, Spotify calls the European Commission to put fair competition obligations in place (including non-discrimination provisions) and interoperability

[56] The theme of interoperability arises in answers to a relatively small subset of questions in both consultations. The most frequent questions are presented with a numbering in Appendix I (this numbering does not correspond to the numbering in the original questionnaires).

obligations for "gatekeeper platforms", presumably including Apple (question 5). With the dispute between Apple and Spotify, we find a situation which is similar to the case study on adversarial interoperability (4.4.2): an asymmetric interoperability requirement for Apple would give Spotify customers full network benefits, but not *vice versa*. IBM also cites strategies of deliberately reducing or hindering interoperability with competitors' services as an unfair commercial practice which reduces the attractiveness of third-party services (answering question 2) and calls on the European Commission to put interoperability obligations in place, alongside additional data portability requirements and measures to ease multihoming (question 5).[57] It is notable that these three firms (IBM, Spotify and Zalando) all compete with major platforms that the European Commission might consider to be gatekeepers in light of their size and previous antitrust scrutiny (i.e., Google, Apple, and Amazon, respectively).

In its submission to the NCT consultation, Open-Xchange denounces the strategy which consists in using open standards such as XMPP and IRC and then switching to proprietary protocols when critical mass has been reached, providing the example of Google Talk (now Hangout) and Slack.[58] Oracle points out that highly vertically integrated firms have an incentive to limit interoperability downstream. This strategy was not discussed in the theoretical model, because I analyzed interoperability between direct competitors (see also responses from NGOs and consumer organizations below). However, this claim is consistent with work by Gabel (1991), who contends that conflicts on compatibility are likely to arise between firms that are vertically integrated and firms that are not.

Asked about case-by-case remedies that could be put in place in the DSA/DMA consultation, Twitter insists that when it comes to social network services, interoperability could take the form of cross-posting (whereby content posted on one platform would also be posted on other platforms). It explicitly claims that reciprocal interoperability requirements could in fact reduce competition, because traffic would be routed back to the largest firms. The model above does not provide any evidence for this, but extensions to multi-sided platforms might shed additional light on this problem. Twitter proposes a prohibition on limiting interoperability (for example by restricting access to APIs) applied to the largest platforms. Yelp also mentions that prohibitions are a better regulatory tool than obligations, given that obligations will arise from antitrust remedies in specific cases investigated by the European Commission (question 5). It is interesting to note that Twitter considers purposeful limitation of interoperability and data portability to be evidence of gatekeeper status. A similar reasoning was used by the FCC in the context of the AOL-Time Warner merger, when it considered that refusal to interoperate was evidence that the market had "tipped" (Faulhaber, 2002, p. 321).

[57] Curiously, measures to ease multihoming and measures to encourage compatibility would seem to contradict each other according to the multihoming extension seen above. Indeed, multihoming generally decreases firms' incentives to interoperate. The same point may apply to data portability, according to Shi et al. (2006).

[58] It may be interesting to explore this strategy with a sequential game. Unless switching costs are prohibitive, it would not be profitable for a firm to adopt such a strategy in the current model, particularly if all the firm's competitors are interoperating. This would be an interesting path to extend the theoretical model.

In addition, a recurring theme in the responses is data portability, data access and data sharing. Several firms mention data interoperability, as opposed to protocol interoperability. Extending data portability requirements (GDPR, Article 20) is mentioned by Twitter in its response to question 5. Google insists that data access does not automatically increase competition, providing the example of competition in the search engine market, where mergers have allegedly not led to increases in search accuracy. According to Google, the current framework for digital services allows extensive data sharing to take place – it further claims that measures have been adopted to promote data mobility, which has increased user choice in a satisfactory manner (question 3). In general, Google warns against far-reaching regulation in the way of interoperability.

Despite being generally favorable to an update of the current regulatory framework, tech companies submit that they are concerned about the effects of interoperability mandates on privacy and on the incentives to invest. Yelp, for instance, calls for interoperability obligations for gatekeepers, but contends that any interoperability mandate should be accompanied with strong guarantees in terms of privacy and security (question 6). Google also mentions that interoperability should be balanced against possible privacy-related issues. While this point of view is uncontroversial and shared by many other stakeholders, it is notable that arguments related to privacy and security have been used before by firms that are reluctant to interoperate. Faulhaber (2002, p. 315) reports that AOL contended that it had privacy and security concerns when it justified restricting interoperability with other instant messaging services in the early 2000s.

4.5.2. Telecoms

The views of telecommunications firms on the DSA are interesting in two regards, namely (1) insofar as they are competitors and sometimes customers of digital "gatekeepers" (see Deutsche Telekom's submission, for instance), and (2) as firms working under wide-ranging sectorial regulation, in particular concerning interconnection and interoperability (see *inter alia* Directive 2018/1972 in the European Union).[59] Telecommunications companies' revenues have been significantly affected by social media, which provide extensive communications features "for free". As such, it is in these firms' interest (1) to denounce possible unfair practices by dominant digital firms which they interact with and (2) to shape new regulation, with the regulatory experience of the telecoms sector in mind. It should also be noted that unlike most digital services studied in the model above, the telecommunications sector was late to monetize personal data, because it traditionally relies on other business models, such as subscription and pay-as-you-go.

[59] Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code (Recast). The history of telecommunications markets is interesting to mention here. Economides (1996, p. 677) explains that cost reduction led to a fragmentation of ownership after the 1980s, with a transition from monopoly to oligopoly. The re-emergence of a competitive telecommunications market in the 1990s was conditioned on an obligation to interconnect (Doganoglu & Wright, 2006, p. 46). This also explains why interconnection and interoperability were important topics of study in the IO literature in the 1980s and 1990s, a prime example being the work of Katz & Shapiro (1985; 1986; 1986) and Farrell & Saloner (1985; 1986).

Various large telecommunications operators participated in the open consultation, including A1 Telekom (Austria), Bouygues (France), Deutsche Telekom (Germany), Orange (France), TIM (Italy), and Vodafone (United Kingdom). As we can expect from firms whose business models have been significantly transformed by digitization, these companies are unambiguously favorable to new interoperability mandates as part of the DSA. Crucially, all telecoms which cite "interoperability" in their submissions explain that they "Fully disagree" with the statement "There is sufficient level of interoperability between services of different online platform companies". Like certain tech companies, they point to gatekeepers deliberately reducing interoperability and interconnection between their services and those of competitors (see submissions by A1 Telekom Group and Orange in response to questions 2 and 1 respectively). Both firms which answer question 9 in the NCT questionnaire (Orange and A1 Telekom Group) give obstacles to interoperability the highest rating in the list of potential structural competition problems. A1 Telekom Group specifically mentions anti-compatibility strategies, for example strategies consisting in restricting access to software, hardware, and standards, but also limiting data portability, while Orange denounces obstacles to multihoming and switching. According to several telecoms, the result of these strategies is lock-in, associated with more market power and less contestability (A1 Telekom Group). Several telecoms point to the technical requirements for (data) interoperability, including a standardization of APIs and of data formats for data sharing (A1 Telekom Group, Deutsche Telekom, Vodafone).

For several firms, an interoperability mandate for gatekeepers would not be sufficient, and should be complemented with additional data portability requirements (A1 Telekom Group, Deutsche Telekom, TIM), transparency and accountability in online advertising (Bouygues), non-discrimination, access and possibly price regulation (Deutsche Telekom), and a promotion of open-source software (Orange). Orange specifically points out that standardization should be left to private companies, but that regulators can make sure that the negotiations take place on fair terms and in full transparency. According to Orange, any licensing following standardization should follow FRAND (fair, reasonable, and non-discriminatory) terms.

4.5.3. NGOs and consumer organizations

One of the main results from the model is that consumers benefit from interoperability, given higher quality of service derived from an increase in the number of potential contacts (recall that with full protocol interoperability, all customers can communicate with each other). As a result, we can expect consumer organizations and NGOs representing civil society to back an interoperability mandate. Alternatively, they may point to possible risks or disadvantages for consumers that are not currently factored into the model, and which may prove to be interesting paths for future research. Only one consumer organization – The European Consumer Organisation (BEUC) – responded to the DSA/DMA and the NCT questionnaires. Meanwhile, 25 NGOs responded to the DSA/DMA questionnaire and 6 NGOs responded to the NCT questionnaire. Some NGOs answered both. Most NGOs which participated in the consultations focus on defending digital rights in the EU.

Answering question 4 on possible prohibitions, the BEUC considers that the "blacklist" approach to gatekeepers' anti-competitive practices would be the most efficient, i.e., establishing a list of practices that are prohibited. It mentions that discrimination and the termination of interoperability (whether contractually or by design) should be prohibited and should thus figure in the blacklist. The BEUC explicitly mentions that case-by-case obligations, such as interoperability mandates, could be part of new sectorial regulation, drawing an analogy with the European Electronic Communications Code (EECC) in the telecommunications sector.[60] Concerning case-by-case remedies, it mentions mandating interoperability and access to APIs when this is necessary to solve structural competition problems. In the consultation for the NCT, the BEUC mentions market-wide interoperability as a possible means of intervention in anti-competitive monopolization cases, along with access to data, enhanced data portability, and a prohibition on defaults/pre-installation. Generally, we can see that the BEUC, which is a coalition of 45 consumer organizations, is favorable to interoperability, mostly insofar as it can increase competition, which benefits consumers.[61]

NGOs which participated in the consultations are highly favorable to an interoperability mandate for gatekeeper platforms. They mostly emphasize the benefits in terms of increased competitive pressure on incumbents, in line with the theoretical model.[62] By reducing market power, they argue, consumers will benefit from lower prices and lower switching costs. A recurring point made by NGOs such as Article 19 (United Kingdom), AlgorithmWatch (Germany), EFF (United States), EDRi (Belgium), and Panoptykon Foundation (Poland) is that curation and hosting should be separated when it comes to social media (several NGOs speak of "unbundling" or "decoupling"). This would allow users to delegate recommendations and personalization to third parties, for instance. Delegating curation relies on social media platforms maintaining open APIs so that users can call on third parties to provide services that are compatible with the core social media services, and so it relies on data interoperability. The underlying point is that many large platforms are highly vertically integrated (see submissions by Article 19 and the Open Technology Institute), and that they have incentives not to interoperate with downstream companies (the Open Technology Institute mentions the example of Twitter acquiring downstream firms which had provided compatible services to users) – see Gabel (1991). This point is mainly relevant for the social media market but could be an interesting addition to the theoretical model, which concentrates on horizontal interoperability (between direct competitors).

Like participants in the consultations, NGOs underline that an interoperability mandate should be accompanied with a prohibition of practices which purposefully restrict interoperability. We saw in the "adversarial interoperability" case study that so long as firms cannot restrict interoperability (even when it is reciprocal), the dominant strategy is often to interoperate. The

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[60] See footnote 59.

[61] It is noteworthy that the BEUC mentions another rationale for putting an interoperability mandate in place, namely media pluralism, especially when it comes to social media.

[62] Like the BEUC, several NGOs mention other rationales for interoperability, namely media pluralism and disinformation (AlgorithmWatch, Panoptykon Foundation) and online discrimination and violence (Global Forum for Media Development).

Electronic Frontier Foundation (United States) points out that some firms have a history of issuing legal threats or suing rivals who create compatible products. They also mention terms of service (especially those required for access to APIs) and patents as tools that are used by gatekeepers to prevent reverse engineering and interconnection. European Horizons (United States) specifically underlines that startups and scaleups are held back by large groups' efforts to hamper interoperability, in line with the notion that vertically integrated platforms have an interest in reducing interoperability downstream. The Panoptykon Foundation shares the view that such practices should be banned. Relatedly, several NGOs contend that an interoperability mandate should be complemented with guarantees that APIs are accessible on FRAND or similar terms (see submissions by European Horizons and the Panoptykon Foundation).

There is some disagreement among NGOs as to the benefits of multihoming as opposed to interoperability. The Center for Democracy & Technology (United States) contends that when multihoming is absent in a given market, there is less competition, and hence that lowering multihoming may decrease competitive intensity. Conversely, the Open Society European Policy Institute argues that multihoming is not a valid alternative to interoperability because it is not cost-free for users. This is in line with the extension seen above (see 4.2.4) and with work done by Doganoglu & Wright (2006), which shows that equilibrium prices and profits are higher when customers multihome. This is because multihoming creates duplicate costs for users, and so firms may prefer incompatibility in the presence of multihoming even when compatibility is socially desirable (Doganoglu & Wright, 2006, p. 47).

Finally, among the possible disadvantages related to interoperability mandates, NGOs cite the tradeoff between increased competition and incentives to invest (Center for Democracy and Technology) and possible risks in terms of privacy and security (Electronic Frontier Foundation). The first issue is crucial and has been addressed in the literature by Farrell & Saloner (1985) and by Kristiansen & Thum (1997), although more work needs to be done in this area. The second points to the necessity of guarantees accompanying interoperability mandates, for example when it comes to data protection. Finally, the Open Society European Policy Institute claims that interoperability would in fact increase incentives to operate and innovate, because use of open standards would enable competitors to reach a wider audience (akin to the *demand expansion* effect seen in the theoretical model). As stated above, this assertion remains speculative, and more work needs to be done on this topic, possibly with multiperiod models.

5. Policy implications

What kind of policy implications can we draw from the model and the submissions to the DMA/DSA and NCT consultations? We saw in the literature review (2.2.3) that there is a "compatibility problem" when compatibility is socially desirable but private incentives are too low (Doganoglu & Wright, 2006, p. 46). In this case, policymakers may want to intervene to promote compatibility. In light of this, I go over the main policy implications that can be derived from the findings. I focus on two important questions, namely the conditions under which public intervention may be warranted, and the policy levers which might be used.

1. **Interoperability can reduce market concentration.**

Encouraging interoperability in digital markets is likely to have two principal effects, namely *demand expansion* and *levelling*. The latter effect is consistent with the objective put forward by public authorities and certain firms, namely, to increase competition and decrease market concentration. With the move to compatibility, firms no longer compete "for" the market but rather "in" the market. Most policymakers and stakeholders seem to be well-aware of these effects, as illustrated by the submissions to the consultations.

2. **Interoperability is beneficial to consumers in the short term, but policymakers should also consider possible drawbacks in the long term.**

Simple models show that consumers always benefit from interoperability in markets with network effects. There is an increase in consumer surplus because consumers enjoy full network benefits by joining any service offered in the market. When considering whether to intervene, policymakers should strike a balance between this benefit and the disutility incurred by loss of variety and the possible reduction in the incentives to invest in the long term. This is especially the case when interoperability follows from standardization.

3. **In some markets, there may be a "compatibility problem".**

Some markets are characterized by low private incentives to interoperate, despite interoperability being socially desirable. This can be the case where one dominant player is holding back compatibility, for example. In this case, the increase in profits for at least one firm is lower than the fixed cost of interoperability, even though this cost is lower than the increase in total surplus.

4. **The compatibility problem is more likely to arise in highly concentrated markets**.

Generally, firms with small market shares are more likely to want to interoperate, because they benefit both from *demand expansion* and from *levelling*. New entrants, for instance, are more likely to want to interoperate, especially if interoperability is accessible at a low fixed cost. Conversely, larger players are only willing to interoperate when the *demand expansion* effect compensates or outweighs the *levelling* effect. This mainly occurs when installed bases are similar, i.e., when markets are relatively symmetric. As a result, dominant players are likely to pursue anti-compatibility strategies: *ex ante* interoperability requirements should focus on these firms.

5. **Encouraging multihoming does not solve the compatibility problem.**

As pointed out by some stakeholders in the public consultations and as borne out by the model, demand-side multihoming is not a good substitute for compatibility. If anything, markets with multihoming may paradoxically deserve more scrutiny from policymakers than markets without multihoming. Indeed, multihoming reduces dominant firms' incentives to interoperate, making the "compatibility problem" more likely to arise.

6. **Policymakers should be most concerned about highly concentrated markets with a high level of data collection and multihoming.**

A key finding is that personalization and data collection mean that firms can attract more customers. Given that this advantage is not shared when firms decide to interoperate, personalization allows firms to maintain part of their network benefits proprietary, even when services are compatible. Because of this, personalization accentuates the effect of the installed bases on firms' willingness to interoperate. When market shares are similar, personalization increases the willingness to interoperate. Conversely, when market shares are very different, personalization decreases the willingness to interoperate. As a result, joint willingness to interoperate is lowest in markets where installed bases are different in size and where personalization is high.

7. **Policymakers and antitrust authorities should beware of cases of less-than-industrywide compatibility.**

Less-than-industrywide compatibility (e.g., a coalition of firms with compatible services) is sometimes a more profitable strategy than industrywide compatibility. Yet industrywide compatibility maximizes total welfare, especially when the cost of interoperability is low. This suggests that private incentives to form compatible coalitions, e.g., through mergers and acquisitions, may sometimes be too high from a social perspective. When mergers and acquisitions allow firms to make networks compatible, antitrust authorities should take this into consideration.

8. **Lifting barriers to adversarial interoperability may be enough to achieve compatibility in certain markets.**

In markets where one firm has a significant installed base advantage, this firm has incentives to maintain incompatibility, even if its competitors want compatibility. Incompatibility is usually maintained through intellectual property, secrecy, or, specifically in the case of online platforms, prohibitive terms of service. In this case, adversarial interoperability is prevented by these barriers. In highly concentrated markets where one dominant player is holding back compatibility, a prohibition on barriers to compatibility may be warranted. When this kind of prohibition is put in place, the dominant strategy will often be to interoperate, even though firms may instead enter coalitions.

6. Conclusion

This master's thesis proposes a new model of interoperability in digital markets, based on seminal work by Katz & Shapiro (1985), Crémer et al. (2000), and Casadesus-Masanell & Hervas-Drane (2015). Generally, the findings provide several hypotheses on the conditions for successful public intervention in the field of interoperability. These hypotheses are particularly relevant to ongoing discussions related to the Digital Markets Act (DMA) in the European Union. I focus both on the kinds of markets that policymakers and regulators should be particularly concerned with when it comes to the "compatibility problem", and on the policy levers which might be used in these markets. After having introduced the literature on competition in network markets (2.1), I provided an interdisciplinary review of compatibility and interoperability (2.2). I then explained my methodology (3), presented the baseline model, and developed hypotheses about the main effects of compatibility on competition and market structures (4.1). The baseline model was extended and generalized in various ways (4.2), which allowed me to tackle issues related to market tipping and multihoming, for example. I also modelled public intervention (4.3). Finally, I presented two case studies (4.4), a concise analysis of important submissions to the DSA/DMA and NCT consultations (4.5), and then drew some general policy implications (5). Below I flesh out three paths for future research on this topic.

Firstly, my analysis of network strategies and compatibility draws mainly on the network economics literature, occulting more recent literature starting with Rochet & Tirole (2003) and focusing on two-sided platforms. Yet many digital services which are characterized by strong direct network externalities (e.g., interpersonal messaging applications or social media) can also be viewed as two-sided platforms which act as intermediaries. Even traditional telephone networks can be treated as multi-sided when one accounts for the fact that termination charges are often paid by receivers, for example (Rochet & Tirole, 2003, p. 1018; Jeon, et al., 2004). This leads Rochet & Tirole (2003, p. 990) to claim that "[many] if not most markets with network externalities are two-sided". Focusing on only one "side" of firms that are in fact multi-sided is a simplification which is useful to flesh out stylized results. It is also a clear limitation of the model presented here, especially insofar as it does not allow for a discussion of markets that are not related to communication, such as the market for e-commerce, for instance. Future work could draw from the literature on multi-sided platforms to analyze the compatibility problem with indirect network effects and more elaborate pricing structures which arise in platform settings, in line with work by Doganoglu & Wright (2006), Casadesus-Masanell & Ruiz-Aliseda (2008), and Miao (2009).

Secondly, for tractability I assumed in the model developed above that there were infinite switching costs, which means that consumers can never switch services once they have made their purchasing decision. Recent work by Chen (2016; 2018) shows that dynamic models of compatibility can successfully combine network externalities and switching costs, in line with previous work conducted by Faulhaber (2002) and Suleymanova & Wey (2011). Extensions of the model presented here could adopt the same approach. This would be especially pertinent given that enhanced data portability (thanks to the GDPR) has probably decreased switching costs in the markets studied here (social media and interpersonal messaging applications). Given that switching costs have complex effects on competition in network markets (see 2.1.3), it is difficult to predict what kind of effect they might have on incentives to interoperate, and this question requires more attention.

Finally, a theme that needs to be explored further is the effect of standardization on the incentives to invest and to innovate, in line with seminal work by Farrell & Saloner (1985) and Kristiansen & Thum (1997), for example. We saw that this is a recurrent concern in firms' submission to the consultations, but it is comparatively under-represented in the literature on compatibility. This would require taking a step back from single-period models, which usually find that compatibility creates short-term demand expansion. Instead, we could design dynamic models to study market structure and incentives to invest in the longer term. This could help policymakers and regulators understand longer-term implications of public intervention in this area.

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Appendix A. Proof of equilibrium capacities in the baseline model

With $i \neq j = 1{,}2$, we have $u_i = \tau + s_i - p_i$, where s_i represents firm i's quality of service, defined as:

$$s_i = v\left([1 + \rho y_i(1 - 2y_i)](\beta_i + q_i) + \theta(\beta_j + q_j)\right).$$

We can show that:

$$\frac{\partial s_i}{\partial y_i} = v\rho(1 - 4y_i)(\beta_i + q_i);\ \frac{\partial^2 s_i}{\partial (y_i)^2} < 0.$$

From this result, we know that the level of personal information provision y_i that maximizes s_i is defined by $1 - 4y_i^* = 0$, which is equivalent to $y_i^* = \frac{1}{4}$. Plugging this back into s_i, we have:

$$u_i = \tau + v\left[\frac{8 + \rho}{8}(\beta_i + q_i) + \theta(\beta_j + q_j)\right] - p_i.$$

We can write $\alpha = \frac{8+\rho}{8}$ to simplify this expression. The hedonic prices are equal, i.e., we have:

$$p_1 - s_1 = p_2 - s_2 = \hat{p}.$$

The marginal consumer is defined by $u_i = 0$, equivalent to $\tau = p_i - s_i = \hat{p}$. Given that τ is uniformly distributed over $[0{,}1]$ and that the population of unattached customers is normalized to 1, there are $1 - \hat{p}$ consumers for whom $\tau > \hat{p}$, i.e., we can write:

$$q_1 + q_2 = 1 - \hat{p} = 1 - (p_i - s_i).$$

Plugging s_i into this equation and rearranging the terms, we can write:

$$p_i^* = 1 - (1 - \alpha v)q_i - (1 - v\theta)q_j + \alpha v\beta_i + v\theta\beta_j.$$

Gross profits are defined as:

$$\pi_i(\theta) = \left(p_i^* + (1 + z_i)^2 y_i^* d_i - c - \frac{1}{2}(z_i)^2\right) q_i - F(\theta),$$

with z_i the data analytics input. Firm i sets z_i to maximize π_i. We can show that:

$$\frac{\partial \pi_i}{\partial z_i} = \frac{1}{8}(1 - 7z_i); \; \frac{\partial^2 \pi_i}{\partial (z_i)^2} < 0.$$

The optimal level of data analytics is defined by $\frac{1}{8}(1 - 7z_i^*) = 0$, which is equivalent to $z_i^* = \frac{1}{7}$. From this result, we can write $\pi_i(\theta) = \left(p_i^* + \frac{1}{14} - c\right) q_i - F(\theta)$. Finally, firms set q_i to maximize gross profits. We can write:

$$\frac{\partial \pi_i}{\partial q_i} = \frac{15}{14} - 2(1 - \alpha v)q_i - (1 - v\theta)q_j + \alpha v \beta_i + v\theta\beta_j - c; \; \frac{\partial^2 \pi_i}{\partial (q_i)^2} < 0.$$

From this, we know that equilibrium capacities are defined by:

$$\frac{15}{14} - 2(1 - \alpha v)q_i^* - (1 - v\theta)q_j^* + \alpha v \beta_i + v\theta\beta_j - c = 0,$$

which is equivalent to:

$$q_i^*(\theta) = \frac{1}{2(1 - \alpha v)}\left(\frac{15}{14} - (1 - v\theta)q_j^* + \alpha v \beta_i + v\theta\beta_j - c\right).$$

From this result, it is easy to show that:

$$q_i^*(\theta) + q_j^*(\theta) = \frac{(\alpha + \theta)v(\beta_i + \beta_j) + \frac{15}{7} - 2c}{2(1 - \alpha v) + (1 - v\theta)},$$

and:

$$q_i^*(\theta) - q_j^*(\theta) = \frac{(\alpha - \theta)v(\beta_i - \beta_j)}{2(1 - \alpha v) - (1 - v\theta)}.$$

Appendix B. Consumer surplus and gross profits in the baseline model

We know consumer surplus is defined as:

$$CS(\theta) = \int_{\hat{p}}^{1} (\sigma + s_i - p_i) \, d\sigma.$$

Recalling that $\hat{p} = p_i - s_i$, it is easy to show that:

$$CS(\theta) = \left[\frac{\sigma^2}{2} - \sigma\hat{p}\right]_{\hat{p}}^{1} = \frac{(1-\hat{p})^2}{2} = \frac{[q_1^*(\theta) + q_2^*(\theta)]^2}{2}.$$

Plugging q_i^* into $\frac{15}{14} - (1-\alpha v)q_i - (1-v\theta)q_j + \alpha v\beta_i + v\theta\beta_j - c$, we can write:

$$\pi_i(\theta) = \frac{1}{2}\left(\frac{15}{14} - (1-v\theta)q_j + \alpha v\beta_i + v\theta\beta_j - c\right)q_i - F(\theta).$$

From this, we can see that:

$$\pi_i^*(\theta) = (1-\alpha v)[q_i^*(\theta)]^2 - F(\theta).$$

Appendix C. Solving the model with variable disclosure

With $i \neq j = 1,2$, we have $u_i = \tau + s_i - p_i$, where s_i represents firm i's quality of service, defined as:

$$s_i = v\left([1 + \rho y_i(1 - y_i - \mu y_i)](\beta_i + q_i) + \theta(\beta_j + q_j)\right).$$

Consumers maximize u_i with regards to y_i, and so we can write $y_i^* = \frac{1}{2(1+\mu)}$. Plugging this back to s_i, we can write:

$$s_i = v\left[\left(1 + \frac{1}{2}\rho y_i^*\right)(\beta_i + q_i) + \theta(\beta_j + q_j)\right].$$

From $q_i + q_j = 1 - \hat{p}$, we can write:

$$p_i^* = 1 - \left[1 - \left(1 + \frac{1}{2}\rho y_i^*\right)v\right]q_i - (1 - v\theta)q_j + \left(1 + \frac{1}{2}\rho y_i^*\right)v\beta_i + v\theta\beta_j.$$

With $\pi_i^*(\theta) = (p_i^* + \mu(y_i^*)^2 - c)q_i - F(\theta)$, it can be shown that equilibrium capacities are defined by:

$$q_i^*(\theta) = \frac{1}{2\left[1 - \left(1 + \frac{1}{2}\rho y_i^*\right)v\right]}\left(1 - (1 - v\theta)q_j^* + \left(1 + \frac{1}{2}\rho y_i^*\right)v\beta_i + v\theta\beta_j + \mu(y_i^*)^2 - c\right).$$

From this result it is easy to write $q_i^*(\theta) - q_j^*(\theta)$ as a function of the installed bases:

$$q_i^*(\theta) - q_j^*(\theta) = \frac{\left(1 + \frac{1}{2}\rho y_i^* - \theta\right) v(\beta_i - \beta_j)}{2\left[1 - \left(1 + \frac{1}{2}\rho y_i^*\right) v\right] - (1 - v\theta)}.$$

Appendix D. Solving the n firm model

With $i \neq j = 1{,}2$, we have $u_i = \tau + s_i - p_i$, where s_i represents firm i's quality of service, defined as:

$$s_i = v\left([1 + \rho y_i(1 - 2y_i)](\beta_i + q_i) + \theta \sum_{j \neq i} (\beta_j + q_j)\right).$$

We can show like above that $y_i^* = \frac{1}{4}$. Using $\sum_{e=1}^{n} q_e = 1 - \hat{p}$, it is easy to show that:

$$p_i^* = 1 - (1 - \alpha v)q_i - (1 - v\theta) \sum_{j \neq i} q_j + \alpha v \beta_i + v\theta \sum_{j \neq i} \beta_j.$$

Like in the duopoly setting, we can write:

$$\pi_i^*(\theta) = \left(p_i^* + \frac{1}{16}(1 + z_i)^2 - c - \frac{1}{2}(z_i)^2\right) q_i - F(\theta).$$

Optimizing like above, we have $z_i^* = \frac{1}{7}$, and we can write:

$$\pi_i^*(\theta) = \left(\frac{15}{14} - (1 - \alpha v)q_i - (1 - v\theta) \sum_{j \neq i} q_j + \alpha v \beta_i + v\theta \sum_{j \neq i} \beta_j - c\right) q_i - F(\theta).$$

Optimizing for q_i, we can write equilibrium capacities as:

$$q_i^*(\theta) = \frac{1}{2(1 - \alpha v)}\left(\frac{15}{14} - (1 - v\theta) \sum_{j \neq i} q_j^* + \alpha v \beta_i + v\theta \sum_{j \neq i} \beta_j - c\right),$$

and plugging this in the definition of gross profits, we have:

$$\pi_i^*(\theta) = (1 - \alpha v)[q_i^*(\theta)]^2 - F(\theta).$$

From the equilibrium capacities, it is easy to express $\sum_{e=1}^{n} q_e^*$ and $\sum_{j\neq i}(q_i^* - q_j^*)$ as a function of the installed bases. We have:

$$\sum_{e=1}^{n} q_e^* = \frac{(\alpha + (n-1)\theta)v\beta + \frac{15}{14}n - nc}{2(1-\alpha v) + (n-1)(1 - v\theta)},$$

and:

$$\sum_{j\neq i}(q_i^* - q_j^*) = \frac{(\alpha - \theta)v}{2(1-\alpha v) - (1 - v\theta)} \sum_{j\neq i}(\beta_i - \beta_j).$$

From $q_i^* = \frac{1}{n}(nq_i^*)$, we can write $q_i^* = \frac{1}{n}(\sum_{e=1}^{n} q_e^* + nq_i^* - \sum_{e=1}^{n} q_e^*)$, which simplifies to:

$$q_i^* = \frac{1}{n}\left(\sum_{e=1}^{n} q_e^* + \sum_{j\neq i}(q_i^* - q_j^*)\right),$$

and with this result we can express q_i^* as a function of the installed bases. Solving $\sum_{j\neq i}(\beta_i - \beta_j) > 0$ for β_i, it is easy to show that this condition is equivalent to:

$$\beta_i > \frac{1}{n-1}\sum_{j\neq i}\beta_j.$$

The right-hand side of this inequality corresponds to $\overline{\beta_{j\neq i}}$, the average installed base of firm i's competitors. Consumer surplus is defined as:

$$CS(\theta) = \int_{\hat{p}}^{1}(\sigma + s_i - p_i)\, d\sigma = \frac{(1-\hat{p})^2}{2} = \frac{1}{2}\left(\sum_{e=1}^{n} q_e^*\right)^2.$$

Finally, total welfare is written as $W(\theta) = \pi^*(\theta) + CS(\theta) - nF(\theta)$ with $\pi^*(\theta)$ aggregate profits defined as $\pi^*(\theta) = \sum_{e=1}^{n}\pi_e^*(\theta)$ with $\pi_i^*(\theta) = (1-\alpha v)[q_i^*(\theta)]^2 - F(\theta)$. From this, we can write $W(\theta)$ as:

$$W(\theta) = (1 - \alpha v)\left(\sum_{e=1}^{n}(q_e^*)^2\right) + \frac{1}{2}\left(\sum_{e=1}^{n} q_e^*\right)^2 - nF(\theta).$$

Appendix E. Solving the multihoming model

With $i \neq j = 1,2$, we have $u_i = \tau + s_i - p_i$, where s_i represents firm i's quality of service. We know that there are $\beta_i - \frac{\omega}{2}$ customers patronizing solely firm i and a fraction of ω multihomers patronizing both firm i and firm j. From this, we can write quality of service s_i as:

$$s_i = v\left([1 + \rho y_i(1 - 2y_i)]\left(\beta_i + \frac{\omega}{2} + q_i\right) + \theta\left(\beta_j - \frac{\omega}{2} + q_j\right)\right).$$

Note that regardless of θ, all users can communicate with multihomers, and they always benefit from personalization. Optimal information provision on the demand side remains unchanged. Indeed, we have:

$$\frac{\partial s_i}{\partial y_i} = v\rho(1 - 4y_i)\left(\beta_i + \frac{\omega}{2} + q_i\right);\ \frac{\partial^2 s_i}{\partial (y_i)^2} < 0,$$

and so $y_i^* = \frac{1}{4}$. Plugging this result into s_i, we have:

$$s_i = v\left[\frac{8+\rho}{8}\left(\beta_i + \frac{\omega}{2} + q_i\right) + \theta\left(\beta_j - \frac{\omega}{2} + q_j\right)\right].$$

Using the same steps as in the baseline model and writing $\alpha = \frac{8+\rho}{8}$, it is possible to write equilibrium price as:

$$p_i^* = 1 - (1 - \alpha v)q_i - (1 - v\theta)q_j + v(\alpha\beta_i + \theta\beta_j) + \omega v\left(\frac{\alpha - \theta}{2}\right).$$

Like above, $z_i^* = \frac{1}{7}$ and so $\pi_i(\theta) = \left(p_i^* + \frac{1}{14} - c\right) q_i - F(\theta)$. Optimizing for capacities yields:

$$q_i^*(\omega, \theta) = \frac{1}{2(1 - \alpha v)}\left(\frac{15}{14} - (1 - v\theta)q_j^* + \alpha v\beta_i + v\theta\beta_j - c\right) + \frac{\omega v}{2}\left(\frac{\alpha - \theta}{2(1 - \alpha v)}\right).$$

From this, we can write the sum of capacities as:

$$q_i^*(\omega,\theta)+q_j^*(\omega,\theta)=\frac{(\alpha+\theta)v\big(\beta_i+\beta_j\big)+\frac{15}{7}-2c}{2(1-\alpha v)+(1-v\theta)}+\omega\left(\frac{(\alpha-\theta)v}{2(1-\alpha v)+(1-v\theta)}\right).$$

Note that the first expression on the right-hand side of this equation corresponds to the sum of equilibrium capacities without multihoming (see Appendix A), which we can note $q_i^*(0,\theta)+q_j^*(0,\theta)$. Noting the following:

$$\frac{(\alpha-\theta)v}{2(1-\alpha v)+(1-v\theta)}=\frac{(\alpha-\theta)v}{3-v(2\alpha+\theta)}=1-\frac{3(1-\alpha v)}{3-v(2\alpha+\theta)},$$

we can write:

$$q_i^*(\omega,\theta)+q_j^*(\omega,\theta)=q_i^*(0,\theta)+q_j^*(0,\theta)+\omega\left(1-\frac{3(1-\alpha v)}{3-v(2\alpha+\theta)}\right),$$

and so, given that the term on the right does not depend on i, we have:

$$q_i^*(\omega,\theta)=q_i^*(0,\theta)+\frac{\omega}{2}\left(1-\frac{3(1-\alpha v)}{3-v(2\alpha+\theta)}\right).$$

Appendix F. General methodology for the case studies

In the theoretical model, parameters are industrywide. A complementary approach is to investigate how the model reacts when firms have different levels of personalization ρ_i, disclosure μ_i, cost c_i, benefit of connectivity v_i. For any consumer patronizing firm i, the optimal level of information provision can be written as:

$$y_i^*=\frac{1}{2(1+\mu_i)},$$

like in the model with variable disclosure (Appendix C). Given this result, the utility for a consumer patronizing firm i can be written as:

$$u_i=\tau+v_i\left[\left(1+\frac{1}{2}y_i^*\rho_i\right)(\beta_i+q_i)+\theta\big(\beta_j+q_j\big)\right]-p_i,$$

with ρ_i firm i's level of personalization. Solving like earlier allows us to write equilibrium prices p_i^*:

$$p_i^* = 1 - \left[1 - \left(1 + \frac{1}{2} y_i^* \rho_i\right) v_i\right] q_i - (1 - v_i \theta) q_j + \left(1 + \frac{1}{2} y_i^* \rho_i\right) v_i \beta_i + v_i \theta \beta_j.$$

Gross profits are given by:

$$\pi_i(\theta) = \left(p_i^* + (1 + z_i)^2 \mu_i (y_i^*)^2 - c_i - \frac{1}{2}(z_i)^2\right) q_i - F(\theta).$$

Optimizing this with regards to data analytics, we can write z_i^* as a function of disclosure. Namely, we have:

$$z_i^* = \frac{2\mu_i (y_i^*)^2}{1 - 2\mu_i (y_i^*)^2}.$$

Plugging z_i^* into π_i and optimizing, we can write equilibrium capacities as:

$$q_i^* = \frac{1 - (1 - v_i \theta) q_j^* + \left(1 + \frac{1}{2} y_i^* \rho_i\right) v_i \beta_i + v_i \theta \beta_j + (1 + z_i^*)^2 \mu_i (y_i^*)^2 - c_i - \frac{1}{2}(z_i^*)^2}{2\left[1 - \left(1 + \frac{1}{2} y_i^* \rho_i\right) v_i\right]}.$$

This specification does not allow elegant expressions of q_i^* building on:

$$q_i^* = \frac{1}{2}\left(\left[q_i^* + q_j^*\right] + \left[q_i^* - q_j^*\right]\right),$$

because neither $q_i^* + q_j^*$ nor $q_i^* - q_j^*$ can be factorized like in the case where the parameters are industrywide. However, the equations which determine q_1 and q_2 are linear in each other and the system can be solved numerically for a given set of parameters. This is the method that is used in the case studies. It can be shown that firm i's gross profits are:

$$\pi_i^*(\theta) = \left[1 - \left(1 + \frac{1}{2} y_i^* \rho_i\right) v_i\right] \left[q_i^*(\theta)\right]^2 - F(\theta).$$

Finally, welfare is defined as $W = \pi^* + CS$ like above, with π^* aggregate profits and CS consumer surplus. When θ is not industrywide, only the firms which enter the compatibility agreement pay the fixed cost of interoperability F. This approach can easily be extended to n firms and to multihoming, along the lines of the generalizations seen above.

Appendix G. Specifications in the Facebook/WhatsApp case study

I use a mix of the different models seen above in this case study. Below are the qualities of service of each firm, the optimal capacities q_i^* used in the different scenarios, as well as total welfare. The optimization is the same as in the proofs shown above. The system can then be solved numerically based on the chosen parameters. Total welfare is written as $W = \pi^* + CS = \pi_f^* + \pi_w^* + \pi_c^* + \frac{1}{2}\left(q_f^* + q_w^* + q_c^*\right)^2$.

G.1. No interoperability

Qualities of service are given by:

$$\begin{cases} s_f = v[1 + \rho_f y_f(1 - 2y_f)]\left(\beta_f + \frac{\omega}{2} + q_f\right) \\ s_w = v[1 + \rho_w y_w(1 - 2y_w)]\left(\beta_w + \frac{\omega}{2} + q_w\right) \\ s_c = v[1 + \rho_c y_c(1 - 2y_c)](\beta_c + q_c). \end{cases}$$

With this specification, equilibrium capacities are given by:

$$\begin{cases} q_f^* = \frac{1}{2(1 - \alpha_f v)}\left(\frac{15}{14} - (q_w^* + q_c^*) + \alpha_f v\left(\beta_f + \frac{\omega}{2}\right) - c\right) \\ q_w^* = \frac{1}{2(1 - \alpha_w v)}\left(\frac{15}{14} - \left(q_f^* + q_c^*\right) + \alpha_w v\left(\beta_w + \frac{\omega}{2}\right) - c\right) \\ q_c^* = \frac{1}{2(1 - \alpha_c v)}\left(\frac{15}{14} - \left(q_f^* + q_w^*\right) + \alpha_c v\beta_c - c\right). \end{cases}$$

Total welfare can be written as:

$$W = (1 - \alpha_f v)\left(q_f^*\right)^2 + (1 - \alpha_w v)(q_w^*)^2 + (1 - \alpha_c v)(q_c^*)^2 + \frac{1}{2}\left(q_f^* + q_w^* + q_c^*\right)^2.$$

G.2. Interoperability between Messenger and WhatsApp

Qualities of service are given by:

$$\begin{cases} s_f = v\left([1 + \rho_f y_f(1 - 2y_f)]\left(\beta_f + \frac{\omega}{2} + q_f\right) + \left(\beta_w - \frac{\omega}{2} + q_w\right)\right) \\ s_w = v\left([1 + \rho_w y_w(1 - 2y_w)]\left(\beta_w + \frac{\omega}{2} + q_w\right) + \left(\beta_f - \frac{\omega}{2} + q_f\right)\right) \\ s_c = v[1 + \rho_c y_c(1 - 2y_c)](\beta_c + q_c). \end{cases}$$

With this specification, equilibrium capacities are given by:

$$\begin{cases} q_f^* = \dfrac{1}{2(1-\alpha_f v)}\left(\dfrac{15}{14} - (1-v)q_w^* - q_c^* + \alpha_f v\left(\beta_f + \dfrac{\omega}{2}\right) + v\left(\beta_w - \dfrac{\omega}{2}\right) - c\right) \\ q_w^* = \dfrac{1}{2(1-\alpha_w v)}\left(\dfrac{15}{14} - (1-v)q_f^* - q_c^* + \alpha_w v\left(\beta_w + \dfrac{\omega}{2}\right) + v\left(\beta_f - \dfrac{\omega}{2}\right) - c\right) \\ q_c^* = \dfrac{1}{2(1-\alpha_c v)}\left(\dfrac{15}{14} - (q_f^* + q_w^*) + \alpha_c v \beta_c - c\right). \end{cases}$$

Total welfare can be written as:

$$W = (1-\alpha_f v)(q_f^*)^2 + (1-\alpha_w v)(q_w^*)^2 + (1-\alpha_c v)(q_c^*)^2 + \frac{1}{2}(q_f^* + q_w^* + q_c^*)^2 - 2F.$$

G.3. Interoperability between Messenger and WhatsApp with data sharing

Qualities of service are given by:

$$\begin{cases} s_f = v[1 + \rho_f y_f(1-2y_f)]\left[\left(\beta_f + \dfrac{\omega}{2} + q_f\right) + \left(\beta_w - \dfrac{\omega}{2} + q_w\right)\right] \\ s_w = v[1 + \rho_w y_w(1-2y_w)]\left[\left(\beta_w + \dfrac{\omega}{2} + q_w\right) + \left(\beta_f - \dfrac{\omega}{2} + q_f\right)\right] \\ s_c = v[1 + \rho_c y_c(1-2y_c)](\beta_c + q_c). \end{cases}$$

With this specification, equilibrium capacities are given by:

$$\begin{cases} q_f^* = \dfrac{1}{2(1-\alpha_f v)}\left(\dfrac{15}{14} - (1-v)q_w^* - q_c^* + \alpha_f v(\beta_f + \beta_w) - c\right) \\ q_w^* = \dfrac{1}{2(1-\alpha_w v)}\left(\dfrac{15}{14} - (1-v)q_f^* - q_c^* + \alpha_w v(\beta_w + \beta_f) - c\right) \\ q_c^* = \dfrac{1}{2(1-\alpha_c v)}\left(\dfrac{15}{14} - (q_f^* + q_w^*) + \alpha_c v \beta_c - c\right). \end{cases}$$

Total welfare can be written as:

$$W = (1-\alpha_f v)(q_f^*)^2 + (1-\alpha_w v)(q_w^*)^2 + (1-\alpha_c v)(q_c^*)^2 + \frac{1}{2}(q_f^* + q_w^* + q_c^*)^2 - 2F.$$

G.4. Full interoperability between the three services

Qualities of service are given by:

$$\begin{cases} s_f = v\left(\left[1+\rho_f y_f(1-2y_f)\right]\left(\beta_f+\frac{\omega}{2}+q_f\right)+\left(\beta_w-\frac{\omega}{2}+q_w\right)+(\beta_c+q_c)\right) \\ s_w = v\left(\left[1+\rho_w y_w(1-2y_w)\right]\left(\beta_w+\frac{\omega}{2}+q_w\right)+\left(\beta_f-\frac{\omega}{2}+q_f\right)+(\beta_c+q_c)\right) \\ s_c = v\left(\left[1+\rho_c y_c(1-2y_c)\right](\beta_c+q_c)+\left(\beta_g+q_g\right)+(\beta_h+q_h)\right). \end{cases}$$

With this specification, equilibrium capacities are given by:

$$\begin{cases} q_f^* = \frac{1}{2(1-\alpha_f v)}\left(\frac{15}{14}-(1-v)(q_w^*+q_c^*)+\alpha_f v\left(\beta_f+\frac{\omega}{2}\right)+v\left(\beta_w+\beta_c-\frac{\omega}{2}\right)-c\right) \\ q_w^* = \frac{1}{2(1-\alpha_w v)}\left(\frac{15}{14}-(1-v)(q_f^*+q_c^*)+\alpha_w v\left(\beta_w+\frac{\omega}{2}\right)+v\left(\beta_f+\beta_c-\frac{\omega}{2}\right)-c\right) \\ q_c^* = \frac{1}{2(1-\alpha_c v)}\left(\frac{15}{14}-(1-v)(q_f^*+q_w^*)+\alpha_c v\beta_c+v(\beta_f+\beta_w)-c\right). \end{cases}$$

Total welfare can be written as:

$$W = (1-\alpha_f v)(q_f^*)^2+(1-\alpha_w v)(q_w^*)^2+(1-\alpha_c v)(q_c^*)^2+\frac{1}{2}(q_f^*+q_w^*+q_c^*)^2-3F.$$

Appendix H. Specifications in the adversarial interoperability case study

To reflect the difference between the dominant firm and the privacy-oriented competitor, I part with the full disclosure assumption in this case study. This makes the specification slightly more complex than the specifications in the Facebook/WhatsApp case study. Generally, equilibrium capacities take the following form:

$$q_i^*(\theta_i) = \frac{1-(1-v\theta_i)q_j^*+\left(1+\frac{1}{2}y_i^*\rho_i\right)v_i\beta_i+v\theta_i\beta_j+(1+z_i^*)^2\mu_i(y_i^*)^2-c_i-\frac{1}{2}(z_i^*)^2}{2\left[1-\left(1+\frac{1}{2}y_i^*\rho_i\right)v\right]}.$$

Like above, total welfare is written as $W = \pi^* + CS = \pi_d^* + \pi_c^* + \frac{1}{2}(q_d^* + q_c^*)^2$. Below I explicitly give the specifications for the two scenarios.

H.1. No interoperability

Qualities of service are given by:

$$\begin{cases} s_d = v[1+\rho_d y_d(1-y_d-\mu_d y_d)](\beta_d+q_d) \\ s_c = v[1+\rho_c y_c(1-y_c-\mu_c y_c)](\beta_c+q_c). \end{cases}$$

With this specification, equilibrium capacities are given by:

$$\begin{cases} q_d^* = \dfrac{1-q_c^*+\left(1+\frac{1}{2}y_d^*\rho_d\right)v\beta_d+(1+z_d^*)^2\mu_d(y_d^*)^2-c-\frac{1}{2}(z_d^*)^2}{2\left[1-\left(1+\frac{1}{2}y_d^*\rho_d\right)v\right]} \\ q_c^* = \dfrac{1-q_d^*+\left(1+\frac{1}{2}y_c^*\rho_c\right)v\beta_c+(1+z_c^*)^2\mu_c(y_c^*)^2-c-\frac{1}{2}(z_c^*)^2}{2\left[1-\left(1+\frac{1}{2}y_c^*\rho_c\right)v\right]}, \end{cases}$$

with:

$$y_i^* = \frac{1}{2(1+\mu_i)},$$

and:

$$z_i^* = \frac{2\mu_i(y_i^*)^2}{1-2\mu_i(y_i^*)^2}.$$

Total welfare can be written as:

$$W = \left[1-\left(1+\frac{1}{2}y_d^*\rho_d\right)v\right](q_d^*)^2+\left[1-\left(1+\frac{1}{2}y_c^*\rho_c\right)v\right](q_c^*)^2+\frac{1}{2}(q_d^*+q_c^*)^2.$$

H.2. Adversarial interoperability

Qualities of service are given by:

$$\begin{cases} s_d = v[1+\rho_d y_d(1-y_d-\mu_d y_d)](\beta_d+q_d) \\ s_c = v\big([1+\rho_c y_c(1-y_c-\mu_c y_c)](\beta_c+q_c)+(\beta_d+q_d)\big). \end{cases}$$

With this specification, equilibrium capacities are given by:

$$\begin{cases} q_d^* = \dfrac{1 - q_c^* + \left(1 + \frac{1}{2} y_d^* \rho_d\right) v\beta_d + (1 + z_d^*)^2 \mu_d (y_d^*)^2 - c - \frac{1}{2}(z_d^*)^2}{2\left[1 - \left(1 + \frac{1}{2} y_d^* \rho_d\right) v\right]} \\ q_c^* = \dfrac{1 - (1 - v) q_d^* + \left(1 + \frac{1}{2} y_c^* \rho_c\right) v\beta_c + v\beta_d + (1 + z_c^*)^2 \mu_c (y_c^*)^2 - c - \frac{1}{2}(z_c^*)^2}{2\left[1 - \left(1 + \frac{1}{2} y_c^* \rho_c\right) v\right]} \end{cases}.$$

with:

$$y_i^* = \frac{1}{2(1 + \mu_i)},$$

and:

$$z_i^* = \frac{2\mu_i (y_i^*)^2}{1 - 2\mu_i (y_i^*)^2}.$$

Total welfare can be written as:

$$W = \left[1 - \left(1 + \frac{1}{2} y_d^* \rho_d\right) v\right] (q_d^*)^2 + \left[1 - \left(1 + \frac{1}{2} y_c^* \rho_c\right) v\right] (q_c^*)^2 + \frac{1}{2}(q_d^* + q_c^*)^2 - F.$$

Appendix I. Key questions in the DSA/DMA and NCT consultations

Table 7. Questions in the responses to which respondents mention interoperability in the DSA/DMA and NCT consultations.

Consultation	Question number	Question
DSA/DMA	1	Have you been affected by unfair contractual terms or unfair practices of very large online platform companies? Please explain your answer in detail, pointing to the effects on your business, your consumers and possibly other stakeholders in the short, medium and long-term?
	2	Are there specific issues and unfair practices you perceive on large online platform companies?
	3	In your view, what practices related to the use and sharing of data in the platforms' environment are raising particular challenges?

	4	Please explain your reply [to the previous question about the need for specific prohibitions for gatekeepers] and, if possible, detail the types of prohibitions that should in your view be part of the regulatory toolbox.
	5	Please explain your reply [to the previous question about the need for specific obligations for gatekeepers] and, if possible, detail the types of obligations that should in your view be part of the regulatory toolbox.
	6	Specifically, what could be effective measures related to data held by very large online platform companies with a gatekeeper role beyond those laid down in the General Data Protection Regulation in order to promote competition and innovation as well as a high standard of personal data protection and consumer welfare?
NCT	7	Please explain your answer. If you replied yes, please also indicate the type of intervention that would be needed. [Do you think that there is a need for the Commission to be able to intervene in situations where structural competition problems may arise due to repeated strategies by companies with market power to extend their market position into related markets?]
	8	Please explain your answer. If you replied yes, please also indicate the type of intervention that would be needed. [Do you think that there is a need for the Commission to be able to intervene in situations where structural competition problems may arise due to repeated strategies by companies with market power to extend their market position into related markets?]
	9	Please indicate which are these other market scenarios that in your view qualify as structural competition problems and rate them according to their importance from 0 to 4 (0 = no knowledge/no experience; 1 = no importance/no relevance; 2 = somewhat important; 3 = important; 4 = very important) [Two of the scenarios are: ‘restricting content/service interoperability’ and ‘limited data portability due to lack of interoperability’].

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Who wants interoperability?

Jules Beley

Abstract

The forthcoming Digital Markets Act (DMA) in the EU will likely contain provisions regarding interoperability in digital markets. Interoperability is viewed by certain stakeholders as a tool to reduce market concentration and increase competitive pressure on dominant firms. This master's thesis investigates the role and effect of protocol interoperability in digital markets based on the theory of industrial organization. I use a theoretical model to evaluate incentives to interoperate at firm level, assess the effect of interoperability on competition and market structures, and define conditions under which mandating or encouraging interoperability may be a sound policy option. I complement this with an analysis of important submissions to EU consultations conducted in 2020 in preparation for the DMA. I find that interoperability may be an interesting policy tool in some markets. Policymakers should be most concerned about highly concentrated markets with personalization and multihoming. When it comes to policy instruments, standardization is not always the best way of achieving interoperability.

Key words

Industrial organization, interoperability, DMA, competition policy, network economics, network effects