Section I

연구논문

Digital Economics

Yves Guéron

Digitization, the process of converting information into a digital format (bits, short for binary digits), has dramatically reduced replication costs, as well as the costs of transmitting information. This survey examines how those important reduction in costs affect economic activity through the lens of incentives, prices and efficiency.

Keywords: Digital economics, Search, Online tracking, Platforms, Privacy, Firm productivity

1. Introduction

Digital Technology is the representation of information in bits. The bit (binary digit, or binary information digit) is a basic unit of information which takes one of two values, usually zero or one, and is represented by an electrical voltage or current pulse in most modern computers.

Digital Economics explores how standard economic models are affected by digitization, or the representation and storage of information in bits. In particular, digitisation has significantly reduced replication costs, as well as the costs of transmitting information. In this survey, we discuss how those have affected economic activity through the lens of incentives, prices and efficiency.

Section 2 discusses how the Internet has affected selling. First, we look at decisions to shop online or offline. Next, we look at tracking, which allows companies to follow customers online activities and purchases. This gives rise to the possibility of price discrimination and personalised advertising. While price discrimination, if anticipated, does not benefit firms because of consumers' strategic reactions, personalised advertising is now prevalent and a major source of revenue for content providers. Finally, we look at bundling, which has gained prevalence as digitization has lowered

the marginal costs of information goods to zero.

In Section 3, we look at whether or not the advent of the Internet, through lower search costs, has contributed to the reduction of prices and price dispersion. While there is evidence of both having occurred, there is still significant price dispersion. This may by the strategic manipulation of firms, trying to increase search costs through obfuscation.

Section 4 follows up the discussion about tracking started in Section 2 with a stronger focus on privacy and the effects of better privacy controls.

Section 5 looks at platforms and network effects, both direct and indirect. Network effects can give rise to momentum or inertia, and can result in the dominance of an inefficient firm. Moreover, competition between platforms often rely on consumers' self-fulfilling expectations, leading to an equilibrium multiplicity issue.

Section 6 discusses open source software and the motivations of developers to join such projects. Participating to open source projects, despite the opportunity cost of time, may help developers enhance their technical skills, but also allows them to increase their network and potentially find more job opportunities.

Section 7 looks at piracy and how it affects the creation of new content. Finally, Section 8 looks at the impact of digitisation on firm productivity and the labour market.

2. Selling

The Internet has transformed the way we buy, as we can now search and purchase from the comfort of our homes. It has also given better means to firms to track our purchases and online traffic. In this section, we explore how the Internet has transformed selling.

2.1. Online vs offline

The Internet has reduced transportation costs, both for digital and physical goods. It

is clear that for digital goods, transportation costs are zero, and information can freely travel around the world. This was not the case when information had to be conveyed through a physical support. Transportation costs for physical goods have also been reduced. For example, it is now more convenient to shop online without having to carry things back from the store. This can allow, for example, for more stockpiling and bulk ordering.

The New Trade Theory has long assumed that without transportation costs, consumption would homogenize throughout the world. What evidence do we have from the digital world? In the popular press, Cairncross (1997) suggests that the low transportation costs of information, due to the rise of the Internet, would lead to the "death of distance". No one would be remain isolated, everyone would be able to plug into the global economy. Rural consumers would have access to the same sets of digital products as other shoppers. Knowledge would be available everywhere. However, it can be argued that distance still matters, as information frictions still matter in international trade and distance increases those frictions.

Lendle et al. (2016) compare the effect of geographic distance on eBay and total international trade flows. They find that the effects of distance on sales is 65% smaller on eBay than with physical sales. The authors attribute this effect to the decline of search costs. The data covers all eBay transactions between 61 countries between 2004 and 2009, disaggregated in 40 product categories, and the authors use gravity equations, standard in the trade literature. The author also control for demographics, noting that eBay users are usually younger, more educated, and have higher income than offline purchasers.

Forman et al. (2009) look at the substitution patterns between offline and online retailing, using data from on the top-selling books from Amazon and from around 1,500 unique locations in the USA, for ten months ending January 2006. At the time, electronic commerce represented just 3% of total retail sales in the US. (The figure has roughly tripled to 9% in 2017.) The paper looks at how the entry of an offline retail store (Wal-Mart, Target, Barnes and Noble, Borders) changes the types of products bought online in that location. They find that people substitute away

from online purchasing towards offline purchasing when a store opens locally, so that distance is still relevant. Would similar results obtain in the 2020s?

2.2. Tracking

The advent of the Internet and online purchasing has given firms the ability to better track their customers, along two dimensions: firms can now better observe the prices customers pay for various goods, and can also better observe their interests. This can give rise to both personalized pricing, that is, price discrimination, and also better ad targeting. We discuss both topics in turns.

Price discrimination

In a market with heterogeneous consumers, it is often the case that firms do not know consumers' values: there is asymmetric information. The advent of tracking can help reduce this asymmetry, as firms can now observe consumers' purchases and learn about their values, which in turn allows them to personalize the prices they can offer over time: consumers who displayed a higher willingness to pay may thus face higher prices in the future. This is known as the *ratchet effect*. If consumers however anticipate this, they might be more reluctant to divulge their information: they may use measures to protect their anonymity, or more dramatically delay their purchases, potentially leading to a loss in profit for firms.

Hart and Tirole (1988) demonstrate this in a setting with one seller of a durable good and one buyer with a private value, in finite time. Without commitment from the seller, the optimal price path for selling the good displays Coasian dynamics, declining over time, while the rental price of the good shows a ratcheting, increasing over time. However, when the horizon becomes arbitrarily large, the price offered in most periods is the lowest price possible, and the seller's profits are lower than in the sales model. That is, the inability to commit, coupled by the strategic anticipation of consumers, pushes the price down and lowers the profit of the firm.

Villas-Boas (2004) also considers a monopolist, but infinitely lived and facing overlapping generations of consumers. The monopolist has the ability to price

discriminate between previous consumers and new consumers. Prices in equilibrium will fluctuate, and the monopolist would achieve a higher profit if it could commit not to price discriminate. Again, this is because forward looking new consumers facing a high price can decide to delay their purchase in order to obtain a better price in the next period.

Acquisti and Varian (2005) also consider a monopolist which can price discriminate over time using past information about consumer purchases, using a two-period model. Consumers can react by choosing to hide past purchases.(1) They find that it is optimal for the monopoly not to use the tracking information to price discriminate.

When considering a duopoly comes the issue of consumer poaching, or how to attract one's rival customers. Villas-Boas (1999) considers a duopoly with infinitely lived firms and overlapping generations of consumers, in which firms have information about their customers past purchases, allowing them to set a different price for those previous customers than for new customers. He finds that customer recognition lowers equilibrium prices, because of customer poaching. Fudenberg and Tirole (2000) also look at customer poaching in a duopoly setting, albeit within a two-period model. They find that firms offer too much discounts to their rival's customers, and that switching is inefficient.

In practice too, price discrimination based on consumer history does not appear to be a very successful idea. Streitfeld (2000) tells a story of price discrimination at Amazon that led to a very negative consumer sentiment. One man had ordered the DVD of Julie Taymor's "Titus," at the price of $24.49. Later, he noticed that the price had increased by almost two dollars, and decided to log out of his account to see that the price was now down to $22.74. Amazon customers started exchanging information on forums, and many noticed that as members, they were being offered DVDs at a higher price than for non-members. They became very vocal about this issue, and Amazon had to deny they were price discriminating, saying that the price

(1) In practice, consumers can choose not to join a loyalty program, to reject or erase cookies, to use multiple credit cards or cash, to voice their displeasure at pricing policies perceived as discriminatory.

variations were purely random for the purpose of demand discovery. They apologized and issued refunds for more than 6,000 consumers. While Amazon does no longer price discriminate in such a way, it performs dynamic pricing, in which prices are constantly adjusted over time to reflect changes in demand and supply conditions.

Personalized advertising

Given the difficulties associated with personalized pricing, and the fact that in practice consumers face a price of zero for many digital goods,(2) personalized pricing may not be of practical relevance. Instead, lower tracking costs have favoured the emergence of personalized advertising, in the hope of increasing its profitability - ad sales represent more than 85% of Alphabet's (Google) revenue. However, it is important to understand whether personalized advertising, and more generally online ad campaigns, are worth the cost. Recently, many economists have teamed up with companies to design and measure the efficacy of such online ad campaigns.

Lewis and Reiley (2014) conducted a randomized experiment for a major US retailer on 1.6 million customers visiting Yahoo!, in the fall of 2007. A key feature of the study was to match the database of the retailer's customers with their Yahoo! account. More than 1.5 million individuals where identified. The experiment simply consisted in showing ads for two weeks to a treatment group and no ads to the control group. About 800,000 users were exposed to the ads. They find that the campaign was profitable and increased sales by 5%, mostly from offline purchases. Also, most of the increase in sales came from consumers who didn't click the ad.

Blake, Nosko, and Tadelis (2015) report the results from a series of controlled experiments conducted at eBay. First, they conducted an experiment about brand key search advertising. Brand terms are search queries that must include the term eBay, such as "eBay shoes". In March of 2012, eBay halted advertising for its brand related terms on Yahoo! and Bing. The outcome was that 99.5% of foregone click traffic from turning off brand keyword paid search was captured by natural search traffic.

(2) For example, Gmail, Facebook, Instagram, Google photos, ...

The authors posit that this is because those queries use search as a way to navigate to eBay's website.

They also report results from an experiment on "non-brand" terms, such as "used Gibson Les Paul", or "cell phone". eBay manages over 100 million of such keywords. In that context, ads have a more relevant informative role to play. The experiment consisted of randomly selecting a treatment group, which would receive ads, and a control group, which would not, and lasted for 60 days. They find that paid search had an overall insignificant effect on sales, but mattered for new or infrequent users. Because frequent eBay shoppers account for most of the sales attributed to paid search, the returns on investment were negative.

This suggests that ads main function is to introduce a brand to those who do not know it, or who do not purchase from it often.

Goldfarb and Tucker (2011a) look at the effectiveness of display advertising (within a website) based on two criteria: matching with the website content, and obtrusiveness. They find that both independently increase purchase intent. However, when used in combination, these two strategies are ineffective, and relate their result to privacy concerns.

Shiller, Waldfogel, and Ryan (2018) look at the effect of ad-blocking software, and find that the widespread use of ad blockers may decrease the quality of websites on the advertising-supported Internet. To avoid any reversed causality issue (people use ad blockers because the quality of websites is low), they use the geographic proximity of users to the source of ad blockers as an instrument. This is done by looking at the geographical patterns of the search term "Adblock Plus" on Google between 2011 and 2016.

2.3. Bundling

Digital goods have a low marginal cost of production, often zero: copying an mp3 file is not costly. Standard microeconomic theory can readily accommodate a zero marginal cost. The real novelty of digital goods, as opposed to physical goods, is that they are non-rival: they can be consumed by one person without reducing the quantity

or quality available to others. If there are no legal or technological means from preventing copying, then what distinguishes the Internet from a “giant, out of control copying machine”?(3)

A popular way of selling digital goods is to bundle them together. For example, network operators often bundle a mobile phone plan, home internet, and cable TV subscription together (this is known as *triple play*); Microsoft bundles its word processor, its spreadsheet, its presentation program, as well as other programs, in Microsoft Office.

In this section we discuss three possible explanations for bundling, and explore how they relate to digital goods: price discrimination; product differentiation; the leverage theory of bundling.

Price discrimination

Here is a very simple illustration as to how bundling can be used for price discrimination. There are two products, Word Processor and Spreadsheets. Half of the population is willing to pay $40 for the word processor and $60 for the spreadsheets, while the other half is willing to pay $60 for the word processor and $40 for the spreadsheets. If each product is sold separately, the optimal price for each product is $40 and the firms makes $80 per customer. However, bundling the two products together allows the firm to charge a price of $100. In this case, bundling is profitable because the demands for the two products are negatively correlated.

Bundling homogenizes consumers’ total reservation value for a collection of products when they differ in their valuations across products. It also acts as a way to price discriminate. In our example, each type of consumer pays a different price for each product, but all consumers end up paying the same price for the whole bundle.

As pointed out, the demands in our example are negatively correlated. McAfee, McMillan, and Whinston (1989) show that bundling is superior to independent pricing when demands are independent, and more recently Armstrong (2013) shows that this

(3) Shapiro and Varian (1998, p. 83).

can also be the case under mild positive correlation.

We now see how bundling and price discrimination apply to digital goods. Recall that digital goods have a very low cost of reproduction and are non-rivals, and note that unlike physical products, it is easy to bundle a large number of digital goods together (with physical goods, this may be too bulky).

Bakos and Brynjolfsson (1999) show how bundling can be vastly superior to independent pricing in the case of digital goods, when the number of is very large. They consider a model with many digital goods, all with a zero marginal cost, and many consumers, who all have a unit demand for each digital good. The valuations for each good are random, and independent and identically distributed. The idea behind bundling a large number of digital goods is that due to the law of large numbers, the average valuation for a consumer will be close to the expected value, such that the seller can extract all surplus from the consumer and reach the first best level of consumption.

This is how music platforms have evolved. Initially, the iTunes store would sell individual songs or albums, but nowadays most music platforms offer access to all their catalogue in exchange of a monthly fee.

Despite the wide array of theoretical work on bundling, empirical studies have been scarcer. Shiller and Waldfogel (2011) question the practice of the iTunes store of offering each song at the same price of $0.99. They use a student survey to elicit valuations for the most popular songs of 2008 and 2009, to find that pure bundling of the top 50 songs would increases revenue by 20 to 30 percent.

Aguiar and Waldfogel (2018) study the effects of music streaming on permanent music downloads and piracy. They use data from 2013 to 2015, which includes the digital track sales for 21 countries, song-streaming levels for the top 50 songs on Spotify, and piracy measures at the artist level, for those countries.

At the song level, they find that streaming on Spotify is positively correlated with song purchases. It could be either because streaming boosts sales, or because population is heterogeneous, some preferring streaming and others downloads. At the aggregate level however, Spotify usage reduces sales and also reduces piracy.

Measuring the effect on artists revenue is difficult because lack of transparency with regard to payments to right holders.

Product differentiation

Even with two firms, price competition when firms are selling homogenous products leads to perfect competition, and firms make zero profits. A way for firms to get market power with price competition is product differentiation - see Hotelling (1929). Bundling can help to achieve product differentiation, and hence reduce the effects of competition.

Chen (1997) considers a duopoly competing in price over a homogeneous primary product. There are secondary products that can be bundled with the primary product, and production of those is perfectly competitive. In a first stage, firms decide whether to bundle or not, and then firms compete in prices. Chen finds that in equilibrium at least one firm chooses to bundle, and both firms earn positive profits, despite producing a homogeneous good and competing in prices. The reason is that bundling creates differentiation between the two firms, which allows for market power and positive profits.

The leverage theory of bundling

The leverage theory of bundling argues that a multi-product firm with a monopoly in one market can use this monopoly power to increase its market share in other markets by bundling its products. The Chicago school has strongly argued against this theory, showing that there is only a “Single Monopoly Profit”(see for example Bork, 1978). That is, the monopolist cannot increase its profit by bundling, as whatever would be gained in the other market would have to be lost in the monopolized market. Crucially, the Chicago school has emphasized the competitive nature of the market for the good sold by multiple firms. The single monopoly profit theory has been shaping antitrust laws in the US.

Whinston (1990) was the first paper to propose a formal model that shows how bundling can be anticompetitive, by relying on an oligopolistic market structure rather

than a competitive one, as the Chicago school did. Whinston argues that bundling acts as a commitment device, and might deter entry from a more efficient competitor facing entry costs, or might push a competitor to exit in the presence of fixed costs. Nalebuff (2004) also finds that bundling can be an effective barrier to entry, by reducing the profits of a potential entrant who must pay an entry cost.

Bundling and digital goods

Digital goods and services often feature networks effects - direct one (e.g. the telephone, instant messaging, social networks) or indirect ones (e.g. two-sided platforms).

When direct network effects are present for a secondary good, bundling can prevent entry in the primary good. This is what Microsoft has been accused of by the American government when including Internet Explorer with each copy of Windows, thereby curtailing the development of other browsers. The case focused on the anticompetitive bundling of Internet Explorer, and resulted in Microsoft being found guilty. In the settlement, Microsoft allowed PC manufacturers to adopt non-Microsoft software.(4) The European Commission also investigated the bundling of Internet Explorer with Windows in 2009, and Microsoft and the Commission agreed to allow competing browsers via a "ballot box," which would let users choose their browser upon setting up their computer. This feature remained absent for a long time from Windows 7 and Microsoft was eventually fined 561 million euros by the European Commission.

Microsoft was also involved in another antitrust case, this time related to a market with indirect network effects: the media streaming market. There are two sides, consumers and content providers, and a media player acts as a platform between them. Microsoft bundled Windows Media Player with Windows, which was deemed predatory by the European Commission, hurting digital media rivals such as RealNetworks. They were fined 497 million euros in 2004, and were asked to produce

(4) *United States v. Microsoft Corporation*, 253 F.3d 34 (D.C. Cir. 2001).

a version of Windows without Windows Media Player.(5)

Another reason for bundling is that with two-sided platforms, a firm may want to set the price for a side of the market below zero, but cannot do so because of institutional constraints. Bundling then act as an implicit subsidy.

3. Price dispersion

Standard models of market competition lead to what we know as the "Law of One Price": identical goods sold in different locations must sell for the same price. However, evidence of price dispersion abounds, implying, as Varian (1980) said, that "the 'Law of One Price' is no law at all."

One of the first attempt to model price dispersion is through the introduction of search costs: consumers must pay a (potentially small) cost to gather information about prices. Another type of models that also result in price dispersion are models in which a third party, an "information clearinghouse," such as a newspaper, provides some consumers with a list of prices.

With digitization and the advent of the Internet, access to information is now easier than ever: search costs have the potential to become arbitrarily small, as there are now many online resources that help consumer discover prices. In 1999,(6) *The Economist* wrote that "The explosive growth of the Internet promises a new age of perfectly competitive markets. With perfect information about prices and products at their fingertips, consumers can quickly and easily find the best deals. In this brave new world, retailers' profit margins will be competed away, as they are all forced to price at cost."

In this section, we first review the theoretical literature on consumer search and clearinghouse models, and then present empirical evidence that the prediction of *The Economist* has not been realized and we still observe a significant amount of price

(5) *Microsoft Corp v Commission* (2007) T-201/04.

(6) *The Economist*, November 20, 1999, p. 112.

dispersion. We conclude this section by discussing how firms' strategic reaction to lower search costs in the age of the Internet may explain why price dispersion is still a prevalent phenomenon.

3.1. Theoretical models of consumer search

Most of the early models of consumer search share a common setting. There is a continuum of price-setting firms competing to sell a homogenous product, with a constant returns to scale technology. There is a continuum of consumers with quasi-linear utility. The novelty is that to acquire the product, consumers must first obtain a quote from a store, and each quote is obtained after incurring a search cost c - for example the cost of visiting a store.

Early search models

In one of the first models of consumer search, Stigler (1961) makes the following assumptions: each consumer wishes to purchase a given quantity; consumers perform a fixed sample search, first determining how many quotes to obtain and then purchase from the store offering the lowest price; firms are non-strategic, and the distribution of prices charged is exogenously given. In this setup, Stigler determines the optimal number of searches and shows that it is increasing in the number of units desired and decreasing in the search cost. Finally, Stigler finds that more price dispersion, all else equal, leads to a reduction in the expected priced and an increase in search efforts.

There are two main drawbacks to Stigler's model. First, the consumer search process is not sequentially optimal: a consumer drawing a price close to the lower bound of the price distribution in their first searches would have little incentives to continue the search and incur more costs. That is, search does not take into account information as it arrives during the search process.(7) Moreover, firms' behaviour is non-strategic and exogenously given. Rothschild (1973) calls this approach a "partial

(7) One reason why it may sometimes be optimal to use a fixed search procedure, rather than the optimal sequential search, is if it takes a long time for firms to provide a quote, and buyers have a deadline in order to purchase the product. In that case, fixed search saves time.

partial-equilibrium," in which consumers' reaction to price variability is modelled but in which price variability itself is not explained.

Diamond's paradox

Diamond (1971) takes those drawbacks into account, assuming that consumer search is sequentially optimal and that firms are strategic. He first establishes that optimal sequential search leads to a threshold policy - consumers purchase if the price falls below a certain threshold and continue to search otherwise and then shows what has been known as "Diamond's Paradox": in equilibrium, all firms charge the monopoly price. Thus, in equilibrium, consumers purchase from the first store they visit.

To see why this is an equilibrium, assume there is an equilibrium in which prices other than the monopoly price are offered, and let p_L denote the lowest price offered. Increasing this price to say $p_L + c/2$ would be profitable, since such a price increase would be too small for consumers to warrant an additional search and incur the cost c.

Diamond's paradox is a striking result: even with a continuum of firms competing in prices, search frictions lead to a market in which the monopoly price prevails. The vast literature that followed Diamond then tried to establish conditions under which costly search could lead to price dispersion.

Price dispersion

In Diamond's model, firms are homogenous and share a common marginal cost.

By introducing heterogeneity in firms' marginal cost, and assuming optimal sequential search and optimal behaviour from firm, Reinganum (1979) obtains an equilibrium with price dispersion, in which firms charge their own monopoly price, provided it falls below the reservation price of consumers, the reservation price being endogenously determined. Price dispersion is therefore determined by the level of heterogeneity in production, and a reduction in search costs decreases the variance of equilibrium prices.

MacMinn (1980) return to Stigler's fixed search procedure, this time with heterogeneous firms and modelling their strategic responses. MacMinn also finds

an equilibrium with price dispersion, yet with an opposite comparative static than Reinganum: price dispersion increases as the search cost decreases. This is more readily seen when firms' costs are uniformly distributed. In equilibrium, each firm charges a price which is a convex combination of its own marginal cost and the highest possible marginal cost. As search costs decrease, consumers sample from more firms, and the increased competition pushes firms to put more weight on their own marginal costs, thereby increasing the level of price dispersion.

Consumer heterogeneity

Burdett and Judd (1983) also obtain an equilibrium with price dispersion, in a model with ex ante identical consumers and firms, and with a fixed search procedure. It is therefore another generalisation of Stigler's model, taking into account firms' strategy, but without firm heterogeneity as in MacMinn. In Burdett and Judd, the equilibrium consists in a price distribution for firms as well as a search distribution for consumers - the probability with which they sample from one, two, three, or more firms. First, if all consumers were to sample from at least two firms, price competition would push all firms to charge the marginal cost, which wouldn't make it optimal for consumers to sample from at least two firms. Thus, in equilibrium, some consumers must sample from only one firm with positive probability. As in Diamond, there is an equilibrium in which consumers search only once and all firms charge the monopoly price. But there is also an equilibrium in which some consumers search only once and others search twice. Therefore, there is ex post heterogeneity among consumers. Burdett and Judd use a model with unit demand, while McAfee (1995) extends the model to allow for multi-unit demand.

Janssen and Moraga-González (2004) consider a model with ex ante consumer heterogeneity: some consumers do not incur any search costs, while others do. They are also among the first to consider a strategic pricing game with a finite number of firms, rather than considering a competitive model. They find three types of equilibria, one with a high search intensity in which uninformed consumers randomise between one and two searches, as in Burdett and Judd, one with moderate search intensity, in

which uninformed consumers search only once, and one with low search intensity in which consumers randomise between one and no search.

3.2. Models with an information clearinghouse

Amongst model with clearing houses, Varian (1980) is probably the most well-known. Varian considers a model with informed and uninformed consumers. Uninformed consumers choose a store at random and purchase if the price is lower than their reservation price, while informed consumers know the distribution of prices and can shop from the store with the lowest price. One interpretation of the model is that stores advertise their sale prices in the weekly newspaper, and informed consumers read the newspaper, while uninformed ones do not.

Varian first establishes that there cannot be a pure strategy price equilibrium and then finds the mixed strategy equilibrium using free entry and indifference conditions. He also discusses what would occur if uninformed consumers could pay a search cost to become informed, and concludes that the mixed equilibrium pertains, provided some consumers have a sufficiently high search cost.

Other notable papers that consider heterogeneity of information for consumers are Salop and Stiglitz (1977) or Rosenthal (1980). In Salop and Stiglitz, as in other models of spatial price dispersion, the equilibrium involves some stores always selling their product at a lower price than others. Varian finds such a pattern implausible and thus favours the idea of intertemporal price discrimination. Rosenthal considers a model with heterogeneity in consumer taste: some consumers are more loyal to a certain brand than others. There is then a tension between charging a low price to attract non-loyal consumers and charging a high price to extract the surplus of loyal consumers, resulting in a mixed strategy equilibrium and price dispersion. The striking result from Rosenthal is that as the number of competing firms increases, the expected prices paid by all consumers go up. This is because it is assumed that the proportion of loyal consumers in the market increases with the number of firms.

More recently, Baye and Morgan (2001) look at the pricing decisions of those information clearinghouses, when deciding how much to price firms to advertise

and consumers to search prices. They find that the clearinghouse has an incentive to charge firms a price above the welfare-maximizing one, so that not all firms choose to advertise on the platform. This is because this would otherwise lead to Bertrand competition and price uniformity, rendering the information clearinghouse useless to consumers.

3.3. Price dispersion in the digital age: empirical evidence

As mentioned, digitization has drastically reduced search and information costs. As those costs converge to zero, many of the models discussed previously reduce to models of perfect competition, where price equals marginal cost. So, did the Internet lead, as *The Economist* predicted, to a "new age of perfectly competitive markets"?

Brynjolfsson and Smith (2000) study price dispersion in the market for books and CDs that are sold online. They investigate whether prices are more homogeneous and cheaper online than offline. To do so, they collected 8,500 price observations over a period of 15 months for books and CDs, from 41 Internet and brick and mortar retailers. Half of the product considered were best-sellers, while others were randomly selected.

They find that (i) Internet prices are lower (9 to 16%); (ii) Internet stores change their prices more often than brick and mortar stores, although the magnitude being significantly smaller; and (iii) that there is still substantial price dispersion in the prices charged by competing Internet retailers.

This finding is confirmed by Baye, Morgan, and Scholten (2004), who look at four million daily price observations for more than 1,000 consumer electronic products on the website shopper.com, over a period of eight months. They find a range of price dispersion between 3.5% and 23% depending on the number of firms offering a product.

More recently, Orlov (2011) looks at the airline industry. Using price data from 1997 to 2003, along with a measure of Internet penetration (which increases from 20% to 70% during that period), he shows that an increase in Internet penetration reduces average price and leads to higher intra-firm price dispersion, but does not

affect inter-firm price dispersion.

Although there is evidence that the rise of the Internet has helped reduce prices, we still observe significant price dispersion. It therefore appears as if the rise of Internet has not put an end to price dispersion. There are two main reasons as to why this might be the case:

Quality differentiation.

Different retailers offer different shopping experiences. For example, Amazon has developed a reputation for being very consumer friendly, making it easy to return a product, whether defective or whether one does not like it.

Obfuscation and loss-leaders.

Search takes place over multiple dimensions: price, quality, reputation, shipping fees, or delivery. Firms can decide which information to put forth and which information to hide, making search more difficult, and thereby endogenizing search costs. The use of loss-leaders on price comparison websites, for example, can attract consumers to one's website, to then present a range of higher quality products on their websites.

3.4. Strategic manipulation by firms: obfuscation and loss leaders

As discussed in the previous subsection, it does not seem like the Internet has brought us to the era of the Law of One Price: price dispersion is still prevalent, and firms charge above marginal cost. One hypothesis as to why this is the case, brought forward by Ellison and Ellison (2005), is that firms have reacted strategically to the reduction in search costs brought forward by the Internet, to increase those search costs through "obfuscation strategies":[8]

> For example, the Internet makes it easy for e-retailers to offer complicated menus of prices (for example, with different options for shipping), to make price offers that search engines

(8) Ellison and Ellison (2005, p. 153).

will misinterpret (like products bundled together), to personalize prices and to make the process of examining an offer sufficiently time consuming so that customers will not want to do it many times.

Ellison and Ellison (2009) provide a more comprehensive empirical study of such obfuscation strategies by looking at the market for computer memory modules and the Internet price search engine Pricewatch, a search engine popular with savvy computer-parts shoppers.

One of the first ways sellers tried to obfuscate was through shipping charges, and Ellison and Ellison report that it was not uncommon for firms to list a price of $1 for a memory module and then inform consumers, at checkout, that there would be a $40 handling and shipping fee. Pricewatch took measures to provide a more transparent assessment of all charges to consumers, although some difficulties still remain, such as regarding shipping time.

Another popular method of obfuscation was to bundle low-quality items with restrictive contractual terms, such as no warranty or a 20% restocking fee on all returns. The variety of such contractual terms makes it difficult for consumers compare items between different sellers.

Finally, Ellison and Ellison discuss what they refer to as a “loss-leader” pricing scheme: stores list damaged goods on the search engine, at a very low price. This attracts customers to their store, who can then browse more items from that store and buy a more expensive product. This is validated by an empirical analysis and an estimation of demand equations, which shows that reducing the price of low-quality products increases sales of medium and high-quality ones.

Search costs would therefore not be exogenous and declining since the advent of the Internet, but endogenous, affected by firms’ strategic choices.

4. Data and privacy

> The question constantly posed by wildlife documentaries is *how* animals should be filmed: they never engage with the debate as to *whether* animals should be filmed at all.
>
> Mills (2010)

In 2010, Brett Mills, a researcher in media studies, published an article titled "Television wildlife documentaries and animals right to privacy," discussing whether it was ethical or not to film animals for documentaries in any circumstance, or whether there were situations in which we should refrain from filming them.

This goes to show that privacy is a prevalent issue in many parts of our society. But what is privacy exactly? Warren and Brandeis (1890), in one of the most influential essays in the history of American law, define privacy as the "right to be let alone". Posner (1978) views privacy as a concept that can encompass many features, such as the right to be free from invasions into one's solitude, the right to be free of publicity which casts one in a false light in the public eye, or the right to control the use of one's name or image for commercial purposes.

Closer to our topic of interest, digital economics, we will focus our discussion on informational privacy: "personal information and the problems and opportunities created by its collection, its processing, its dissemination, and its invasion." (Brandimarte and Acquisti, 2012.)

So, what are the trade-offs from more or less privacy on the Internet? Less privacy can lead, as we have discussed in 2, to price discrimination. While price discrimination might be optimal from a welfare perspective, it can shift surplus from consumers to producers, and policy, such as antitrust policy, generally focuses on consumer welfare. Moreover, a more invasive Internet allows for the resale of data to third party services, often resulting in unsolicited marketing and spam.

On the other hand, less privacy can lead to a better personalisation of online services. For example, Gmail now offers a "Smart Compose" functionality, which offers suggestions as one types an email, and can thus help write faster. Moreover,

less privacy allows for more ad revenue, which allows service providers to offer online content at low prices, usually for free.

Edelman (2009) discusses the benefits of a zero-price policy for online services, such as email or web search, as opposed to charging a small fee. He argues that a zero price reduces transaction costs (no need for billing, user accounts), favours experimentation (consumers trying out products and figuring which has the best match for them), and that consumers overwhelmingly favour zero price over a small positive price. However, he also argues that often the marginal cost for online services is not zero (e.g. server capacity upgrade, scaling up costs), and that a zero price can lead to over consumption.

Lenard and Rubin (2010) also defend the usage of tracking data, arguing that if people want more privacy online then there will be less benefits for consumers: there is no "free lunch." They also argue that: targeted ads give useful information to consumers and generate revenue to support new services online; information is a public good with a zero marginal cost, so that a zero price will lead to the most productive usage; the information collected for ad targeting is used anonymously; personalized pricing is good for efficiency.

4.1. Theory

As previously discussed, Acquisti and Varian (2005), Hart and Tirole (1988), Villas-Boas (2004) all show that a monopoly may not benefit from being able to use tracking information in order to price discriminate, if consumers anticipate such price discrimination.

Taylor (2004) considers the possibility that tracking information may be sold or acquired by online retailers.(9) Taylor consider a model with two monopolists which may be able to exchange information about customers. When consumers are naïve, retailers will charge high prices to gather more information about customers and then eventually sell that information. When consumers anticipate the selling of their

(9) There are in fact companies specializing in the collection of personal consumer information, such as Double Click, acquired by Google in 2007 for $3.1 billion.

information, they may have incentives to delay their purchases, while the monopolists may prefer to be able to commit to not selling their data.

Calzolari and Pavan (2006) also look at the exchange of information between two companies interested in finding consumers' willingness to pay, and look at the welfare effects of privacy regulations. They find that transmission of personal information between companies can sometimes increase welfare. On the other hand, Hermalin and Katz (2006) show that privacy can lead to optimal outcomes.

Campbell et al. (2015) develop a theoretical model to investigate how privacy policy affects industry structure. In particular, they want to see whether privacy policy can help small firms, which usually have less access to data than big firms. In their model, there is a generalist website, which appeals to many viewers, and a specialist one, focused on niche content. Both websites' profits depend on how many visitors they attract and the efficacy of their ad targeting. With no privacy laws, viewers visit either both or none of the websites. With privacy law, there is a one-time request from the website to use data for tracking, which generates a one-time cost to consumers. Under certain circumstances, this affects more the small website, and it may no longer find it profitable to participate in the market. The reason is that if consumers are willing to pay the fixed cost only once, they may do so for the generalized website only.

4.2. Empirics

Goldfarb and Tucker (2011b) look at the effect of privacy regulation on ad effectiveness. Using 3.3 million survey responses from users having been randomly exposed to ads, they study the effectiveness of ads after the introduction of the EU "Privacy and Electronic Communications Directive" (2002), which limits how websites can collect data and use it to display ads. They find that this regulation has reduced ad effectiveness by 65% in Europe (looking at Europeans' behaviour when visiting EU vs US websites). This can have a very large cost for content providers.

Tucker (2014) looks at the effect of better privacy controls on ad effectiveness, and shows that there is a positive effect. The setup is a randomized control trial for ads on

Facebook from a non-profit organization (NPO) which aims at improving education for women in Africa. They could either show personalized ads (say with the picture of a celebrity one followed or liked) or generic ads. In the middle of the experiment, Facebook announced some privacy changes, giving users more control over which of their data could be used by third parties. This change was not anticipated by the NPO. They found that personalized ads were twice as effective after the policy change. However, the data covers a five-weeks period, and it would be interesting to see whether this effect persists in the long run.

Johnson (2013) looks at the impact of privacy policy on the auction market for online display advertising. Using a structural estimation, he compares three policies: opt-out, in which consumers must explicitly opt-out of tracking; opt-in, in which consumers must explicitly opt-in tracking; and tracking ban. Under opt-out, only 10% will drop out, leading to a 4% loss in revenue for online publishers, and a 5% decline in welfare. Under opt-in, only 10% do opt-in. Revenue drops by 35% and welfare by 41%. Finally, under no tracking, revenue drops by 39%. Thus, the impact of privacy regulation on content providers and the content they offer can be significant.

Miller and Tucker (2009) and Miller and Tucker (2011) look at the effect of privacy regulations in the healthcare market. In the first paper, they look at the effect of privacy regulations on the adoption of the Electronic Medical Record (EMR). Invented in the 70s, their adoption rate in 2005 was around 41% in US hospitals, even though widespread adoption could save billions in administrative costs. They show that privacy regulation reduces adoption of EMR by suppressing network effects: in sates without privacy regulations, the adoption of EMR by one hospital increases the probability that neighbouring ones will adopt EMR by 7%. It is 0% in states with privacy regulations. They estimate that privacy laws are responsible for a lower adoption rate of EMR by 24%.

The second paper estimates the cost of this lower adoption rate of EMR, using 12 years of US county-level data. They find that an increase in 10% of the adoption rate of EMR would reduce neo-natal mortality by 16 deaths per 100,000 (out of 251 deaths, that is a reduction of 3%). Using complementary obstetrics software could

increase that number to 40 death avoided.

4.3. Do consumers care about privacy?

Consumers claim they want privacy, but do their actions also say so? Athey et al. (2017) look at a field experiment conducted at MIT in which $100 worth of bitcoins were offered to undergraduate students. They find that small incentives have big effects on the disclosure of private information, that small navigation costs have a strong effect on behaviour, and that irrelevant but reassuring information about privacy make people less likely to try and avoid data surveillance.

During the field experiment, students were faced with three privacy questions: disclose the contact details of their closest friends; make a choice in order to maximize the privacy of their transactions; take additional steps to protect the privacy of their transactions. They find that: most students would give up their close friends contact details in exchange of a slice of pizza a 50% of students were offered pizza in exchange for contacts. Most gave up the data for the pizza; the randomization of the order of digital wallets and the amount of information led to large differences in technology adoption; some students who were randomly told that their answers would be encrypted were less likely to take additional measures to protect their privacy.

5. Network effects and platforms

Traditionally, economic models of supply have relied on the notion of constant or diminishing returns to scale. Consider farming for example: one can assume that farmers first exploit the best lands for their crops, such that expanding production would lead to the utilization of less fertile soils, leading to lower yields. In a world of decreasing returns, market equilibrium exists, and prices and market shares are predictable.

In contrast, with increasing returns, a firm ahead of its competitors enjoys a positive feedback mechanism, such that leaders tend to stay ahead. Increasing returns are then

characterized by “market instability, multiple potential outcomes, unpredictability, the ability to lock in a market, the possible predominance of an inferior product, and fat profits for the winner.” (Arthur, 1996.)

One source of increasing returns that is prevalent with information goods or services is network effects. While some products are often used in isolation, this is rarely the case for information goods and technologies. For example, Instant Messaging (IM), email or social media all require other users to communicate and share with. Network goods are goods or services for which users benefit increases with the number of other users. Such network effects can be direct, as is the case with IM: the more users of the IM service, the more people you can chat with. Or they can be indirect: an operating system with a larger user base will attract more developers, increasing the app offering and thus increasing the benefits of using that operating system.(10)

In this section, we first discuss the literature on network effects, which started in the 80’s. We see how network effects impact demand and supply, and also what strategies firms use in the presence of network effect. We then discuss the more recent literature on two-sided markets, which emerged in the early 2000’s, and which focuses on the strategy and pricing of an intermediary platform connecting two different groups of consumers (e.g. credit card companies, connecting buyers with merchants).

5.1. Network goods

We start this subsection with a simple monopoly setting, which allows us to highlight the importance of expectations as users face a coordination problem when deciding whether or not to join a network. We then introduce a model of competition, and present an application to Internet connectivity.

Network effects

The typical utility function used when considering network effects has the following

(10) This is why, for example, Windows phone never offered a quality app market place. Its market share always remained below 3%, and developers had very little incentives to take time away from developing apps for iOS and Android.

form:

$$u = v + f(n).$$

The first term, v, is the intrinsic utility from using the technology, also called the stand-alone benefit. The second term, f(n), represent the benefit from being in the network, and is increasing with the size n of the network. Heterogeneity can be introduced for both components of the utility function: consumers can differ by their intrinsic utility, their network benefit, or both.

When consumers decide to join a network, they do not know how its size will evolve over time. Myopic consumers use the current size of the network to evaluate network benefits, while rational consumers form expectations about the future size of the network - and those expectations will be fulfilled in equilibrium.

Demand for a single network good, expectations, and under-provision

Because network effects involve forming expectations and fulfilled equilibrium, there are often multiple equilibria. The following simple setting illustrates this. Consider a single network good, and consumers with no intrinsic benefits from consumption but only a benefit from the network effect: $u = v \times n$. There is a mass one of heterogeneous consumers and the marginal benefit from network size, v, is uniformly distributed in [0,1]. Consumers are rational, and therefore form expectations about the expected network size.

Given that network benefits are increasing in the type, if a type v joins the network then any type v' > v also joins the network. There is then a critical type v^* such that all types $v \geq v^*$ join the network, and the network size is n = 1 − v^*. The critical type gets a value $n(1 - n)$, so that $p(n) = n(1 - n)$ is the price consistent with a network size of n. For any price p, there are thus three consistent network sizes: 0 = $n_0(p)$, and the two roots $n_1(p) < n_2(p)$ of the quadratic equation p = n(1 − n). All sizes rely on fulfilled expectations: if, given a price p, people expect a network size $n_k(p)$, $k \in \{0,1,2\}$, then precisely that number of people will want to join the network.

This multiplicity of equilibria is common in models that rely on fulfilled

expectations, but there are selection criteria available to rule out some of those equilibria. For example, $n_1(p)$ is unstable, while the Pareto criterion leads us to select $n_2(p)$ over $n_0(p)$.

Once introducing a cost for the network provider, we can then compare the resulting network size with a monopolist or a perfectly competitive firm. As can be expected, the monopolist offers a smaller network size than the competitive firm. More surprisingly, the network size offered by the competitive firm is also too small from a welfare perspective. The reason why the competitive network size is inefficient is because when joining the network, consumers only compare their private benefit with the cost of joining, but do not take into account the positive externality their participation generates on other users.

Demand for incompatible network goods - momentum, inertia, and dominance

As mentioned, increasing returns can lead (potentially inferior) firms to lock a market - what we also know as winner-takes-all markets. Arthur (1989) develops a simple model that illustrates this. There are two incompatible goods with network effects,[(11)] and a heterogeneous population of consumers, each being a "fan" of either one of the goods. Fans enjoy a greater standalone utility from the good they like, but all consumers are homogeneous with respect to network effects.

Consumers arrive sequentially and must decide which network to join based on the current network size for each good (consumers are therefore myopic rather than forward looking). In this setting, once one of the two goods reach a certain critical relative size, it will attract all the new customers, irrespective of their preferences. As this occurs almost surely, competition between incompatible network goods eventually lead to the dominance of one single good. Which good ends up dominating depends purely on luck, that is, on the order in which new consumers arrive. Therefore, nothing precludes an inefficient good from eventually dominating the market.

Farrell and Saloner (1985) consider a model with forward looking agents who must

(11) Two network goods are incompatible if the network effects for a good depend only on the customer base for that good.

sequentially decide whether or not to adopt a new technology. Both the old and the new technology have network effects. With complete information about the benefits from switching to the new technology, they show that all firms will adopt the new technology when it is unambiguously better. However, with incomplete information, there can be excess inertia, and it is possible that a beneficial new technology remains unadopted. This may explain, for example, why keyboards remain set on the "QWERTY" standard, even though many believe that other alternatives, such as Dvorak, are more efficient.

Competition and standardization

Since network effects can lead to the dominance of a single firm, it is important to understand how firms compete in order to achieve such dominance. Under the assumption of price competition, firms would undercut each other to achieve dominance, and we would end up in a symmetric equilibrium as with Bertrand competition. For that reason, Katz and Shapiro (1985) consider Cournot competition between several firms offering goods with network effects. Their objective is twofold: first, they characterize how network effects affect market competition; then, they consider incentives for making one's network compatible with its rival's.

Their model is as follows. There are n firms. Consumers first form expectations as to the size of the network for each firm. Given those expectations, firms choose their network capacity, which generates a set of prices. Given those prices, consumers make their purchasing decisions. Finally, in equilibrium, consumers expectations must be fulfilled. Consumers' utility depends on a standalone utility from consuming a product, as well as network effects. Consumers are homogeneous along the network effect dimension, but heterogeneous with respect to the standalone utility.

They consider various compatibility regimes between the technologies. Under complete compatibility, users benefits from network effects from all consumers, irrespective of the firm they have chosen. Under complete incompatibility, users benefits only from network effects from consumers having chosen the same firms. They also consider intermediate cases.

The first series of results concerns the impact of network effects on market equilibrium, under various compatibility settings. Under complete compatibility there is a unique equilibrium, which is symmetric, and which converges to perfect competition when the number of firms becomes increasingly large. This is because network effects do not play a role when choosing a firm, given the complete compatibility.

On the other hand, under complete incompatibility, there is a multiplicity of equilibria: there is a symmetric equilibrium in which all firms are active; there are equilibria in which some firms are inactive and other firms behave symmetrically; and there are asymmetric equilibria, with some firms having a large market share and others having a smaller one. Asymmetry is common with fulfilled expectations: a firm can have a larger market share simply because consumers expect it. Output is lower than under complete compatibility.

In the second part of the paper, Katz and Shapiro look at firms' incentives for compatibility. First, they show that even when firms can make side-payments to one another, they may fail to achieve complete compatibility when it is socially efficient to do so. Restricting attention to two firms, they then show that the adoption of an industry standard is more likely when the incompatibility equilibrium is symmetric. If, on the other hand, it is asymmetric, then the larger firm has less incentives to push for standardization, while the smaller one may have socially excessive incentives to develop an adapter to make its technology compatible.

Crémer, Rey, and Tirole (2000) apply the model of Katz and Shapiro to study competition between two Internet backbone service providers (BSPs). The Internet backbone consists of many large interconnected networks. They transmit the data generated by Internet service providers (ISPs) over very large regions of the world using long-hall fibre optic cables.

Competing BSPs must cooperate and reach agreements on protocols and standards in order to exchange traffic and offer end-users a high quality and uninterrupted service. Cremer, Rey and Tirole find that enhanced compatibility between BSPs leads to an increased market size and a larger consumer surplus. However, in an asymmetric

setting, the larger provider has incentives to degrade the quality of interconnection.

5.2. Two-sided markets

Rather than being sold directly from the producer to the buyer, many goods are sold through some intermediary. We distinguish four different roles for intermediaries: dealers, which buy goods or services from suppliers and resell them to buyers - e.g. a department store; platform operators, which provide a platform where buyers and sellers can interact; infomediary, which provide easier access to information about products to consumers; trusted third parties, which act as certification agents by revealing information about the quality of a product, or a seller's reliability.

The Internet has seen the rise of platforms as intermediaries that enable exchange between other parties. For example, Apple can be thought of as a hardware and software platform that connects users with software developers. Google provides a platform - search - that brings together potential buyers and advertisers. Digital markets give rise to platforms because the reduced search costs facilitate matching, and also because they increase the efficiency of trade. This section focuses on platforms, and more specifically two-sided platforms. There are two groups of agents that interact with the platform, *buyers* and *sellers*. The platform can charge a *membership fee*, which is a fixed fee to access the platform, and/or a *transaction fee*, which is paid at every transaction between buyers and sellers.

With platforms, each side of the market exerts a positive network effect on the other side: the more sellers there are, the better it is for buyers; similarly, the more buyers there are the better it is for sellers. Hence there are indirect network effects within each group: a buyer may not directly benefit from more buyers, but more buyers will attract more sellers to the platform, which in turns is beneficial for other buyers.

Rochet and Tirole (2006) define a two-sided market as a market "in which the volume of transactions between end-users depends on the structure and not only on the overall level of the fees charged by the platform."

A seminal example of two-sided market discussed in Rochet and Tirole (2003) and Rochet and Tirole (2006) is the one of credit cards. Credit card companies can choose

what transaction fees to impose on buyers and on sellers, and the structure of the fee matters. Indeed, one can think that if buyers were to face a transaction fee for using their credit cards, they may substitute towards other means of payment, such as cash or debit cards.

Other examples of two-sided platforms include video game consoles, which match gamers with game developers, or music or video platforms, which match content providers with users, telecommunication networks or the Internet.

Monopoly pricing

In their seminal 2003 paper, Rochet and Tirole consider a platform where the sellers and buyers are already present, and must decide whether or not to make a transaction after a match is formed. Here the focus is solely on the transaction fee, and the optimal monopoly price follows the standard Lerner formula: the total fee is the marginal cost times a markup that depends on the sum of the elasticities. How the total fee is split between each side of the market depends on the ratio of elasticities.

Caillaud and Jullien (2001, 2003), as well as Armstrong (2006), consider not only the decision to participate in a transaction but also the decision to join the network. While Caillaud and Jullien consider both membership and transaction fees, Armstrong focuses on membership fees. Again, the optimal monopoly price follows the standard Lerner formula, where the cost is adjusted to take into account the benefit one side provides to the other side. The side that benefits less from the other side of the market, all else equal, will have a lower price. The optimal price can also be negative, although in practice this may be implemented through a zero price along with some gifts. As is the case with the standard monopoly pricing, those prices are higher than the socially efficient prices because of the markup.

Platform competition, single or multi-homing

As with networks, competition between platforms also faces a multiplicity issue, with equilibria depending on consumer beliefs. Caillaud and Jullien (2003) characterize the full set of equilibria using the concept of “pessimistic beliefs,”

which assumes that agents always coordinate on the least favourable demand for one pre-determined platform. Armstrong (2006), on the other hand, assumes enough differentiation, using a Hotelling formulation, to avoid the multiplicity issue altogether.

The main drawback, however, is that this analysis is done under the assumption that prices are such that all the market is covered, which means that there is no scope for a welfare analysis.

Competition can take two forms: under single-homing, users can only register with one platform. For example, one's computer must either be a Mac or a PC, but cannot be both.(12) Multi-homing assumes that users can register with both platforms - for example, one can use multiple social networks, such as Twitter and Facebook.

Under single-homing, the equilibrium membership fee then consists in the cost of service plus the transportation cost (market power), which is the standard Hotelling price, reduced by a term that takes into account the positive externality that participation of one user has on the users on the other side of the platform.

Finally, Armstrong considers the case in which one side of the market can multi-home while the other cannot. Effectively, the platforms now compete fiercely for the side that cannot multi-home while ignoring the side that can. Fees are set up to maximize profit plus the surplus of the size that cannot multi-home, and the side that can now pay a higher price than if it could not multi-home. It pays the price to gain access to consumers on the other side of the market, which are exclusive to each platform.

6. Digital commons

A good is excludable if it is possible to prevent access to it from people who have not paid. Public goods are, by definition, non-excludable. When it comes to information goods, providers can deliberately decide to make then non-excludable.

(12) Although it is possible to run Windows using bootcamp on a Mac, or Linux on a Windows computer using a dual boot.

Two prominent examples of non-rival public digital goods: open-source software (OSS), and Wikipedia. In this section, we question why do some provider of digital goods decide to make them non-excludable, focusing on the decision to participate to OSS development. Lerner and Tirole (2002) argue that most of the development in open-source software (OSS) can be explained by the traditional 'career-concern' model.

6.1. A brief history of open source software

Lerner and Tirole first provide a historical account of the development of OSS. Many key aspects of computer operating systems and the Internet were developed in academic settings, such as Berkeley and MIT in the 60's and the 70's, and at research centres such as AT&T Bell Labs or Xerox's Research Center. At the time, the sharing of code was commonplace. This period saw the development of Unix and the C language at Bell Labs, which were shared freely. This sharing accelerated with the diffusion of Usenet, and there were no efforts to determine property rights during this time.

In the early 1980's, AT&T began enforcing intellectual property rights related to Unix, threatening litigation. This led to an awareness of the importance of well-defined property rights: the Free Software Foundation was established in 1983. Its aim was to disseminate software without a cost. It introduced a General Public Licence (GPL) which stipulated that developers of cooperatively developed software had to agree to make source code freely available.

The 1990's saw a sharp rise in the development of OSS, thanks to the diffusion of the Internet. Linus Torvald developed Linux in 1991. Licencing also became more flexible than under the GPL, as Debian, who was distributing Linux, established the Open Source Definition. One innovation was that proprietary software could now be bundled along with OSS.

Despite the important rise in OSS, it is not without its challenges. In particular, it is often said that it is usually for a tech savvy audience and difficult to use for general users.

6.2. Who contributes to OSS?

Ghosh and Prakash (2000) look at data on 3,149 distinct OSS projects, with over 13,000 contributors. They paint a picture of a small elite of developers, contributing to most of OSS projects: more than 75% of contributors only contributed once, while only 4% of contributors had more than five contributions. The top 10% of contributors accounted for 72% of all the code. This small core of contributors who are most active achieve an important status amongst their peers. As suggested by Lerner and Tirole (2002), signalling and career concerns may be an important reason for the participation in the development of OSS.

Lerner and Tirole investigate what economic theory can tell us about contributions to OSS projects. There is an opportunity cost of time for developers participating to the development of OSS projects: independent contractors cannot take on paid projects, and workers cannot focus on their own work.

There are then some immediate benefits from participating in OSS projects: it can improve performance in related tasks at work; it can provide a more enjoyable work balance; it can help learn new techniques.

There are also some delayed rewards. First, participating in OSS projects is an important tool for networking: it can open future job opportunities, shares in open-source based companies, future access to venture capital. It can also serve as an ego gratification, as developers may seek for the recognition of their peers. It is however difficult, in practice, to distinguish between signalling incentives and ego incentives.

The literature on career concern, initiated by Holmström (1999), suggest that signalling incentives are stronger when performance is more visible to the relevant audience, when effort has a higher impact on performance, and when good performance is a good indicator of talent. This gives rise to strategic complementarities: software developers will want to work on OSS projects that attract many other software developers, which can give rise to coordination problems: a project can flourish or be abandoned depending on programmers' beliefs about their peers' interest. This can also give rise to fads - working in a hot topic.

Xu, Nian, and Cabral (2019) investigate empirically the relevance of the signalling

incentives in the participation to digital public goods by looking at data from Stack Overflow (SO), an online community of questions and answers, along with data from Stack Overflow Careers, which allows users to post resumes online and link to their SO profile.

In SO, one can answer questions and build up a reputation from those contributions (through a system of votes), but one can also edit questions and answer to improve readability for other members. While answering questions helps build up a reputation, editing questions and answers does not.

First, they consider a simple theoretical model, in which agents are SO users and job seekers, and must choose, in each period, how to allocate their time between three types of tasks: Work, Answers, and Edits. A key assumption is that the probability of transitioning to another job increases with one's reputation. Their model predicts that after a job change, time spent on answers decline. This could simply be due to being busier with a new job. However, the signalling hypothesis implies that the time spent on editing will decline less, as it is unrelated with reputation.

Using a difference-in-difference estimation, they find that after a job change, there is a 23.7% decline in Answers, compared to a decline of Edits of only 7.4%. This supports the assumption that signalling plays an important role in the participation to digital public goods.

7. Intellectual property and creativity

Over the past 20 years, the development of the Internet and of the digitization of information products (movies, music, books, software) have led to the phenomenon of digital piracy.

Content industries, especially record companies have blamed piracy for the loss in revenue and have taken legal action. In 2001, the heavy metal band Metallica filed a law suit against Napster, and other artists such as the rapper Dr. Dre joined in. This eventually led Napster to file for bankruptcy.

Policy makers have reacted by strengthening copyright laws, thanks in part to the important lobbying efforts of the content industry.

Intellectual Property (IP) refers to the legal rights that result from intellectual activity in the industrial, scientific, literary and artistic fields. It can be protected by patents, trade secrets, trademarks (inventions, processes, machines, brand names, industrial designs) or by copyrights (literature, music, choreography, films ...). Patents protect ideas and the expression of the idea, while copyrights protect only the expression of the idea, but typically last much longer than a patent (currently life + 70 years in the USA). Copyrights are also subject to a fair use policy. Piracy is the unauthorized reproduction, use or diffusion of copyrighted work.

Information goods can be considered as public goods, as they can be both nonrival and nonexcludable. Because of that, content creators can face difficulties in appropriating revenue from creation, which can lead to the underproduction of such creations. IP laws aim to address this issue by granting excludability through legal means, thus restoring incentives to create. However, this create a static efficiency issue, as the price of this content will be above the marginal cost (zero in the case of digital goods).

Despite this excludability granted by the law, some consumers choose to become digital pirates. In what follows, we discuss why some make this choice, and what are the costs and benefits for content creators. We then present some empirical evidence regarding the effects of digitization on the content creators.

7.1. A simple model of piracy

Bae and Choi (2006) develop a simple model of piracy with the following features: a monopolist provides a single original product; copies are of lower quality than the original; consumers are heterogeneous. Digital copies compete with the original product, pushing prices down and improving static efficiency. However, the loss in revenue may introduce dynamic inefficiencies, as incentives to produce high quality drop.

They consider two possible responses from the monopolist to digital piracy: limit

pricing or acceptance. With limit pricing, the monopolist lowers the price such that all consumers prefer to purchase the original rather than resort to piracy. Under acceptance, the monopolist accepts piracy and increases its price to sell only to consumers with a high willingness to pay.

They find that a strengthening of IP laws may have ambiguous effects on piracy, depending on whether IP laws target the quality of pirated versions or the costs of obtaining them. Finally, they consider the long-run incentives for creation and find that under all regimes, quality will be too low, even though acceptance of piracy would lead to a larger usage.

7.2. Revenue

Most studies find that free online copies reduce revenue. Liebowitz (2008) uses album sales data as well as Internet penetration data between 1998 and 2003 and estimates that file sharing is responsible for all the drop in record sales during that period.

Waldfogel (2010) performs an empirical analysis with data from 2009 and 2010, a time in which the iTunes store was already a well-established legal offering. The paper uses survey data of undergraduate students, a population in which file sharing is common. The paper finds that most music obtained through file sharing had a low value to users, such that they would not have purchased it otherwise. The paper finds that an additional stolen song reduces paid consumption by between a third and a sixth of a song.

Peukert et al. (2017) look at the effect of the unexpected shutdown of Megaupload on box office revenues. They use weekly revenue data for 14 movies in 2011 and 2012 and a difference-in-difference estimation strategy. They show that only the very popular movies benefited from the shutdown of Megaupload. However other movies were negatively affected by this shutdown, the idea being that file sharing can be an effective way to spread information about movies.

Reimers (2016) looks at the effort of the book industry to prevent piracy by using network surveillance. That is, they contract with private companies whose task is

to search the web for pirated content and then request for it to be removed, usually without appealing to courts. The paper uses a dataset from digital sales of titles offered only in that format by one publisher (RosettaBooks), along with physical sales of those titles (by other publishers), over the course of three years (2010 - 2013). The dataset also includes the piracy protection efforts of Digimarc, a large piracy protection company. Using difference-in-differences, the paper finds that efforts to reduce piracy increase e-book sales by 15%, while having no effects on the sales of physical books. The data, however, focuses on books published seven years prior. The dynamics of piracy may be very different, and more reactive, for recent titles.

7.3. Creation of new works

How copyrights affect creation of new work is more difficult, as we would need to observe a world with and a world without copyrights, and compare creation in both cases. Waldfogel (2012) attempts to do so by looking at the evolution of music quality since 1960, along with data from music sales. The RIAA (Recording Industry Association of America) has argued the music industry is an “investment-intensive business” and that piracy affects incentives to create music and makes it more difficult to invest in finding new talents. However, technological changes have also reduced the costs of producing, promoting and distributing music, which could offset the cost of piracy.

When assessing how creation is affected, looking at the total volume of newly created music is one thing, but all this music is rarely consumed. Also, the author ponders what sales threshold would be relevant given the new era of piracy. Instead, the author proposes three approaches to measure the evolution of quality over time. First, he creates an index of music quality since 1960, by looking at retrospective best albums lists. Two other approaches infer music quality from airplay: accounting for time elapsed, music of higher quality should receive more airplay. He finds that music quality started to decline in the early 90s and stopped declining after the arrival of free online copying in 1999.

The author argues that the reason quality does not decline, despite the loss of

revenue, is because digitisation also came with a decline in the cost of producing music. This effect on the supply side was enough to compensate for the effect of revenue reduction and led to an increase in music quality. This idea is supported by a documented increase in the share of independent record labels producing albums that top the charts.

Digitisation also leads to a problem of firms copying other firms' digital products. This is prevalent in the news industry with news aggregators. So far research has focused on the beneficial effects of exploration, but not on the issue of content creation. This has been an ongoing issue between Google, offering the aggregator service Google News, and content providers. In 2016, the EU started thinking about reforming copyright law to adapt it to the digital age. The directive was approved in March 2019, with the aim of content providers being better compensated by digital platforms: Google, Facebook and YouTube. Google is refusing to pay news providers to link to their content, as it claims it will not pay anyone to be featured in their search results. Instead it is giving more control to publisher as to how Google News displays information in Europe - e.g. snippets of news articles. Goole is by default removing snippets, and publishers must voluntarily opt-in. France and Germany's major publishers are fighting back against Google refusal to pay them when their content appears in its search index.

7.4. Innovation and reuse

A typical issue with patents and copyrights is that they affect incentives to build on prior work, as that work is protected. Williams (2013) shows that intellectual property has reduced research on the sequencing of the human genome.

Heald (2009) shows that copyrighted music is less used in the movies than non-copyrighted one. Similarly, Nagaraj (2017) looks at data from Google Books and Wikipedia to find that the protection of old sports magazines reduces the quality of Wikipedia pages decades later.

8. Productivity and the labour market

> You can see the computer age everywhere but in the productivity statistics.
>
> Solow (1987)
>
> We see transformative new technologies everywhere but in the productivity statistics.
>
> Brynjolfsson et al. (2019)

As Solow famously pointed out in a book review for the New York Times, the technological revolution brought forth by the advent of computing, which has had profound effects on our methods of production, has been accompanied by a slowing-down of productivity growth.

Brynjolfsson et al. (2019) make a parallel with what Solow brought up more than thirty years ago: the progress of technology is astonishing (artificial intelligence to name only one) and can affect all aspects of our lives, including production, yet productivity growth has been slowing down over the past ten years.

However, while the digital age may have proven to be, from a statistical point of view, disappointing, Brynjolfsson and Smith (2000) offer a possible hopeful resolution: it takes "considerable time to be able to sufficiently harness new technologies," meaning that their impact on productivity growth might be reflected much later in statistics. They argue that two factors are required for current new technologies to have an impact on aggregate productivity statistics: first, there needs to be a sufficient stock of such new technologies; and second, there needs to be an array of complementary production processes that can use those new technologies.

8.1. Firm level productivity

Despite the decline in productivity growth documented by Brynjolfsson and Smith (2000), there are many studies documenting the correlation between Information and Communication Technologies (ICTs) and productivity at the firm level. The evidence suggests that both are positively correlated, albeit with significant heterogeneities. Evidence on causation, however, is more limited.

Brynjolfsson and Hitt (2003) use standard growth accounting methodology to examine the relationship between the growth in computer spending and the productivity growth for 527 large firms between 1987 and 1994. They find that over the short run, computers do not contribute to productivity growth. However, they have a significant impact on productivity over the long run. Hempell (2005), using data from German and Dutch firms from 1998, finds significant effects of ICTs on productivity.

Bloom et al. (2012) note that a significant part of the recent productivity growth in the US is due both to the IT sector and to sectors that use IT as an input. On the other hand, in the EU, the IT sector has also shown a significant productivity growth, while this was not the case for sectors using IT as an input. They suggest two possible reasons for that: first, US firms can take better advantage of falling IT prices, through tougher market competition, lower regulation and larger market size; second, the way US firms are managed may allow them to better reap the benefits of IT. They confirm this hypothesis by comparing US owned companies operating in Europe with European owned companies, noting that US owned companies in Europe obtain significantly higher productivity gains from IT than non-US companies.

Using data from 1980 to 2009, and focusing on the manufacturing sector, Acemoglu et al. (2014) find very limited IT-driven productivity growth. As discussed by Brynjolfsson and Smith (2000), it may still be early to observe the impact of new technologies on productivity.

8.2. Labour markets

> The world of A.D. 2014 will have few routine jobs that cannot be done better by some machine than by any human being.
>
> Isaac Asimov, 1964

When asked by the New York Times about his predictions as to how the world would be fifty years down the road, Isaac Asimov foresaw that machines would play a significant role in the labour force.

More than thirty years before, Keynes also predicted that the rapid rise of automation would bring “technological unemployment.”

Nowadays, the fear that robots will take over human jobs is still prevalent, impacting highly-skilled workers the least. This is reflected in the data, as the twentieth century has seen significant shifts in labour demand towards more skilled and educated workers. (See for example Autor et al. (1998).)

One of the reasons put forward is *skill-biased technical change* (SBTC): the advent of new technologies has shifted labour demand towards high-skilled and highly educated workers.

Bresnahan et al. (2002) argue that technology not only has direct effects on the labour force, but also indirect ones: the usage of IT technologies is encompassed in a more global transformation of the workplace, accompanied with other innovations, organisational changes and product innovations.

However, the impact of technology does not simply discriminate between high and low-skilled workers. Instead, as Autor et al. (2003) show, technology discriminates between routine and non-routine tasks: looking at data ranging from 1960 to 1998, they find that computer capital can substitute for human labour in performing routine tasks, while it can complement human labour for more complex, non-routine tasks. While their model explains more than half of the shift in the labour demand towards a college-educated workforce, it shows evidence of job polarization: an increase in demand for the highly educated at the expense of the middle educated, with little effect on low-educated workers.

Goos and Manning (2007), looking at British data from 1979 to 1999, also find evidence of job polarization following the advent of information and communications technologies, with a falling demand for middling jobs.

Similarly, Michaels et al. (2014) look at data ranging from 1980 to 2004 and find that industries with faster ICT growth has shifted labour demand from middle-educated workers to highly educated ones.

One of the first studies that aims at documenting the general equilibrium effects of robotisation on employment and wages is Acemoglu and Restrepo (2020), which

uses data ranging from 1993 to 2014. At the local level, they find that exposure to robots has a strong negative impact on the employment-to-population ratio and on the average wage. However, the use of robots in production has benefits on a national level, through lower prices for goods produced by robots and through shared capital income gains. Taking those into account, Acemoglu and Restrepo still find a negative general equilibrium impact of robotisation on employment and wages.

9. Conclusion

As digitisation progresses, costs are reduced and economic incentives are affected. All fields of activity are impacted, and this survey aimed at presenting how this could be the case.

This survey is by no means exhaustive, and one important topic that has not been discussed is antitrust and regulation. Current regulatory policies have been developed with little consideration for network effects and platforms, which are prevalent actors of the digital economy. See for example, Katz and Shapiro (1999), Clemons and Madhani (2010), or Lenard (2011).

Yves Guéron
Assistant Professor, Department of Economics, Seoul National University
Gwanak-ro, Gwanak-gu, Seoul, 08826, South Korea
Phone: (02) 880-6377
E-mail: ygueron@snu.ac.kr

References

Acemoglu, D., D. Dorn, G. H. Hanson, B. Price, et al.(2014): “Return of the Solow paradox? it, productivity, and employment in us manufacturing,” *American*

Economic Review, **104**, **5**, 394–399.

Acemoglu, D. and P. Restrepo(2020): "Robots and jobs: Evidence from US labor markets," *Journal of Political Economy,* **128**, **6**, 2188–2244.

Acquisti, A. and H. R. Varian(2005): "Conditioning prices on purchase history," *Marketing Science,* **24**, **3**, 367–381.

Aguiar, L. and J. Waldfogel(2018): "As streaming reaches flood stage, does it stimulate or depress music sales?," *International Journal of Industrial Organization,* **57**, 278–307.

Armstrong, M.(2006): "Competition in two-sided markets," *The RAND Journal of Economics,* **37**, **3**, 668–691.

_____(2013): "A more general theory of commodity bundling," *Journal of Economic Theory*, **148**, **2**, 448–472.

Arthur, W. B.(1989): "Competing technologies, increasing returns, and lock-in by historical events," *The Economic Journal,* **99**, **394**, 116–131.

_____(1996): "Increasing returns and," *Harvard Business Review,* **74**, **4**, 100–109.

Athey, S., C. Catalini, and C. Tucker(2017): "The digital privacy paradox: Small money, small costs, small talk," Technical report, National Bureau of Economic Research.

Autor, D. H., L. F. Katz, and A. B. Krueger(1998): "Computing inequality:

have computers changed the labor market?," *The Quarterly Journal of Economics,* **113**, **4**, 1169–1213.

Autor, D. H., F. Levy, and R. J. Murnane(2003): "The skill content of recent technological change: An empirical exploration," *The Quarterly journal of economics,* **118**, **4**, 1279–1333.

Bae, S. H. and J. P. Choi(2006): "A model of piracy," *Information Economics and Policy,* **18**, **3**, 303–320.

Bakos, Y. and E. Brynjolfsson(1999): "Bundling information goods: Pricing, profits, and efficiency," *Management Science,* **45**, **12**, 1613–1630.

Baye, M. R. and J. Morgan(2001): "Information gatekeepers on the internet and the competitiveness of homogeneous product markets," *American Economic Review,* **91**,

3, 454–474.

Baye, M. R., J. Morgan, and P. Scholten(2004): "Price dispersion in the small and in the large: Evidence from an internet price comparison site," *The Journal of Industrial Economics,* **52**, **4**, 463–496.

Blake, T., C. Nosko, and S. Tadelis(2015): "Consumer heterogeneity and paid search effectiveness: A large-scale field experiment," *Econometrica,* **83**, **1**, 155– 174.

Bloom, N., R. Sadun, and J. Van Reenen(2012): "Americans do it better: Us multinationals and the productivity miracle," *American Economic Review,* **102**, **1**, 167–201.

Bork, R. H.(1978): "*The antitrust paradox: A policy at war with itself*," Volume 79. Basic books New York.

Brandimarte, L. and A. Acquisti(2012): "The economics of privacy. In M. Peitz and J. Waldfogel (Eds.)," *The Oxford handbook of the digital economy*, Chapter 20, pp. 547–571, Oxford University Press.

Bresnahan, T. F., E. Brynjolfsson, and L. M. Hitt(2002), "Information technology, workplace organization, and the demand for skilled labor: Firm-level evidence," *The Quarterly Journal of Economics,* **117**, **1**, 339–376.

Brynjolfsson, E. and L. M. Hitt(2003): "Computing productivity: Firm-level evidence," *Review of Economics and Statistics,* **85**, **4**, 793–808.

Brynjolfsson, E., D. Rock, and C. Syverson(2019): "Artificial intelligence and the modern productivity paradox," *The Economics of Artificial Intelligence: An Agenda*, **23**.

Brynjolfsson, E. and M. D. Smith(2000): "Frictionless commerce? a comparison of internet and conventional retailers," *Management Science,* **46**, **4**, 563–585.

Burdett, K. and K. L. Judd(1983): "Equilibrium price dispersion," *Econometrica,* 955–969.

Caillaud, B. and B. Jullien(2001): "Competing cybermediaries," *European Economic Review,* **45**, **4-6**, 797–808.

_____(2003): "Chicken & egg: Competition among intermediation service providers," *The RAND Journal of Economics*, 309–328.

Cairncross, F.(1997): "*The death of distance: how the communications revolution will change our lives*," Number C20-21, Harvard Business School.

Calzolari, G. and A. Pavan(2006): "On the optimality of privacy in sequential contracting," *Journal of Economic Theory,* **130**, **1**, 168–204.

Campbell, J., A. Goldfarb, and C. Tucker(2015): "Privacy regulation and market structure," *Journal of Economics & Management Strategy,* **24**, **1**, 47–73.

Chen, Y.(1997), "Equilibrium product bundling," *Journal of Business*, 85–103.

Clemons, E. K. and N. Madhani(2010): "Regulation of digital businesses with natural monopolies or third-party payment business models: Antitrust lessons from the analysis of google," *Journal of Management Information Systems,* **27**, **3**, 43–80.

Crémer, J., P. Rey, and J. Tirole(2000): "Connectivity in the commercial internet," *The Journal of Industrial Economics,* **48**, **4**, 433–472.

Diamond, P. A.(1971): "A model of price adjustment," *Journal of Economic Theory,* **3**, **2**, 156–168.

Edelman, B.(2009): "Priced and unpriced online markets," *Journal of Economic Perspectives,* **23**, **3**, 21–36.

Ellison, G. and S. F. Ellison(2005): "Lessons about markets from the internet," *Journal of Economic Perspectives,* **19**, **2**, 139–158.

_____(2009): "Search, obfuscation, and price elasticities on the internet," *Econometrica,* **77**, **2**, 427–452.

Farrell, J. and G. Saloner(1985): "Standardization, compatibility, and innovation," *The RAND Journal of Economics*, 70–83.

Forman, C., A. Ghose, and A. Goldfarb(2009): "Competition between local and electronic markets: How the benefit of buying online depends on where you live," *Management Science,* **55**, **1**, 47–57.

Fudenberg, D. and J. Tirole(2000): "Customer poaching and brand switching," *The RAND Journal of Economics*, 634–657.

Ghosh, R. A. and V. V. Prakash(2000): "The orbiten free software survey," *First Monday,* **5**, **7**.

Goldfarb, A. and C. Tucker(2011a): "Online display advertising: Targeting and

obtrusiveness," *Marketing Science,* **30**, **3**, 389–404.

_____(2011b): "Privacy regulation and online advertising," *Management Science,* **57**, **1**, 57–71.

Goos, M. and A. Manning(2007): "Lousy and lovely jobs: The rising polarization of work in Britain," *The Review of Economics and Statistics,* **89**, **1**, 118–133.

Hart, O. D. and J. Tirole(1988): "Contract renegotiation and coasian dynamics," *The Review of Economic Studies,* **55**, **4**, 509–540.

Heald, P. J.(2009): "Does the song remain the same-an empirical study of bestselling musical compositions (1913-1932) and their use in cinema (1968-2007)," *Case Western Reserve Law Review,* **60**, **1**.

Hempell, T.(2005): "What's spurious, what's real? measuring the productivity impacts of ict at the firm-level," *Empirical Economics,* **30**, **2**, 427–464.

Hermalin, B. E. and M. L. Katz(2006): "Privacy, property rights and efficiency: The economics of privacy as secrecy," *Quantitative Marketing and Economics,* **4**, **3**, 209–239.

Holmström, B.(1999): "Managerial incentive problems: A dynamic perspective," *The review of Economic Studies,* **66**, **1**, 169–182.

Hotelling, H.(1929): "Stability in competition," *Economic Journal,* **39**, **153**, 41–57.

Janssen, M. C. and J. L. Moraga-González(2004): "Strategic pricing, consumer search and the number of firms," *The Review of Economic Studies,* **71**, **4**, 1089–1118.

Johnson, G.(2013): "The impact of privacy policy on the auction market for online display advertising," Working paper

Katz, M. L. and C. Shapiro(1985): "Network externalities, competition, and compatibility," *The American Economic Review,* **75**, **3**, 424–440.

_____(1999): "Antitrust in software markets," In *Competition, Innovation and the Microsoft monopoly: Antitrust in the digital marketplace*, pp. 29–81, Springer.

Lenard, T. M.(2011): "Introduction: Antitrust and the dynamics of competition in high-tech industries," *Review of Industrial Organization*, 311–317.

Lenard, T. M. and P. H. Rubin(2010): "In defense of data: Information and the costs of privacy," *Policy & Internet,* **2**, **1**, 149–183.

Lendle, A., M. Olarreaga, S. Schropp, and P.-L. Vézina(2016): "There goes gravity: ebay and the death of distance," *The Economic Journal,* **126**, **591**, 406–441.

Lerner, J. and J. Tirole(2002): "Some simple economics of open source," *The Journal of Industrial Economics,* **50**, **2**, 197–234.

Lewis, R. A. and D. H. Reiley(2014): "Online ads and offline sales: measuring the effect of retail advertising via a controlled experiment on yahoo!," *Quantitative Marketing and Economics,* **12**, **3**, 235–266.

Liebowitz, S. J.(2008): "Research note—testing file sharing's impact on music album sales in cities," *Management Science,* **54**, **4**, 852–859.

MacMinn, R. D.(1980): "Search and market equilibrium," *Journal of Political Economy,* **88**, **2**, 308–327.

McAfee, R. P.(1995): "Multiproduct equilibrium price dispersion," *Journal of Economic Theory,* **67**, **1**, 83–105.

McAfee, R. P., J. McMillan, and M. D. Whinston(1989): "Multiproduct monopoly, commodity bundling, and correlation of values," *The Quarterly Journal of Economics,* **104**, **2**, 371–383.

Michaels, G., A. Natraj, and J. Van Reenen(2014): "Has ict polarized skill demand? evidence from eleven countries over twenty-five years," *Review of Economics and Statistics,* **96**, **1**, 60–77.

Miller, A. R. and C. Tucker(2009): "Privacy protection and technology diffusion: The case of electronic medical records," *Management Science,* **55**, **7**, 1077– 1093.

_____(2011): "Can health care information technology save babies?" *Journal of Political Economy,* **119**, **2**, 289–324.

Mills, B. (2010): "Television wildlife documentaries and animals' right to privacy," *Continuum,* **24**, **2**, 193–202.

Nagaraj, A.(2017): "Does copyright affect reuse? evidence from google books and Wikipedia," *Management Science,* **64**, **7**, 3091–3107.

Nalebuff, B.(2004): "Bundling as an entry barrier," *The Quarterly Journal of Economics,* **119**, **1**, 159–187.

Orlov, E.(2011): "How does the internet influence price dispersion? evidence from the

airline industry," *The Journal of Industrial Economics,* **59**, **1**, 21–37.

Peukert, C., J. Claussen, and T. Kretschmer(2017): "Piracy and box office movie revenues: Evidence from megaupload," *International Journal of Industrial Organization,* **52**, 188–215.

Posner, R. A.(1978): "Privacy, secrecy, and reputation," *Buffalo Law Review,* **28**, **1**.

Reimers, I.(2016): "Can private copyright protection be effective? evidence from book publishing," *The Journal of Law and Economics,* **59**, **2**, 411–440.

Reinganum, J. F.(1979): "A simple model of equilibrium price dispersion," *Journal of Political Economy,* **87**, **4**, 851–858.

Rochet, J.-C. and J. Tirole(2003): "Platform competition in two-sided markets," *Journal of the European Economic Association,* **1**, **4**, 990–1029.

_____(2006): "Two-sided markets: a progress report," *The Rand Journal of Economics,* **37**, **3**, 645-667.

Rosenthal, R. W.(1980): "A model in which an increase in the number of sellers leads to a higher price," *Econometrica*, 1575–1579.

Rothschild, M. (1973): "Models of market organization with imperfect information: A survey," *Journal of Political Economy,* **81**, **6**, 1283–1308.

Salop, S. and J. Stiglitz(1977): "Bargains and ripoffs: A model of monopolistically competitive price dispersion," *The Review of Economic Studies,* **44**, **3**, 493–510.

Shapiro, C. and H. R. Varian(1998): "*Information rules: a strategic guide to the network economy*," Harvard Business Press.

Shiller, B. and J. Waldfogel(2011): "Music for a song: an empirical look at uniform pricing and its alternatives," *The Journal of Industrial Economics,* **59**, **4**, 630–660.

Shiller, B., J. Waldfogel, and J. Ryan(2018): "The effect of ad blocking on website traffic and quality," *The RAND Journal of Economics,* **49**, **1**, 43–63.

Solow, R. M.(1987, July): "We'd better watch out," *New York Times Book Review,* **36**.

Stigler, G. J.(1961): "The economics of information," *Journal of Political Economy,* **69**, **3**, 213–225.

Streitfeld, D.(2000): "On the web price tags blur: What you pay could depend on who you are," *The Washington Post* (September 27).

Taylor, C. R.(2004): “Consumer privacy and the market for customer information,” The *RAND Journal of Economics*, 631–650.

Tucker, C. E.(2014): “Social networks, personalized advertising, and privacy controls,” *Journal of Marketing Research,* **51**, **5**, 546–562.

Varian, H. R.(1980): “A model of sales,” *The American Economic Review,* **70**, **4**, 651–659.

Villas-Boas, J. M.(1999): “Dynamic competition with customer recognition,” *The Rand Journal of Economics*, 604–631.

_____(2004): “Price cycles in markets with customer recognition,” *The RAND Journal of Economics*, 486–501.

Waldfogel, J.(2010): “Music file sharing and sales displacement in the iTunes era,” *Information Economics and Policy,* **22**, **4**, 306–314.

_____(2012): “Copyright protection, technological change, and the quality of new products: Evidence from recorded music since Napster,” *The Journal of Law and Economics,* **55**, **4**, 715–740.

Warren, S. D. and L. D. Brandeis(1890): “Right to privacy,” *Harvard Law Review,* **4**, 193.

Whinston, M. D.(1990): “Tying, foreclosure, and exclusion,” *American Economic Review,* **80**, **4**, 837–859.

Williams, H. L.(2013): “Intellectual property rights and innovation: Evidence from the human genome,” *Journal of Political Economy,* **121**, **1**, 1–27.

Xu, L., T. Nian, and L. Cabral(2019): “What makes geeks tick? a study of stack overflow careers,” *Management Science*, **66**, **2**, 587-604.