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Consequences of Resorting to Fines and Investments to Regulate Data Portability

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Many jurisdictions have implemented data portability regulation (DPR) that requires that Data Controllers (DCs) to enable users to download their personal data so that they can port their data to competing DCs. The intention of DPR is to return partial control of data to users, improve user choice of DCs, and increase DC participation in the market and reduce industry concentration. To achieve this, if non-monetary corrective measures (e.g., warnings, orders to comply) to obtain portability compliance fails, then DPR allows policy-makers to impose fixed or variable (based on revenue) fines on DCs that do not comply. Additionally, policy-makers may invest to decrease compliance costs for DCs. We model this interaction as a two-stage game where in the first stage the policy-maker sets fines and makes investments. In the second stage DCs decide whether to participate in the market, and if so whether to comply with DPR. Contrary to the current regulatory objectives, we find that with partial compliance both fines and investment decrease DC participation and increase industry concentration. Comparing the use of fines and investment to achieve a predetermined level of compliance, the use of fixed fines has a smaller (larger) collateral effect on concentration (participation) than either variable fines or investment. Once all DCs that participate comply – full compliance – then additional investment increases participation. Moreover, full compliance and full participation can occur only if there is a DPR-induced demand expansion, such as from multi-homing, and investment is the only instrument that can attain this outcome.

Keywords: Data Portability, Regulation, Fines, Investments, Data Controllers.

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1. Introduction

Data Controllers (DCs) such as Facebook (in social media) and Strava (in fitness apps) are able to leverage the personal data of users to provide personalized value-added features[1]. This personal data provides a competitive advantage for DCs. For example, Facebook uses personal data to provide

[1] Following terminology from the Council of European Union (2016), we define a data controller (DC) as the body which "determines the purposes and means of processing of personal data"

customized news feeds, friend suggestions, and auto-tagging of friends. Facebook's capability is in monetizing this use of personal data through targeted advertising to users. In fitness apps Strava provides individual activity and progress reports, and exploits this capability to convert users to paying subscribers and charge a higher subscription price. Competitors to Facebook – such as Flickr, X, and Gettr; and to Strava – such as Komoot and Endomondo; are at a disadvantage in providing the same level of service without access to a given user's personal data.

Some policy-makers view this as user lock-in where a DC's use of user personal data hinders users from moving to another DC that they might otherwise prefer (European Political Strategy Centre 2017). This lock-in is thought to have undesirable implications for DC participation, industry concentration, user surplus, and welfare. In part, the E.U. passed the General Data Protection Regulation (GDPR, Council of European Union 2016) to alleviate these issues – this regulation requires that DCs allow users to download their personal data and easily port it to a competing DC. DCs that violate DPR can be subject to fines of up to 20M EUR, or variable fines of up to 4% of the total worldwide revenue. The State of California's Consumer Privacy Act (CCPA, California State Legislature 2018) has similar data portability requirements from DCs. We refer to such regulatory interventions requiring DCs to enable data portability as *data portability regulations* (DPR).

Moreover, policy-makers plan to invest in processes and standards for porting of data to decrease compliance costs for DCs. For example, the Digital Markets Act in the E.U. specifies future investments in developing tools and specialized standards for data portability, which are to be developed by European standardization bodies (Council of European Union 2022, Article 96). Current examples of investments to decrease the cost of DPR compliance include government-developed tools to port energy consumption data from smart meters (OECD 2021, p. 37) and transfer of banking data via open banking (Competition and Markets Authority 2021, Australian Banking Association 2025).

The U.S. ACCESS Act of 2021 mandates analogous regulations on data portability, the objectives of which are similar to the GDPR and the CCPA. The act has been ordered to be introduced in the U.S. House of Representatives (United States House Committee on the Judiciary 2021), which adds urgency to the need for an evaluation of the effects of DPR. Apart from providing context by explaining the mechanism through which fines and investments affect participation, concentration, compliance, and welfare, we provide novel and actionable insights to policy-makers by answering the following research questions. First, under what conditions may an instrument (e.g., fines, investment) increase or decrease participation? Second, which of fixed fines or variable fines to enforce DPR or investments made to decrease compliance costs have larger collateral effects on participation and on industry concentration?

We follow DPR policy-makers and define a DC as compliant with DPR if it allows its users to download their data so that they can port it to other DCs (Council of European Union 2016, Article 20). For example, Strava allows bulk download of user activities through the GPX standard, which captures all of the activity information in a single file including route map, speed, and heart rate data (Strava 2024). A non-compliant DC does not allow its users to download their data. By requiring that DCs make their data easily portable to competing DCs, DPR is expected to diminish lock-in and restore competition in the digital economy by giving a measure of control over personal data to users. The basis for imposing DPR with fines for at-fault DCs and investments to decrease compliance costs is that portability hinders the market power of large DCs, increasing participation and decreasing concentration (Council of European Union 2016, Article 4, United States House of Representatives 2020, p. 20 and pp. 40-44, Cyphers and O'Brien 2018, Seamans and Bytes 2018).

We use a general model to study the implications of DPR where DCs differ in their capability and decide on their output and compliance. We define capability as the ability to generate more revenue per unit of output. Although we illustrate our setting using the social media and fitness tracking industries, our analysis applies to any set of competing DCs that derive value from personal data. The policy-maker implements DPR with the help of three instruments: fixed and variable fines for non-compliant DCs, and investment to reduce the cost of compliance for DCs. Each DC maximizes profit by choice of output, and decides if it should participate in the market, and whether to comply with DPR or not comply and pay the fine. Then we characterize the effects of policy-maker instruments on the structure of the industry, including on participation, concentration, and compliance, as well as on consumer surplus and social welfare.

We consider four effects on DCs from the imposition of DPR, of which the first two pertain to non-compliant DCs and the next two apply to compliant DCs. The first effect is fixed and variable (as proportion of revenue) fines for non-compliant DCs. The second effect is the loss in revenue resulting from a reduction in appeal of non-compliant DCs due to the lack of portability as a feature. This effect is moderated by the proportion of compliant DCs. The third effect is the gain or loss in revenue of compliant DCs due to the ability of users to port their data. The fourth effect is the cost of compliance for compliant DCs, which can be reduced by policy-maker investment.

Contrary to the intention of the regulation, we find that these regulations and related instruments may instead decrease participation and increase concentration. We begin by describing the broad effects of fines and investments on participation and concentration before describing our findings related to the main research questions outlined above.

On participation: Not only do we find that with partial compliance fixed fines and variable fines decrease participation from DCs, but that investments also decrease participation: the least capable DCs exit, the moderately capable DCs participate but do not comply with DPR and pay the fines, and the most capable DCs participate and comply. This is in stark contrast with the policy objective of increased participation. The mechanism is not through disproportionate costs of compliance for less capable DCs, extent of data collection, or what data can be ported as seen in prior literature, but rather because portability itself may be detrimental to the demand generated by less capable DCs.

On concentration: We also find that each instrument further decreases the output of DCs that have smaller market shares and increases the aggregate output of DCs that have greater market shares, thereby increasing industry concentration. Again, this is in contrast with the policy objective of lessened industry concentration. The increase in concentration is independent of the decrease in participation and is due to the effect on demand of a fundamental and underlying process that is specific to some DCs enabling portability.

Thus, resorting to fines and investments to increase compliance with DPR can come with the collateral effect of decreasing participation and increasing concentration. We now turn our attention to addressing our primary research questions.

On whether an instrument can increase participation: Firstly, we find that once full compliance is achieved the effect of investments on participation reverses, and investments now increase participation. Thus, the elimination of non-compliance is required for investment to increase participation. Secondly, we find that the policy-maker cannot necessarily achieve full compliance and full participation with the instruments available. Instead, market expansion is necessary to achieve this outcome. Market expansion can happen when users multi-home so that they continue to consume services from the focal DC as well as from the DC that they port their data to. The market can also expand when users from another industry port their data to the focal industry, thereby consuming services from both industries. In other words, multi-homing softens the collateral effects of fines and investment on participation. Conditional on market expansion, the only instrument that can achieve full compliance and full participation is investment.

On comparison of instruments: The effect of each instrument on participation and concentration differs. To achieve any pre-determined level of compliance, fixed fines have a larger collateral effect on participation as compared to variable fines and to investments. On the other hand, both variable fines and investments have a larger collateral effect on concentration as compared to fixed fines. Thus, the policy-maker has to choose between lesser participation or greater industry concentration when deciding which instrument to employ.

Our results hold irrespective of network effects and the degree of porting effectiveness, and consequently apply to a wide array of industry settings. Moreover, our results are robust to whether users single-home or multi-home. Indeed, full compliance and full participation mentioned above can only be achieved if the gains from portability to the least capable DC are non-negative, which can occur when the market expands, for instance, when users multi-home.

2. Literature Review

Firms in many industries use customer data to improve their products and attract more customers. This provides a competitive advantage to incumbent firms (Hagiu and Wright 2023), which policy-makers aim to address through DPR (Council of European Union 2016, California State Legislature 2018). The academic research on DPR finds mixed results. Using arguments in competition law, Graef et al. (2013) and Swire and Lagos (2012) suggest that DPR could stifle competition, innovation, and investments, and go on to suggest that DPR can lead to a decrease in consumer welfare. Further, Lam and Liu (2020) find that if DPR encourages users to share more data with their current DC because of the prospect of easier porting, then this could strengthen the incumbent and raise the entry barrier for new DCs. Christensen et al. (2013) estimate the financial impact of data protection regulation, including DPR, on firms within the E.U.. They consider the costs of compliance and lack of access to data and estimate a significant negative impact on firms and the economy as a result of enforcement of DPR. Wohlfarth (2019) considers the impact of DPR on the amount of data that DCs collect on users, finding that in some situations the increase in data collection due to DPR enforcement may harm users. We extend this stream of literature and uncover the mechanisms by which fines and investments influence a DC's decisions about output levels, DPR compliance, as well as competition, user surplus, and DC surplus. We find that fines on DCs for violations of DPR and investments to decrease compliance costs can have unintended implications for the structure of the industry. Contrary to the previous literature, our findings do not rely on the financial costs of compliance that disproportionately impact smaller firms or the impacts through changes in data collection. Instead, we uncover mechanisms that are mainly due to the impact of regulation on DC revenues as result of their compliance decisions.

Our analysis is also related to the literature on asset ownership, which we extend to include data as an asset. Hart and Moore (1990) show that, in the presence of incomplete contracts, asset ownership should reside with the party that is most able to generate value from it. If this is not the case, then there is resulting under-investment. Brynjolfsson (1994) and Bakos and Nault (1997) apply the Hart-Moore framework to information assets and electronic networks, respectively. Along with the right to data portability, GDPR provides users with the right to access, erase, and restrict the processing of their data by any DC (Council of European Union 2016). Given that Hart and

Moore (1990) define asset ownership as the right to exclude others from its use, GDPR can be viewed as a partial transfer of data asset ownership from DCs to users, which may impact DC investments. Similarly, the actions of DCs can be evaluated through the lens of the principal-agent model (Hölmstrom 1979, Lambert 2001). The principal (user) assigns an agent (DC) to create value from their data – this value is then shared between the user and DC. With DPR, the nature of the contract between the two parties changes – the user has the ability to port their data to a different DC, thereby potentially changing the actions of the DC.

The structure of our assumptions is related to Nault and Zimmermann (2019), where DC (edge provider in their model) costs and profits change with decisions made in earlier stages. Our use of inverse demand (price) and profit functions in a Cournot setting is related to an established stream of research that enables a focus on a firm's production choices and interactions between external parties and the firm (Jehle and Reny 2011, pp. 147-150, Tirole 1988, pp. 218-226, Nault 1996, Levi and Nault 2004, Nault and Zimmermann 2019). Our theoretical contribution to this literature is the measurement of change in revenues when DPR is implemented, which enable us to examine the intricacies of the impact of DPR on the industry.

Finally, our work contributes to the emerging literature on the impact of data on competition. Braulin and Valletti (2016) consider the exclusivity of data sales by a monopolist data broker to two competing retailers and find that the data broker sells data exclusively to either the high-quality or the low-quality retailer. Kim et al. (2019) study the impact of data on horizontal mergers and its implications for consumer surplus. de Corniere and Taylor (2020) propose a competition-in-utilities framework for studying the impact of data on competition, specifically in the contexts of data-based algorithms, targeted advertising, price discrimination, and data-driven mergers. There is also an established literature on the competitive advantages that firms can generate from customer data and its effects on competition between firms (Farboodi et al. 2019, Hagiu and Wright 2023). This stream focuses on the competitive effects from exclusive access to data, but does not reserve a right for customers to access or port their data. We extend this literature by considering the implications of enabling users to port their data on competition, concentration, compliance, and welfare.

3. Notation and Assumptions

Following Dixit and Stiglitz (1977), Melitz (2003) and Nocco et al. (2014), we analyze an industry that consists of competing heterogeneous DCs. We use the term *capability*, which we define to be a DC's ability to generate more revenue per unit of output, and which describes the dimension along which DCs are distributed. This is consistent with a widely used measure in media and other industries – average revenue per user (ARPU, Kenton 2022, Deshpande and Narahari 2014, Rodriguez 2019). For instance, Gal-Or et al. (2018) model firms that have different targeting capabilities, Cho et al. (2016) model firms that differ in the revenue rate per unit of content, and Mei et al. (2022) model firms that differ in their ARPU. In our model, capability is a representation of a DC's production technology, marketing expertise, and/or ability to estimate user preference, and can include product quality, process productivity and efficiency, expertise in application development, and expertise in data analytics and user acquisition, all of which lead to higher ARPU. We denote DC capability by θ, which is normalized to be in $[0,1]$, and is uniformly distributed, $g(\theta) \sim U[0,1]$, so that the density is positive over its support, $g(\theta) > 0 \,\forall\, \theta \in [0,1], G(0) = 0$, and $G(1) = 1$. The policy-maker knows the distribution of θ but cannot infer the capability of a specific DC. Other than capability, we allow users to have horizontal preferences for DCs. That is, users have a common ranking of DCs by capability but have different rankings of DCs on other dimensions so that users choose different DCs in equilibrium.

In the context of social media and fitness tracking, more capable DCs may provide better services and user interface to users or be better at marketing and user acquisition. For example, Facebook is dominant in this respect compared to its rivals (Rodriguez 2019, Goldman 2016). Competitors to Facebook include well known DCs such as X and Flickr, as well as lesser known DCs such as Foursquare Swarm and Gettr which provide differentiated services, content, and connectivity making them the preferred choice for some users. Similar to Facebook, Strava is considered a dominant DC in its industry due to its superior interface, ease of use, and marketing (McGuire 2021). Even then, many users prefer Komoot for fitness tracking over Strava based on their preferences and tastes for aspects such as design, user interface, and connectivity.

DCs provide products or services to users. We denote a generic unit of revenue-generating output, that we hereafter refer to as *output*, by $x \in [0, \bar{x}]$. An example of output can be the number of users (Yoo et al. 2007) or user impressions and clicks which are monetized by DCs on a cost per impression or cost per click basis. We denote DC output with the subscript θ so that x_θ represents output from the DC with capability θ. We refer to the vector of DC outputs over the support of θ as $\vec{x} = (x_\theta, \vec{x}_{\setminus\theta})$ where $\vec{x}_{\setminus\theta}$ is a vector of outputs from DCs other than θ.

For each DC the revenue is given as $x_\theta r(\theta, x_\theta, \vec{x}_{\setminus\theta})$ where $r(\theta, x_\theta, \vec{x}_{\setminus\theta}) \in \mathbb{R}$ is the inverse demand (price) function. The inverse demand function specifies the relationship between price and output for a given θ. For example, for Strava, the inverse demand function specifies the subscription price that is required to achieve a desired output in terms of users; whereas for Facebook, it specifies the ad density and data disclosure in secondary markets in lieu of prices. This inverse demand function depends on capability, own output, and output from other DCs. We take the inverse demand of a DC with zero capability as zero, $r(\theta = 0, x_\theta, \vec{x}_{\setminus\theta}) = 0$. Our first assumption defines reasonable properties of $r(\theta, x_\theta, \vec{x}_{\setminus\theta})$. For more information on inverse demands, we refer the reader to the established stream of work on the use of inverse demand and profit functions in a Cournot setting

(Jehle and Reny 2011, pp. 147-150, Tirole 1988, pp. 218-226, Nault 1996, Levi and Nault 2004, Nault and Zimmermann 2019). We provide a parameterized model of user decision making which results in our assumed inverse demands in Appendix A.

ASSUMPTION 1 **(Inverse Demand)**. *(a) DC inverse demand is increasing in capability, decreasing and concave in output, and weakly decreasing in output from other DCs; (b) marginal inverse demand is increasing in capability.*

Mathematically the parts of Assumption 1 are

$$(a)\ \frac{\partial r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial\theta} > 0,\ \frac{\partial r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_\theta} < 0,\ \frac{\partial^2 r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_\theta^2} \leq 0,\ \frac{\partial r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_{\setminus\theta}} \leq 0;$$
$$(b)\ \frac{\partial^2 r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial\theta\partial x_\theta} \geq 0.$$

In Assumption 1(a), we take inverse demand to be decreasing and concave in output. Further, inverse demand is decreasing in other DCs' output as is characteristic in Cournot competition (pp. 221-224 Tirole 1988, Bhargava 2021a). Allowing DC inverse demand to decrease in output from other DCs means that the resulting profit function can accommodate almost any form of DC competition as we show in Section 4.1.

Assumption 1(a) also defines the effect of DC capability in our model: users prefer more capable DCs and such DCs have higher revenue per unit of output as per our definition of capability. This is effectively a demand shift whereby a higher capability DC receives higher revenue per unit of output at each level of output. In Assumption 1(b) more capable DCs generate greater marginal inverse demand. See Appendix B.1 for an example of the effect of capability on inverse demand.

Network Effects As a demand-side network effect, the presence of demand from users makes a DC more desirable to other users. This network effect can exist in a one-sided market where the value enjoyed by a user depends on the number of other users on the DC (Asvanund et al. 2004, Gu et al. 2007). For example, social networks such as Facebook become more desirable as more users join. In an inverse demand function, this can be captured as a positive argument which is increasing in output (Yoo et al. 2007). Thus, this effect softens the standard negative effect of output on inverse demand. In other words, if network effects are large, then the extent to which inverse demand decreases in output is lessened, that is, $\partial r(\theta, x_\theta, \vec{x}_{\setminus\theta})/\partial x_\theta$ becomes less negative. Given that these network effects are such that the inverse demand remains decreasing in output (Bhargava 2021b, Yoo et al. 2007, Economides and Katsamakas 2006, Asvanund et al. 2004), our model captures such demand-side network effects in a general way and our analysis is not impacted by the extent of network effects. A parameterized example of user decision making that demonstrates this and our other assumptions is provided in Appendix A.

3.1. Imposition of DPR: Fines and Investments

As outlined in Section 1, the imposition of DPR has four effects, the first two of which apply to non-compliant DCs. The first is that DCs that do not comply with DPR are fined. Following GDPR and CCPA, we model both fixed fines, $F \in \mathbb{R}_{\geq 0}$, and variable fines as a proportion of revenues, $f \in [0,1]$. The policy-maker chooses the level of fines. There is no fine for compliant DCs. The second effect is that a given DC is less attractive to users if it does not comply compared to if it does, because portability is an additional feature.

The third and fourth effects concern DCs that comply. The third effect is that users using a compliant DC can port their data to another DC. Such porting can be single-homing, in which case the user ports and no longer uses the origin DC; or multi-homing, where the user ports but uses both the origin and destination DCs. Thus, for DCs that comply, there is potentially either decreased demand (users port to other DCs in net) or increased demand (users port from other DCs in net). The fourth effect is the compliance cost that compliant DCs incur, and the policy-maker can invest to decrease this cost.

Pre-DPR, when DCs have not yet enabled portability, given distributions of DCs by capability, an equilibrium occurs when users choose a DC. Post DPR, this equilibrium changes because the user valuation of DCs changes as some DCs comply with DPR. As described above, compliance with DPR implies the provision of the additional feature of portability. This increases the value that a user can gain from each competing compliant DC. We make the reasonable presumption that the compliant DCs' decision to provide the additional feature of portability does not cause users to leave the market.

Compliance or non-compliance results in new inverse demand functions – that is, new prices, after DPR. We denote the *compliant inverse demand* function as $r^c(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta}) \in \mathbb{R}$, which depends on DC capability, the proportion of DCs that comply, where for the moment we use ρ to denote the proportion of DCs that comply, and the output of all DCs. The compliant inverse demand can be higher, lower, or similar to the inverse demand prior to DPR as the third effect described above can cause compliant DCs to lose or gain business to or from other DCs. Similarly, we denote the *non-compliant inverse demand* function as $r^{nc}(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta}) \in \mathbb{R}$, which also depends on DC capability, the proportion of DCs that comply, and the output of all DCs. Non-compliant inverse demand is lower than the inverse demand prior to DPR due to the second effect described above.

Our formulation also incorporates cross-DC network effects whereby the proportion of compliant DCs, ρ, affects inverse demand as portability enables the movement of users among DCs. As the proportion of compliant DCs increases, there is a negative cross-DC network effect on non-compliant DCs because compliant DCs have the added feature of portability. This causes non-compliant inverse demand to decrease. This effect is in total and at the margin as detailed in our Assumption 2 below.

Assumption 2 **(Proportion of Compliant DCs)**. *Non-compliant inverse demand and marginal non-compliant inverse demand are decreasing in the proportion of compliant DCs.*

Mathematically the parts of Assumption 2 are

$$\frac{\partial r^{nc}(\theta,\rho,x_\theta,\vec{x}_{\setminus\theta})}{\partial\rho}<0;\ \frac{\partial^2 r^{nc}(\theta,\rho,x_\theta,\vec{x}_{\setminus\theta})}{\partial\rho\partial x_\theta}\leq 0.$$

Assumption 2 implies that non-compliant DC inverse demand and marginal non-compliant inverse demand decrease in the proportion of compliant DCs because there are more alternative compliant DCs for users to choose from. The lack of portability on the part of non-compliant DCs in conjunction with an increase in the proportion of compliant DCs leads to lower inverse demand for non-compliant DCs. A parameterized example of user decision making that demonstrates this assumption is provided in Appendix A. The proportion of compliant DCs, ρ, is derived endogenously in our model as result of each DC's decision on compliance, as we discuss in Section 4.2.

Business and Compliance Costs: DCs face a *business cost* which depends solely on own output, $C(x_\theta)\in\mathbb{R}_{\geq 0}$. Business costs include costs of business operations, financing, and user acquisition, and are convex (Bhargava 2022, p. 5237). Compliant DCs also face *compliance costs*, $\gamma(x_\theta,I)\in\mathbb{R}_{>0}$, which are costs to enable users to port their data, and where I is investments defined below. Compliance costs include the costs of development of additional processes, database capabilities, and administrative tasks that are needed to comply with the standards and requirements for porting that the policy-maker sets.

As an instrument, the policy-maker can decrease the cost of compliance that DCs incur by investing in standards, protocols, and tools for porting of data. Using the term *investments*, we define $I\in\mathbb{R}_{\geq 0}$ to represent policy-maker investment to decrease compliance costs. These investments may include creating standards, APIs, or platforms for porting of data such as those for porting energy and banking data described in the Introduction, or initiatives similar to Data Transfer Initiative[2] and the Universal Digital Profile[3] developed by the policy-maker. Such investments substitute in part for DC compliance costs. Next, we characterize the two types of DC costs.

Assumption 3 **(Cost)**. *(a) DC compliance costs are decreasing in investments in total and at the margin; and (b) total costs are convex in output.*

Mathematically the parts of Assumption 3 are

$$(a)\ \frac{\partial\gamma(x_\theta,I)}{\partial I}<0,\ \frac{\partial^2\gamma(x_\theta,I)}{\partial I\partial x_\theta}<0;\ (b)\ \frac{\partial^2 C(x_\theta)}{\partial x_\theta^2}+\frac{\partial^2\gamma(x_\theta,I)}{\partial x_\theta^2}>0.$$

[2] `https://dtinit.org/`

[3] `https://techcrunch.com/2018/05/22/the-birth-of-the-universal-digital-profile/`

Assumption 3(a) is the main effect of the investment instrument. Assumption 3(b) takes total costs to be convex in output, implying that acquisition of users becomes harder as more users are acquired, which is a standard assumption. A large proportion of DC costs are typically apportioned to convex costs. For example, Meta reports that in 2021, their costs of revenue, selling and marketing, and general and administrative – typically convex costs – were \$46.5B (Meta Platforms Inc. 2021). At the same time depreciation and amortization related to their capital assets, including technology and buildings – possibly linear or concave costs – were \$8B.

Next we consider the relative effects of capability on compliant versus non-compliant inverse demand, and of output on marginal profits from non-compliance.

Assumption 4 **(Relative Effects)**. *(a) Capability increases compliant inverse demand more than it does non-compliant inverse demand and (b) for a DC that makes identical payoffs from compliance and non-compliance, marginal profits from non-compliance are negative when evaluated at the optimal output from compliance,* x^c_θ.

We use $\Pi^c(\cdot)$ and $\Pi^{nc}(\cdot)$ to denote payoffs from compliance and non-compliance, respectively, the arguments of which are defined later in Section 4.2. Mathematically, Assumption 4 is

$$(a)\ \frac{\partial r^c(\theta,\rho,x_\theta,\vec{x}_{\setminus\theta})}{\partial\theta} > \frac{\partial r^{nc}(\theta,\rho,x_\theta,\vec{x}_{\setminus\theta})}{\partial\theta};$$

$$(b)\ r^{nc}(\theta,\rho,x_\theta,\vec{x}_{\setminus\theta}) + x_\theta\frac{\partial r^{nc}(\theta,\rho,x_\theta,\vec{x}_{\setminus\theta})}{\partial x_\theta} - \frac{\partial C(x_\theta)}{\partial x_\theta}\bigg|_{x_\theta=x^c_\theta} < 0 \quad if\ \Pi^c(\cdot)=\Pi^{nc}(\cdot).$$

From Assumption 1(a), inverse demand increases in capability for both non-compliant and compliant DCs. Given that compliant DCs allow for data portability, they experience additional gains and losses of users. The benefits to users from DCs that comply with DPR also depend on DC capability. In other words, the additional value from portability for compliant DCs is also positive and increasing in capability. Thus, in Assumption 4(a) as capability increases the inverse demand of compliant DCs increases more than that of non-compliant DCs.

Assumption 4(b) states that for a given DC that makes identical payoffs from compliance and non-compliance, it generates negative marginal profit from non-compliance at x^c_θ, the optimal output from compliance. In practice, this assumption implies that for a DC that makes identical payoffs from compliance and non-compliance, the optimal output from non-compliance is smaller than the optimal output from compliance. Moreover, a positive variable fine further decreases marginal revenue, and consequently optimal output from non-compliance. In Appendix B we characterize our inverse demand functions, derive optimal output, and provide a basis for our Assumption 4(b).

Data portability does not enable the perfect transfer of the data that a DC has on a user because some of the richness of, the inferences on, and the social networking aspects of the data

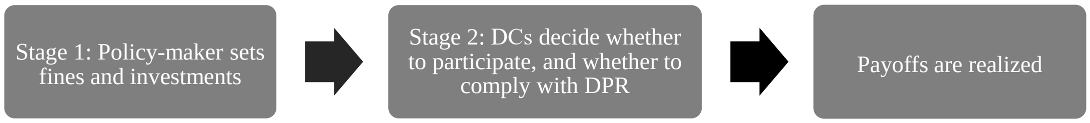


Figure 1 Stages of the game

could be lost during the transfer. This results in varying levels of porting effectiveness: Porting effectiveness increases the value from porting, thereby increasing the compliant inverse demand and decreasing the non-compliant inverse demand. These differences are captured by our general model through the magnitudes of the inverse demand functions, therefore our results and insights are not qualitatively impacted by the level of porting effectiveness.

4. The Effects of Data Portability

Our goal is to explain the effect of fines and investments to encourage data portability on the structure of the DC industry. We analyze a setting where DCs have complete information and we use the terms *participating* to denote DCs that make positive profits and *non-participating* to denote DCs that do not. These latter DCs choose zero output and exit the industry.

We model the process of policy-maker choices of instruments, and DC compliance and participation as a two-stage game where the latter stage has two decisions. In Stage 1 the policy-maker sets fines and investments. In Stage 2, DCs decide on participation, and if they participate, whether to comply with DPR. Finally, payoffs are realized (Figure 1). We work backwards by first solving the DC compliance decision on the basis of optimal production (output) when complying with DPR and not, and next choosing whether to participate. Then we solve the policy-maker's decision on fines and investments, and analyze the effect of fines and investments on consumer surplus (user surplus), producer surplus (DC surplus), and social welfare.

Given that the purpose of DPR is to enable users to port their data to a different DC by increasing the value provided by competing DCs, we first consider the status quo as the equilibrium prior to the imposition of DPR. We then consider the setting where the imposition of DPR results in some users porting to other DCs. Following Tirole (1988, pp. 218-226) and Nault and Zimmermann (2019) we consider quantity (Cournot) competition and use reduced form inverse demand, revenue, and profit functions as the key units of analysis. Just as demand functions abstract away from preferences and utilities, revenue and profit functions abstract away from demand functions, thereby enabling models to focus on a DC's external interactions rather than on how demand aggregates.

4.1. Pre-DPR

Prior to the imposition of DPR each DC maximizes profits by choice of own output,

$$\max_{x_\theta} \Pi(\theta, x_\theta, \vec{x}_{\setminus\theta}) = \max_{x_\theta} [x_\theta r(\theta, x_\theta, \vec{x}_{\setminus\theta}) - C(x_\theta)], \tag{1}$$

and the resulting set of first-order and second-order conditions are

$$\frac{\partial \Pi(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_\theta} = x_\theta \frac{\partial r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_\theta} + r(\theta, x_\theta, \vec{x}_{\setminus\theta}) - \frac{\partial C(x_\theta)}{\partial x_\theta} = 0, \ \forall \ \theta \in [0,1], \quad \textit{and} \tag{2}$$

$$\frac{\partial^2 \Pi(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_\theta^2} = x_\theta \frac{\partial^2 r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_\theta^2} + 2\frac{\partial r(\theta, x_\theta, \vec{x}_{\setminus\theta})}{\partial x_\theta} - \frac{\partial^2 C(x_\theta)}{\partial x_\theta^2} < 0, \ \forall \ \theta \in [0,1].$$

The second order conditions are satisfied by Assumptions 1(a) and 3(b). With concavity of the profit function and output defined in (2) (continuous over a compact set), the first-order conditions lead to pre-DPR Nash equilibrium output for all DCs, $x_\theta^{pre}(\vec{x}_{\setminus\theta})$, where we use the superscript *pre* to denote output pre-DPR. Thus, (2) defines the equilibrium output for all DCs in a generalized Cournot setting where every DC's output affects a given DC's inverse demand.

Next, we move to the analysis post-DPR and study the DC decisions on compliance and participation.

4.2. Compliance

DCs that Comply with DPR: If they comply, then payoffs for DCs are revenues from compliance less business and compliance costs. Compliant DCs are not fined. The payoff maximization problem for a compliant DC is

$$\max_{x_\theta} \Pi^c(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta}, I) = \max_{x_\theta} [x_\theta r^c(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta}) - C(x_\theta) - \gamma(x_\theta, I)]. \tag{3}$$

Using $\Pi^c(\cdot)$ to capture the arguments in the left-hand side of (3), the first-order condition is

$$\frac{\partial \Pi^c(\cdot)}{\partial x_\theta^c} = x_\theta^c \frac{\partial r^c(\theta, \rho, x_\theta^c, \vec{x}_{\setminus\theta})}{\partial x_\theta^c} + r^c(\theta, \rho, x_\theta^c, \vec{x}_{\setminus\theta}) - \frac{\partial C(x_\theta^c)}{\partial x_\theta^c} - \frac{\partial \gamma(x_\theta^c, I)}{\partial x_\theta^c} = 0 = \psi_1(\theta, \rho, x_\theta^c, \vec{x}_{\setminus\theta}, I), \tag{4}$$

where $\psi_1(\theta, \rho, x_\theta^c, \vec{x}_{\setminus\theta}, I) = 0$ implicitly defines $x_\theta^c(\rho, \vec{x}_{\setminus\theta}, I)$, which is an optimal value function denoting output of a compliant DC. Economizing on notation so that $\psi_1(\theta, \rho, x_\theta^c, \vec{x}_{\setminus\theta}, I) = \psi_1(\cdot)$, and differentiating (4) with respect to output we get

$$\frac{\partial^2 \Pi^c(\cdot)}{\partial [x_\theta^c]^2} = \frac{\partial \psi_1(\cdot)}{\partial x_\theta^c} = x_\theta^c \frac{\partial^2 r^c(\theta, \rho, x_\theta^c, \vec{x}_{\setminus\theta})}{\partial [x_\theta^c]^2} + 2\frac{\partial r^c(\theta, \rho, x_\theta^c, \vec{x}_{\setminus\theta})}{\partial x_\theta^c} - \frac{\partial^2 C(x_\theta^c)}{\partial [x_\theta^c]^2} - \frac{\partial^2 \gamma(x_\theta^c, I)}{\partial [x_\theta^c]^2} < 0, \tag{5}$$

which is negative by Assumptions 1(a) and 3(b).

DCs that Do Not Comply with DPR: If they do not comply, then payoffs for DCs are revenues from non-compliance adjusted by the variable fine on revenues, less business costs and the fixed fine. In the payoff maximization problem for a non-compliant DC below, f is the proportion of DC revenues paid as variable fines, and F is the fixed fine. The payoff maximization is

$$\max_{x_\theta} \Pi^{nc}(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta}, F, f) = \max_{x_\theta} \big[[1-f][x_\theta r^{nc}(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta})] - C(x_\theta) - F\big]. \tag{6}$$

Using $\Pi^{nc}(\cdot)$ to capture the arguments in the left-hand side of (6), the first-order condition is

$$\frac{\partial \Pi^{nc}(\cdot)}{\partial x_\theta^{nc}} = [1-f]\left[x_\theta^{nc}\frac{\partial r^{nc}(\theta,\rho,x_\theta^{nc},\vec{x}_{\setminus\theta})}{\partial x_\theta^{nc}} + r^{nc}(\theta,\rho,x_\theta^{nc},\vec{x}_{\setminus\theta})\right] - \frac{\partial C(x_\theta^{nc})}{\partial x_\theta^{nc}} = 0 = \psi_2(\theta,\rho,x_\theta^{nc},\vec{x}_{\setminus\theta},f), \tag{7}$$

where $\psi_2(\theta,\rho,x_\theta^{nc},\vec{x}_{\setminus\theta},f)=0$ implicitly defines $x_\theta^{nc}(\rho,\vec{x}_{\setminus\theta},f)$, which denotes optimal output if not complying. Further economizing on notation so that $\psi_2(\theta,\rho,x_\theta^{nc},\vec{x}_{\setminus\theta},f)=\psi_2(\cdot)$ and differentiating with respect to output we get

$$\frac{\partial \psi_2(\cdot)}{\partial x_\theta^{nc}} = \frac{\partial^2 \Pi^{nc}(\cdot)}{\partial [x_\theta^{nc}]^2} = [1-f]\left[x_\theta^{nc}\frac{\partial^2 r^{nc}(\theta,\rho,x_\theta^{nc},\vec{x}_{\setminus\theta})}{\partial [x_\theta^{nc}]^2} + 2\frac{\partial r^{nc}(\theta,\rho,x_\theta^{nc},\vec{x}_{\setminus\theta})}{\partial x_\theta^{nc}}\right] - \frac{\partial^2 C(x_\theta^{nc})}{\partial [x_\theta^{nc}]^2} < 0, \tag{8}$$

which is negative from Assumptions 1(a) and 3(b).

With each DC's decision of whether to comply, the combination of (4) and (7) across DCs yields a Nash equilibrium in output. The payoffs for DCs from compliance are as in (3) where outputs are stated as optimal value functions $x_\theta^c(\rho,\vec{x}_{\setminus\theta},I)=x_\theta^c(\cdot)$. On the other hand, the payoff for DCs from non-compliance are as in (6) where output is $x_\theta^{nc}(\rho,\vec{x}_{\setminus\theta},f)=x_\theta^{nc}(\cdot)$. Given a level of fines and investments, each DC compares its payoff from compliance against its payoff from non-compliance. To find the DC that is indifferent between complying and not complying with DPR, denoted by $\tilde{\theta}$, we equate the payoffs to compliance and non-compliance so that

$$x_{\tilde{\theta}}^c(\cdot)r^c(\tilde{\theta},\rho,x_{\tilde{\theta}}^c(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot)) - C(x_{\tilde{\theta}}^c(\cdot)) - \gamma(x_{\tilde{\theta}}^c(\cdot),I) = [1-f]x_{\tilde{\theta}}^{nc}(\cdot)r^{nc}(\tilde{\theta},\rho,x_{\tilde{\theta}}^{nc}(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot)) - C(x_{\tilde{\theta}}^{nc}(\cdot)) - F.$$

Re-arranging so that the difference between the payoffs from compliance and non-compliance equal zero, we have

$$\begin{aligned} &x_{\tilde{\theta}}^c(\cdot)r^c(\tilde{\theta},\rho,x_{\tilde{\theta}}^c(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot)) - C(x_{\tilde{\theta}}^c(\cdot)) - \gamma(x_{\tilde{\theta}}^c(\cdot),I) - x_{\tilde{\theta}}^{nc}(\cdot)r^{nc}(\tilde{\theta},\rho,x_{\tilde{\theta}}^{nc}(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot)) \\ &+ f x_{\tilde{\theta}}^{nc}(\cdot)r^{nc}(\tilde{\theta},\rho,x_{\tilde{\theta}}^{nc}(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot)) + C(x_{\tilde{\theta}}^{nc}(\cdot)) + F = 0 = \psi_3(\tilde{\theta},\rho,x_{\tilde{\theta}}^c(\cdot),x_{\tilde{\theta}}^{nc}(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot),F,f,I), \end{aligned} \tag{9}$$

where $\psi_3(\tilde{\theta},\rho,x_{\tilde{\theta}}^c(\cdot),x_{\tilde{\theta}}^{nc}(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot),F,f,I) = 0 = \psi_3(\cdot)$ implicitly defines the indifferent DC, $\tilde{\theta}(\rho,x_{\tilde{\theta}}^c(\cdot),x_{\tilde{\theta}}^{nc}(\cdot),\vec{x}_{\setminus\tilde{\theta}}(\cdot),F,f,I)$, which we denote by $\tilde{\theta}(\cdot)$. Our first Lemma relates the rate at which payoffs from compliance and payoffs from non-compliance increase with capability, as well as the significance of the indifferent DC, $\tilde{\theta}(\cdot)$. Proofs for all Lemmas and Theorems are in Appendix D.

Lemma 1. *Payoffs and output increase with capability. Payoffs from compliance increase faster in capability than do payoffs from non-compliance. DCs that are more capable than $\tilde{\theta}(\cdot)$ comply with DPR. The optimal output from compliance for $\tilde{\theta}(\cdot)$ is higher than its optimal output from non-compliance.*

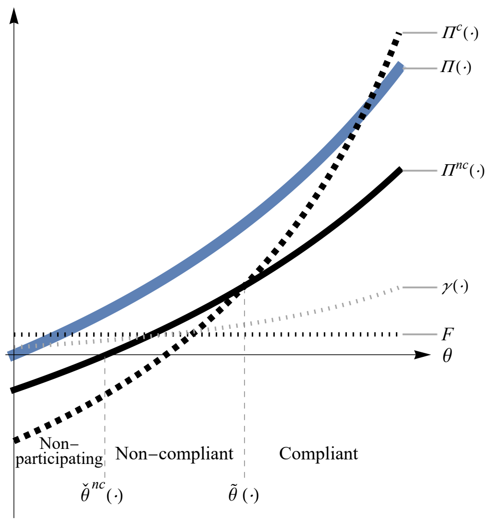


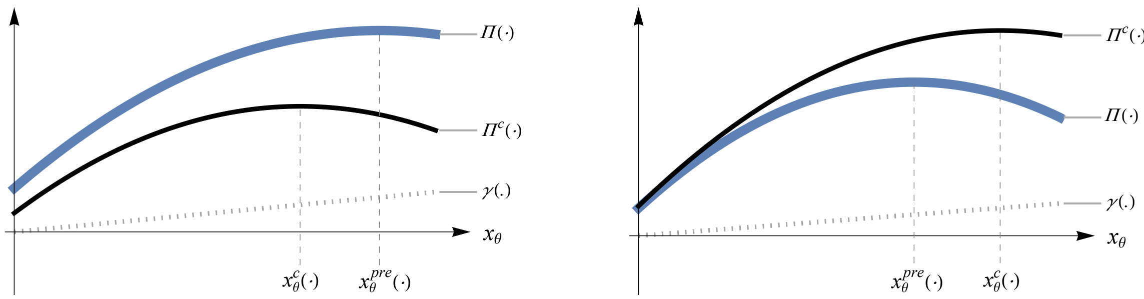
Figure 2 DC payoff from compliance and non-compliance: An illustrative example

The essence of Lemma 1 is a single crossing condition, $\partial\Pi^c(\cdot)/\partial\theta > \partial\Pi^{nc}(\cdot)/\partial\theta$. To discern the intuition behind this Lemma, consider when variable fines and investments are zero, so that only fixed fines are in effect. Figure 2 provides an illustration of DC payoffs from compliance and non-compliance, $\Pi^c(\cdot)$ and $\Pi^{nc}(\cdot)$ from (3) and (6), respectively; profits pre-DPR, $\Pi(\cdot)$; compliance costs, $\gamma(\cdot)$; all of which include outputs as optimal value functions; and fixed fines, F. The intersection of $\Pi^c(\cdot)$ and $\Pi^{nc}(\cdot)$ defines $\tilde{\theta}(\cdot)$. For this DC, $x^c_{\tilde{\theta}}(\rho, \vec{x}_{\setminus\tilde{\theta}}) > x^{nc}_{\tilde{\theta}}(\rho, \vec{x}_{\setminus\tilde{\theta}}, f)$ from Lemma 1. Because compliant inverse demand increases more than non-compliant inverse demand from Assumption 4(a), the payoff from compliance increases more with capability than does the payoff from non-compliance (Lemma 1). Therefore, the payoff from compliance for any DC that is more capable than $\tilde{\theta}(\cdot)$ is higher than its payoff from non-compliance.

We can now define the proportion of DCs that comply as the set of DCs between $\tilde{\theta}(\cdot)$ and 1, so that with $\theta \sim U[0,1]$ we can determine $\rho(\tilde{\theta}(\cdot)) = 1 - \tilde{\theta}(\cdot)$ and $d\rho(\cdot)/d\tilde{\theta} = -1 < 0$. Therefore, the proportion of compliant DCs, $\rho(\tilde{\theta}(\cdot))$, is derived endogenously as result of the DCs' decision on compliance through $\tilde{\theta}(\cdot)$. We now analyze the impact of fixed fines, variable fines, and investments on DC compliance.

Lemma 2. *Fixed fines, variable fines, and investments increase the proportion of compliant DCs.*

The indifferent DC $\tilde{\theta}(\cdot)$ decreases in all policy-maker instruments (that is, moves to the left in the capability continuum), so that $\partial\tilde{\theta}(\cdot)/\partial F$, $\partial\tilde{\theta}(\cdot)/\partial f$, $\partial\tilde{\theta}(\cdot)/\partial I < 0$. For exposition we write $\partial\rho(\cdot)/\partial F$, $\partial\rho(\cdot)/\partial f$, $\partial\rho(\cdot)/\partial I > 0$. The effect of the fixed fine can be inferred from Figure 2 – any increase in the fixed fine decreases the payoffs from non-compliance, shifting the indifferent DC, $\tilde{\theta}(\cdot)$, to the left. With a positive variable fine, a proportion $f \in [0,1]$ of revenues from non-compliance is transferred to the policy-maker. This implies that the variable fine decreases the payoff from



(a) Loss of payoff from compliance (b) Gain in payoff from compliance

Figure 3 DC output and payoffs from compliance: An illustrative example

non-compliance further from what is illustrated in Figure 2, thereby moving $\tilde{\theta}(\cdot)$ further to the left. If $\Pi^c(\cdot)$ contains non-zero compliance costs, then investments have the effect of decreasing compliance costs thereby increasing $\Pi^c(\cdot)$. This moves $\tilde{\theta}(\cdot)$ to the left, although the mechanism is through increased payoffs from compliance rather than decreased payoffs from non-compliance. A comparison of the rate at which investments decrease compliance to the rate at which fines decrease compliance simplifies to the following two equations:

$$\frac{\partial\tilde{\theta}(\cdot)/\partial I}{\partial\tilde{\theta}(\cdot)/\partial F} = -\frac{\partial\gamma(\cdot)}{\partial I}, \quad \text{and} \quad \frac{\partial\tilde{\theta}(\cdot)/\partial I}{\partial\tilde{\theta}(\cdot)/\partial f} = -\frac{\partial\gamma(\cdot)/\partial I}{x^{nc}_{\tilde{\theta}}(\cdot) r^{nc}(\tilde{\theta}, \rho, x^{nc}_{\tilde{\theta}}(\cdot), \vec{x}_{\setminus\tilde{\theta}}(\cdot))}.$$

Compared to fixed fines, the effectiveness of investments in increasing compliance depends solely on the rate at which compliance costs decrease with investments. However, compared to variable fines, the effectiveness of investments depends on both the rate at which compliance costs decrease with investments and the revenues of $\tilde{\theta}(\cdot)$. We can also quantify the relative effect of fixed and variable fines on compliance,

$$\frac{\partial\tilde{\theta}(\cdot)}{\partial f} = x^{nc}_{\tilde{\theta}}(\cdot) r^{nc}(\tilde{\theta}, \rho, x^{nc}_{\tilde{\theta}}(\cdot), \vec{x}_{\setminus\tilde{\theta}}(\cdot)) \frac{\partial\tilde{\theta}(\cdot)}{\partial F}.$$

In other words, the extent of the move to the left through variable fines is weighted by the revenues generated by the indifferent DC, $\tilde{\theta}(\cdot)$, that is, $x^{nc}_{\tilde{\theta}}(\cdot) r^{nc}(\cdot)$.

We now analyze the effect of policy-maker instruments on compliant and non-compliant DC output. Pre-DPR profit is optimized at $x^{pre}_{\theta}(\cdot)$. We first use Figure 3 to describe the compliant DC output, which is derived by solving (4). This figure illustrates the payoffs from compliance for a particular DC, θ, with output on the horizontal axis. Depending on a DC's capability, the compliant inverse demand can be lower ($r^c(\cdot) < r(\cdot)$ as seen in Figure 3a), or higher ($r^c(\cdot) > r(\cdot)$ as in Figure 3b), which results in a consequently lower or higher payoff and output from compliance. On the other hand, Figure 4 describes the non-compliant optimal output that DCs choose by solving (7). After imposition of DPR, non-compliance results in a decrease in revenues from $x^{pre}_{\theta}(\cdot) r(\cdot)$ to $x^{nc}_{\theta}(\cdot) r^{nc}(\cdot)$, and a decrease in output from $x^{pre}_{\theta}(\cdot)$ to $x^{nc}_{\theta}(\cdot)$.

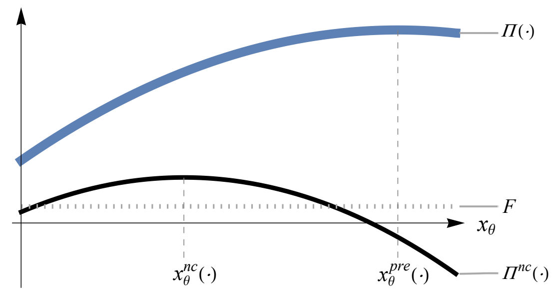


Figure 4 **DC output and payoffs from non-compliance: An illustrative example**

In our next Lemma, we describe the effect of policy-maker instruments and increased compliance on output.

Lemma 3. *For non-compliant DCs, output decreases in (a) the proportion of compliant DCs, and (b) fixed fines, variable fines, and investments.*

Mathematically, this Lemma states that

$$(a)\ \partial x_\theta^{nc}(\cdot)/\partial\rho \le 0, \ \ and\ \ (b)\ \partial x_\theta^{nc}(\cdot)/\partial F,\ \partial x_\theta^{nc}(\cdot)/\partial f,\ \partial x_\theta^{nc}(\cdot)/\partial I \le 0.$$

The underlying cause of the decrease in optimal output is the decrease in the non-compliant inverse demand or marginal revenue. In Lemma 3(a) the proportion of compliant DCs decreases the non-compliant inverse demand by Assumption 2, which decreases output.

Moving to Lemma 3(b), from Lemma 2 each of fixed fines, variable fines, and investments increase the proportion of compliance DCs, which in turn decreases non-compliant output by the above Lemma 3(a). In addition, variable fines decrease marginal revenue from non-compliance as can be seen in (7), thereby further decreasing output. In other words, variable fines also have a direct effect on non-compliant DC output.

4.3. Participation

Here we analyze the mechanisms through which fines and investments impact DC participation. We denote the DC that generates zero payoffs from non-compliance by $\check{\theta}^{nc}$. This DC is determined by setting (6) to zero where outputs are stated as optimal value functions, so

$$\begin{aligned}\Pi^{nc}(\check{\theta}^{nc},\rho(\cdot),x^{nc}_{\check{\theta}^{nc}}(\cdot),\vec{x}_{\setminus\check{\theta}^{nc}}(\cdot),F,f) =& [1-f]x^{nc}_{\check{\theta}^{nc}}(\cdot)r^{nc}(\check{\theta}^{nc},\rho,x^{nc}_{\check{\theta}^{nc}}(\cdot),\vec{x}_{\setminus\check{\theta}^{nc}}(\cdot)) - C(x^{nc}_{\check{\theta}^{nc}}(\cdot)) - F = 0\\ =& \psi_4(\check{\theta}^{nc},\rho(\cdot),x^{nc}_{\check{\theta}^{nc}}(\cdot),\vec{x}_{\setminus\check{\theta}^{nc}}(\cdot),F,f), \quad (10)\end{aligned}$$

where $\psi_4(\check{\theta}^{nc},\rho(\cdot),x^{nc}_{\check{\theta}^{nc}}(\cdot),\vec{x}_{\setminus\check{\theta}^{nc}}(\cdot),F,f) = 0$ implicitly defines $\check{\theta}^{nc}(\rho(\cdot),x^{nc}_{\check{\theta}^{nc}}(\cdot),\vec{x}_{\setminus\check{\theta}^{nc}}(\cdot),F,f)$, or $\check{\theta}^{nc}(\cdot)$.

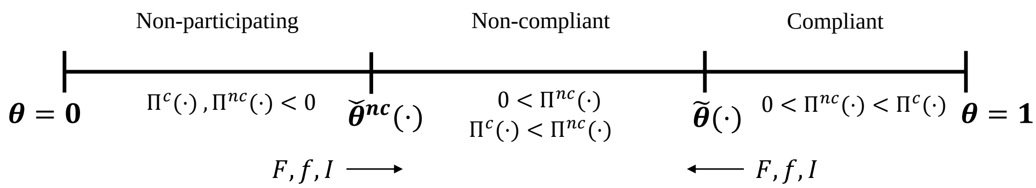


Figure 5 DC segmentation in the case of partial compliance: An illustration

The compliant DC that is indifferent between participating and not participating also realizes zero payoffs. This indifferent DC, $\check{\theta}^c$, is determined by setting (3) equal to zero and with outputs stated as optimal value functions so that

$$\begin{aligned}\Pi^c(\check{\theta}^c, \rho(\cdot), x^c_{\check{\theta}^c}(\cdot), \vec{x}_{\setminus\check{\theta}^c}(\cdot), I) &= x^c_{\check{\theta}^c}(\cdot) r^c(\check{\theta}^c, \rho(\cdot), x^c_{\check{\theta}^c}(\cdot), \vec{x}_{\setminus\check{\theta}^c}(\cdot)) - C(x^c_{\check{\theta}^c}(\cdot)) - \gamma(x^c_{\check{\theta}^c}(\cdot), I) = 0 \\ &= \psi_5(\check{\theta}^c, \rho(\cdot), x^c_{\check{\theta}^c}(\cdot), \vec{x}_{\setminus\check{\theta}^c}(\cdot), I), \end{aligned} \tag{11}$$

where $\psi_5(\check{\theta}^c, \rho(\cdot), x^c_{\check{\theta}^c}(\cdot), \vec{x}_{\setminus\check{\theta}^c}(\cdot), I) = 0$ implicitly defines $\check{\theta}^c(\rho(\cdot), x^c_{\check{\theta}^c}(\cdot), \vec{x}_{\setminus\check{\theta}^c}(\cdot), I)$, or $\check{\theta}^c(\cdot)$.

We now describe how DCs are segmented facing fines and investments to encourage DPR.

LEMMA 4. *There are two ways that DCs can be segmented: (a) partial compliance where DCs are segmented by capability into non-participating DCs, participating non-compliant DCs, and participating compliant DCs; (b) full compliance where DCs are segmented by capability into non-participating DCs, and participating compliant DCs.*

All DCs that are more capable than $\check{\theta}^{nc}(\cdot)$ generate positive payoffs from non-compliance, while all DCs that are more capable than $\check{\theta}^c(\cdot)$ generate positive payoffs from compliance. Lemma 4 defines two sets of segmentations, *partial compliance* and *full compliance*. The segmentation for partial compliance is illustrated in Figure 5, where, by Lemma 1, compliant DCs lie on the right side of $\tilde{\theta}(\cdot)$, and non-compliant DCs lie on the left side of $\tilde{\theta}(\cdot)$. If payoffs to $\tilde{\theta}(\cdot)$ are positive, then partial compliance in Lemma 4(a) is obtained. Here, DCs between 0 and $\check{\theta}^{nc}(\cdot)$ do not participate because of negative payoffs, DCs between $\check{\theta}^{nc}(\cdot)$ and $\tilde{\theta}(\cdot)$ participate but do not comply, and DCs between $\tilde{\theta}(\cdot)$ and 1 participate and comply. On the other hand, if payoffs to $\tilde{\theta}(\cdot)$ are negative the segmentation for full compliance is obtained per Lemma 4(b), and as illustrated later on in Figure 7, all DCs that participate comply: DCs between 0 and $\check{\theta}^c(\cdot)$ do not participate and DCs between $\check{\theta}^c(\cdot)$ and 1 participate and comply.

By Lemma 2, each policy-maker instrument increases compliance. Our first Theorem describes the collateral effect of fixed fines, variable fines, and investments on participation.

THEOREM 1. *With partial compliance, fixed fines, variable fines, and investments decrease participation.*

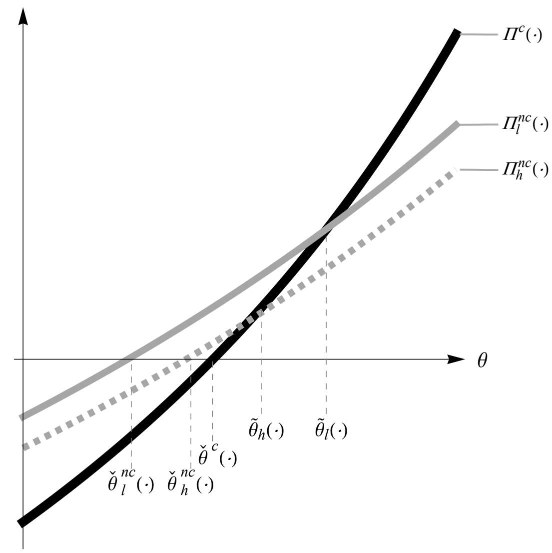


Figure 6 **Impact of fines on DC compliance and participation: An illustrative example**

Theorem 1 is an important result: if there is partial compliance, then any use of policy-maker instruments decreases participation. This occurs even if the policy-maker uses investments as their instrument of choice.

Fixed fines, variable fines, and investments increase the proportion of compliant DCs (Lemma 2), which in turn lowers the non-compliant inverse demand by Assumption 2. This indirect effect is the underlying cause for participation to decrease in investments. Separately, the direct effect of an increase in fixed fines is to decrease the payoff to $\check{\theta}^{nc}(\cdot)$ from non-compliance so that $\check{\theta}^{nc}(\cdot)$ now generates negative payoffs and ceases to participate. Variable fines also have a direct effect on non-compliant payoffs – similar to fixed fines. From (10), the payoffs to $\check{\theta}^{nc}(\cdot)$ do not directly depend on investments.

Figure 6 illustrates the impact of increased fixed fines on DC compliance and participation in the case of *partial compliance*. Consider a regime with low-fines l and one with high-fines h. Using subscripts to denote the regime, the intersection of $\Pi_l^{nc}(\cdot)$ and the horizontal axis (where payoff is zero) gives the DC that generates zero payoffs from non-compliance, $\check{\theta}_l^{nc}(\cdot)$. DCs that are more capable than $\check{\theta}_l^{nc}(\cdot)$ generate positive payoffs from non-compliance. Similarly, the intersection of $\Pi^c(\cdot)$ with the horizontal axis gives $\check{\theta}^c(\cdot)$, the DC that generates zero payoffs from compliance. DCs that are more capable than $\check{\theta}^c(\cdot)$ generate positive payoffs from compliance. Because payoffs from compliance increase faster with capability than do payoffs from non-compliance by Lemma 1, $\Pi^c(\cdot)$ and $\Pi_l^{nc}(\cdot)$ intersect only once and the location of intersection defines the DC that is indifferent between complying and not complying under the low-fines regime, $\tilde{\theta}_l(\cdot)$.

An increase in fixed fines decreases payoffs from non-compliance from $\Pi_l^{nc}(\cdot)$ to $\Pi_h^{nc}(\cdot)$. As fines increase, $\tilde{\theta}(\cdot)$ moves to the left (Lemma 2), the payoffs to $\tilde{\theta}(\cdot)$ decrease, and $\check{\theta}^{nc}(\cdot)$ moves to the right

(Theorem 1). With a sufficient increase in fines, the limit to where partial compliance transitions to full compliance is reached where payoffs to $\tilde{\theta}(\cdot)$ are zero and at this point $\breve{\theta}^{nc}(\cdot) = \breve{\theta}^{c}(\cdot) = \tilde{\theta}(\cdot)$. In sum, when the payoffs to $\tilde{\theta}(\cdot)$ are (weakly) negative, full compliance is obtained. The segmentation for full compliance is illustrated in Figure 7, where DCs that are more capable than $\breve{\theta}^{c}(\cdot)$ participate and comply, but the others do not participate. Further increases in fixed fines moves $\tilde{\theta}(\cdot)$ further to the left and $\breve{\theta}^{nc}(\cdot)$ further to the right in Figure 6. The ordering is then $\tilde{\theta}(\cdot) < \breve{\theta}^{c}(\cdot) < \breve{\theta}^{nc}(\cdot)$, the indifferent DC, $\tilde{\theta}(\cdot)$, has negative payoffs, and full compliance is maintained. However, once full compliance is reached, only $\breve{\theta}^{c}(\cdot)$ is material as shown in Figure 7, and the fine-induced movements of $\tilde{\theta}(\cdot)$ to the left and $\breve{\theta}^{nc}(\cdot)$ to the right have no consequence for the equilibrium. Thus, with full compliance, further increasing fines has no impact on participation or output.

In Theorem 1 and Figure 5 we showed that full compliance can be achieved through the use of any policy-maker instrument by simultaneously reducing participation and converting DCs from non-compliant to compliant; this is true even if investments are used in order to increase compliance. Once full compliance has been achieved the effect of investments on participation reverses and investments begin to increase participation. Even so, investments cannot ensure that all DCs participate and comply unless a specific market-based condition is satisfied. The policy-maker may be interested in the conditions under which their stated objective of increasing competition can be achieved while ensuring compliance. To this end, in our next Theorem we examine whether and how all DCs can comply profitably. We term such an outcome as full participation and full compliance.

Theorem 2. *(a) With full compliance, investments increase participation. (b) A necessary condition for full participation and full compliance is DPR-induced demand expansion. (c) Conditional on the necessary condition, the sufficient condition for full participation and full compliance can be attained by policy-maker investment but not by fixed or variable fines.*

Theorem 2 shows that once full compliance has been achieved, investments increase participation. Thus, the elimination of non-compliance is a pre-requisite for investments to increase participation.

An important finding from this Theorem is that investments by the policy-maker cannot achieve full participation and compliance without the right market conditions. Full compliance and full

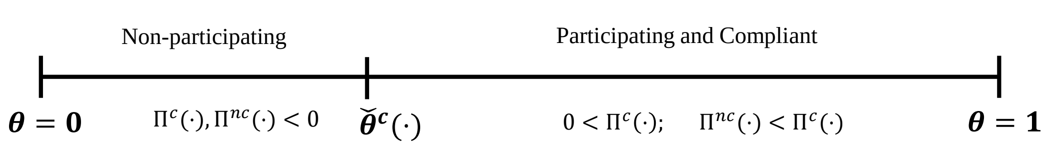


Figure 7 DC segmentation in the case of full compliance: An illustration.

participation is a special case of full compliance described in Figure 7, but with $\check{\theta}^c(\cdot) = 0$. This requires that inverse demand increases for $\theta = 0$ if it complies with DPR so that $r^c(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta}) > r(\theta, x_\theta, \vec{x}_{\setminus\theta})|_{\theta=0}$. This is a necessary condition for full participation and full compliance.

This necessary condition occurs when the market expands as a result of DPR. Multi-homing can be such an instance of market expansion, where less capable DCs do not lose users if they comply. Instead, users copy their data over to another DC, thereby consuming services with two DCs. A second instance is a market expansion through a generic inflow of users into the focal DC industry from another industry. Such users bring their data with them and enjoy the added value from the focal DC industry as a result of DPR. If such incoming users highly value portability, then the compliant inverse demand function can be positive throughout the domain of θ.

Although the above market condition is necessary, it may not be sufficient because with higher compliance costs, the sufficient condition, $\Pi^c(\cdot)|_{\theta=0} \geq 0$, may not be met. However, investments decrease compliance costs so that subject to the necessary market-based condition being met, full compliance and full participation can be achieved through policy-maker investments. Fines can be used to eliminate non-compliance. However, because fines have no effect on the equilibrium once full compliance is achieved, they cannot be used to achieve full compliance and full participation. For the remainder of the analysis we focus on partial compliance because with full compliance, further increases in fines have no impact on participation or output.

5. Fines and Investments

In Stage 1, the policy-maker decides the level of fines and investments. In our setup, user surplus (US) is a measure of consumer surplus and is increasing in aggregate output, $X(F, f, I) \in \mathbb{R}_{>0}$ that we define below, so that $\partial US(X(\cdot))/\partial X > 0$. DC surplus (DCS) is a measure of producer surplus and is the aggregate payoffs to DCs after transfers to policy-makers (such as fines). Because fines are a transfer, they do not affect social welfare directly. Therefore, for the purposes of deriving social welfare, in Section 5.3, we develop a measure of DCS without fines, DCS_{-f}. In this section, we first analyze the effect of fines and investments on each of US and DCS and then on social welfare.

5.1. Aggregate Output and Industry Concentration

Aggregate output consists of the output of DCs between $\tilde{\theta}(\cdot)$ and 1 that participate and comply with DPR so individual DC output is $x^c_\theta(\cdot)$ and the output of DCs between $\check{\theta}^{nc}(\cdot)$ and $\tilde{\theta}(\cdot)$ that participate but do not comply with DPR so each DC produces $x^{nc}_\theta(\cdot)$,

$$X(F, f, I) = \int_{\check{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)} x^{nc}_\theta(\cdot)d\theta + \int_{\tilde{\theta}(\cdot)}^{1} x^c_\theta(\cdot)d\theta. \tag{12}$$

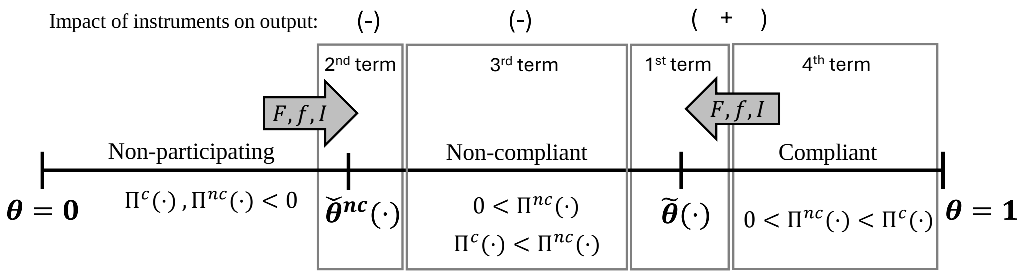


Figure 8 The effects of fixed fines, variable fines, and investments on DC output

DCs that do not participate, $\theta \in [0, \check{\theta}^{nc}(\cdot)]$, do not produce any output.

We now totally differentiate aggregate output in (12) with respect to fixed fines, variable fines, and investments to analyze the impact of these on output. We begin with fixed fines, apply Leibnitz's rule, and drop the terms that are zero to get

$$\begin{aligned}\frac{dX(\cdot)}{dF} = [x^{nc}_{\tilde{\theta}}(\cdot) - x^{c}_{\tilde{\theta}}(\cdot)]\frac{\partial\tilde{\theta}(\cdot)}{\partial F} - x^{nc}_{\check{\theta}^{nc}}(\cdot)\frac{\partial\check{\theta}^{nc}(\cdot)}{\partial F} \\ + \int_{\check{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)} \frac{\partial x^{nc}_{\theta}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial F}d\theta + \int_{\tilde{\theta}(\cdot)}^{1} \frac{\partial x^{c}_{\theta}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial F}d\theta,\end{aligned} \tag{13}$$

where we simplify the notation for aggregate output using $X(\cdot)$. Next, we totally differentiate (12) with respect to variable fines, to get

$$\begin{aligned}\frac{dX(\cdot)}{df} =& [x^{nc}_{\tilde{\theta}}(\cdot) - x^{c}_{\tilde{\theta}}(\cdot)]\frac{\partial\tilde{\theta}(\cdot)}{\partial f} - x^{nc}_{\check{\theta}^{nc}}(\cdot)\frac{\partial\check{\theta}^{nc}(\cdot)}{\partial f} \\ &+ \int_{\check{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)} \left[\frac{\partial x^{nc}_{\theta}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial f} + \frac{\partial x^{nc}_{\theta}(\cdot)}{\partial f}\right]d\theta + \int_{\tilde{\theta}(\cdot)}^{1} \frac{\partial x^{c}_{\theta}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial f}d\theta.\end{aligned} \tag{14}$$

Finally, we totally differentiate (12) with respect to investments, so that

$$\begin{aligned}\frac{dX(\cdot)}{dI} =& [x^{nc}_{\tilde{\theta}}(\cdot) - x^{c}_{\tilde{\theta}}(\cdot)]\frac{\partial\tilde{\theta}(\cdot)}{\partial I} - x^{nc}_{\check{\theta}^{nc}}(\cdot)\frac{\partial\check{\theta}^{nc}(\cdot)}{\partial I} \\ &+ \int_{\check{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)} \frac{\partial x^{nc}_{\theta}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial I}d\theta + \int_{\tilde{\theta}(\cdot)}^{1} [\frac{\partial x^{c}_{\theta}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial I} + \frac{\partial x^{c}_{\theta}(\cdot)}{\partial I}]d\theta.\end{aligned} \tag{15}$$

On the basis of the above equations, we construct our next Theorem where we describe the collateral effect of the use of the instruments to increase compliance on industry concentration. As described in Section 1, industry concentration measures the extent to which market shares are concentrated among DCs.

THEOREM 3. *Fixed fines, variable fines, and investments increase industry concentration.*

Theorem 3 is an important result: any use of the policy-maker's instruments increases industry concentration – in stark contrast to the intent of DPR.

The structures of (13), (14), and (15) are similar – each consists of four terms, and the effect captured by each of these terms is illustrated in Figure 8. Working from left to right in Figure 8, each instrument decreases participation from the least capable DCs thereby losing their output (second term in (13), (14), and (15)), decreases the output of non-compliant DCs (third term), and converts non-compliant DCs into compliant DCs and increases the aggregate output of compliant DCs (first and fourth terms). Moreover, by Lemma 1, more capable DCs produce greater output and the output of compliant DCs ($\tilde{\theta}(\cdot) \leq \theta$) is higher than the output of non-compliant DCs ($\theta < \tilde{\theta}(\cdot)$). Thus, any increases in fixed fines, variable fines, and investments increase the aggregate output of compliant DCs and decrease the output of non-compliant DCs, thereby increasing industry concentration.

Even though each policy-maker instrument decreases participation (Theorem 1), and increases industry concentration (Theorem 3), the magnitude of the effect of each instrument differs. Compared to fixed fines in (13), variable fines have an additional effect on aggregate output in (14). This is an infra-marginal *direct effect* captured by the second expression within the third term, $\partial x_\theta^{nc}(\cdot)/\partial f$. This expression is negative from Lemma 3 – variable fines decrease output for each non-compliant DC that continues to participate because variable fines decrease marginal revenues. Thus, both expressions under the third term in (14) are negative. Next, compared to fixed fines in (13), investments also have an additional effect on aggregate output in (15), but this time on compliant DC output as seen in the last expression in the fourth term, $\partial x_\theta^{c}(\cdot)/\partial I$. Investments decrease compliant DCs' marginal compliance costs and therefore increase output. We formalize these implications in our next Theorem.

THEOREM 4. *a) Compared to variable fines and investments, the use of fixed fines to achieve a predetermined level of compliance has a larger collateral effect on participation. b) Compared to variable fines and investments, the use of fixed fines to achieve a predetermined level of compliance has a smaller collateral effect on industry concentration from participating DCs.*

Theorem 4 considers when the policy-maker has a target level of compliance: the policy-maker has to choose between greater industry concentration or lesser participation depending on the instrument chosen.

Both fixed and variable fines decrease payoffs from non-compliance. However, because less capable DCs pay the same fixed fine as more capable DCs, fixed fines disproportionately affect less capable DCs. In other words, the impact of variable fines on the extent to which participation decreases is partly moderated by $x_\theta^{nc} r^{nc}(\theta, \rho, x_\theta, \vec{x}_{\setminus\theta})$, that is, the (low) revenues from non-compliance of the least capable participating DC. The same is not the case with fixed fines. For this reason, compared to variable fines, the use of fixed fines to achieve a pre-determined level of compliance has a larger collateral effect on participation. In addition, each of fixed fines, variable fines, and investments have an indirect negative effect on participation through the proportion of compliant DCs. Because investments have no direct effect on non-compliant DC payoffs, they have the least negative effect on participation of the three instruments. However, investments do come at a cost to the policy-maker, which should be accounted for. Figure 9 illustrates the differences in the collateral effects on participation from the policy instruments in achieving a pre-determined level of compliance.

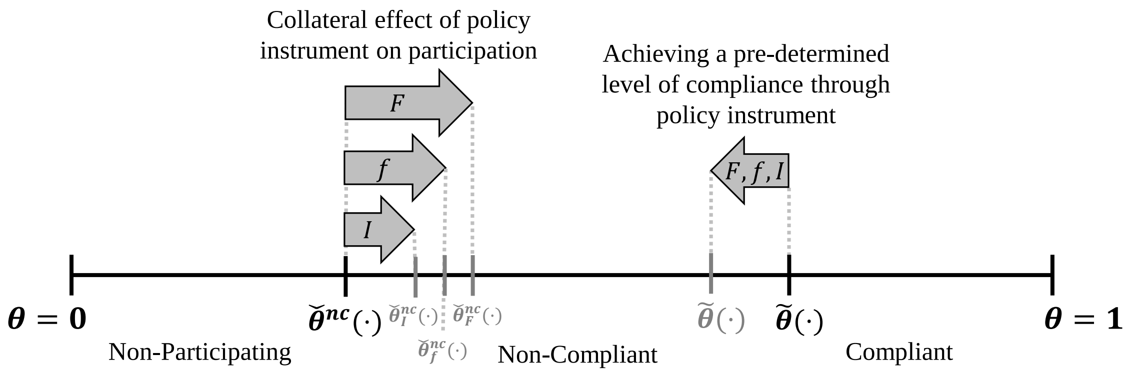


Figure 9 Achieving a predetermined level of compliance through the use of fixed fines, variable fines and investments: collateral effects on participation. Fixed fines have the largest collateral effect on participation.

Consider now the effects of the different instruments on industry concentration. Fixed fines, variable fines, and investments increase the proportion of compliant DCs thereby *indirectly* affecting output. These are captured in the terms through $\rho(\cdot)$ under the integrals in (13), (14), and (15). In addition, there are *direct effects* whereby variable fines decrease the marginal revenues of non-compliant DCs thereby decreasing their output, whereas investments decrease the marginal compliance costs of compliant DCs thereby increasing their output. For participating DCs, each of these direct and indirect effects lead to increased concentration. However, fixed fines is the only instrument that does not have a direct effect on marginal revenues or costs, making it the most benign in terms of its effect on industry concentration as we explain below.

If the policy-maker increases fixed fines, variable fines, and investments so as to achieve the desired increase in compliance, then the terms through $\tilde{\theta}(\cdot)$ and $\rho(\cdot)$ in (13), (14), and (15), which capture the direct and indirect effects on output through compliance, are equal. This leaves the direct effects of variable fines on non-compliant DC output (a negative effect) and the direct effect of investments on compliant DC output (a positive effect). In other words, variable fines have a direct effect on output because a proportion of marginal revenues are transferred to the policy-maker leading to lower output from non-compliant DCs. Investments decrease marginal compliance cost for compliant DCs, which then respond by increasing output. The only policy-maker instrument that does not have a direct effect on marginal revenue or marginal cost is fixed fines. Figure 10 illustrates the differences in the collateral effect on DC output when each of fixed fines, variable fines and investments are used to achieve a pre-determined level of compliance.

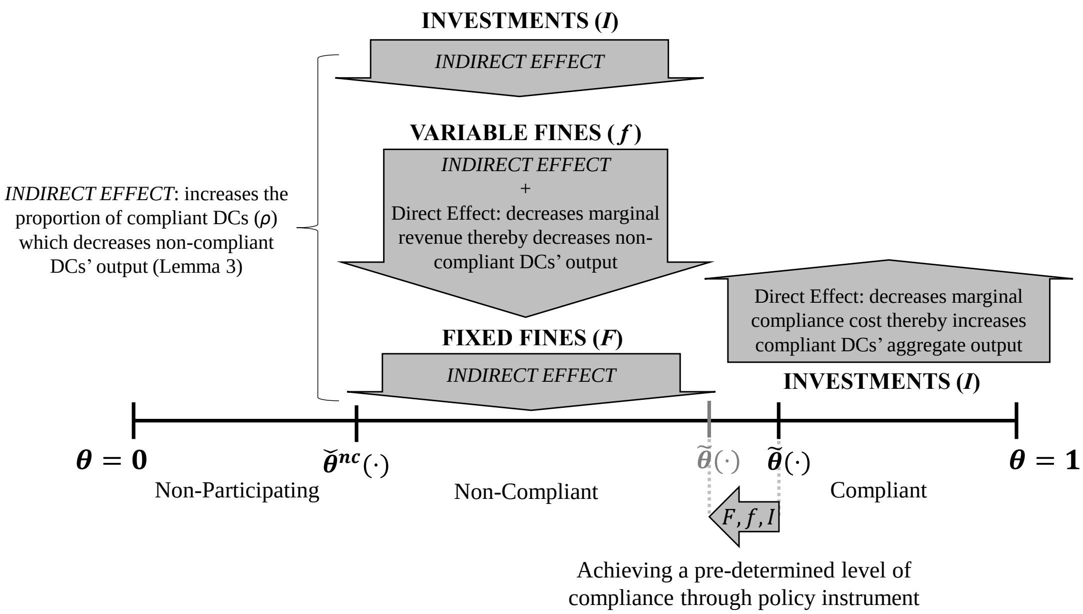


Figure 10 **Achieving a predetermined level of compliance through the use of fixed fines, variable fines and investments: collateral effects on DC output. Fixed fines have the smallest collateral effect on industry concentration.**

5.2. DC Surplus

DC surplus is the aggregate payoff to compliant and non-compliant DCs, so that

$$DCS(F,f,I)=\int_{\breve{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)}\Pi^{nc}(\theta,\rho(\cdot),x_\theta(\cdot),\vec{x}_{\setminus\theta}(\cdot),F,f)d\theta+\int_{\tilde{\theta}(\cdot)}^{1}\Pi^{c}(\theta,\rho(\cdot),x_\theta(\cdot),\vec{x}_{\setminus\theta}(\cdot),I)d\theta. \qquad (16)$$

The payoffs from non-compliance are as defined in (6) but with optimal outputs $x_\theta^{nc}(\cdot)$, whereas payoffs from compliance are defined by (3) with optimal output for compliance, $x_\theta^{c}(\cdot)$. We now evaluate the effect of fixed fines, variable fines, and investments on DCS. Totally differentiating DCS with respect to fixed fines and applying the envelope theorem we have

$$\frac{dDCS(\cdot)}{dF}=\int_{\breve{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)}\left[[1-f]x_\theta^{nc}(\cdot)\frac{\partial r^{nc}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial F}-1\right]d\theta+\int_{\tilde{\theta}(\cdot)}^{1}x_\theta^{c}(\cdot)\frac{\partial r^{c}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial F}d\theta. \qquad (17)$$

Now totally differentiating DCS with respect to variable fines we have

$$\frac{dDCS(\cdot)}{df}=\int_{\breve{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)}\left[[1-f]x_\theta^{nc}(\cdot)\frac{\partial r^{nc}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial f}-x_\theta^{nc}(\cdot)r^{nc}(\cdot)\right]d\theta+\int_{\tilde{\theta}(\cdot)}^{1}x_\theta^{c}(\cdot)\frac{\partial r^{c}(\cdot)}{\partial\rho}\frac{\partial\rho(\cdot)}{\partial f}d\theta. \qquad (18)$$

Finally, totally differentiating DCS with respect to investments,

$$\frac{dDCS(\cdot)}{dI} = \int_{\breve{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)} [1-f] x_\theta^{nc}(\cdot) \frac{\partial r^{nc}(\cdot)}{\partial \rho} \frac{\partial \rho(\cdot)}{\partial I} d\theta + \int_{\tilde{\theta}(\cdot)}^{1} \left[x_\theta^c(\cdot) \frac{\partial r^c(\cdot)}{\partial \rho} \frac{\partial \rho(\cdot)}{\partial I} - \frac{\partial \gamma(x_\theta^c(\cdot), I)}{\partial I} \right] d\theta. \quad (19)$$

Several terms cancel out or drop to zero leading to the equations (17), (18), and (19), the details of which are provided in Appendix E. In each of these equations the first term under the first integral captures the increased compliance due to fines or investments, which leads to lower non-compliant inverse demand. The second term under the first integration sign in (17) and (18) are the increased fines transferred to the policy-maker. In (18), this is $x_\theta^{nc}(\cdot) r^{nc}(\cdot)$ instead of 1 in (17), because the effect of an increase in variable fines depends on the revenues from non-compliance. These losses apply to non-compliant (and therefore less capable) DCs, $\breve{\theta}^{nc}(\cdot) < \theta \leq \tilde{\theta}(\cdot)$. The first term under the second integral captures the increased compliance from each policy-maker instrument which changes the compliant inverse demand. The second term under the second integral in (19) captures the decreased compliance costs to compliant DCs due to investment, which increases their payoffs. In summary, the effect of fines and investments is to decrease the payoffs to non-compliant DCs and potentially increase the payoffs to compliant DCs.

5.3. Social Welfare

We defined DCS as the aggregate payoffs to DCs after subtracting fines. As fines are a transfer, they do not directly impact social welfare. For this reason, we create a measure of DCS without transfers,

$$\begin{aligned} DCS_{-f}(F,f,I) = & \int_{\breve{\theta}^{nc}(\cdot)}^{\tilde{\theta}(\cdot)} [x_\theta^{nc}(\cdot) r^{nc}(\theta, \rho, x_\theta^{nc}(\cdot), \vec{x}_{\setminus\theta}(\cdot)) - C(x_\theta^{nc}(\cdot))] d\theta \\ & + \int_{\tilde{\theta}(\cdot)}^{1} [x_\theta^c(\cdot) r^c(\theta, \rho, x_\theta^c(\cdot), \vec{x}_{\setminus\theta}(\cdot)) - C(x_\theta^c(\cdot)) - \gamma(x_\theta^c(\cdot), I)] d\theta, \end{aligned} \quad (20)$$

so that social welfare (SW) consists of DCS without fines and US less the investment, $SW(F,f,I) = DCS_{-f}(F,f,I) + US(X(F,f,I)) - I$. Thus, the effect of fixed fines on social welfare is $dSW(F,f,I)/dF = dDCS_{-f}(F,f,I)/dF + US'(X(F,f,I))dX(F,f,I)/dF$, which we derive by differentiating (20) with respect to the fixed fine, and substituting for $dX(F,f,I)/dF$ from (13). The effects through variable fines and investments are similar. In the below Corollary to Theorems 1 and 3, we describe the sources of gains and losses to social welfare from the use of fines and investments to enforce DPR.

Corollary 1. *Fines and investments increase welfare produced from more capable DCs and decreases welfare produced from less capable DCs. Thus DPR can increase social welfare.*

Noting that output increases in capability from Lemma 1, all the gains to social welfare accrue from more capable DCs, $\tilde{\theta}(\cdot) < \theta$, whereas the losses to social welfare are from less capable DCs, $\theta \leq \tilde{\theta}(\cdot)$. If the gains are larger than the losses, then the social welfare increases due to DPR. In particular, from Theorems 1 and 3, the use of fines or investments to regulate DPR causes the least capable participating DCs, $\check{\theta}^{nc}(\cdot)$, to cease participating, and decreases the output generated by the less capable DCs that continue to participate, $\check{\theta}(\cdot)^{nc} < \theta < \tilde{\theta}(\cdot)$. Each of these contribute negatively to social welfare. On the other hand, each instrument increases the output of the most capable DCs ($\tilde{\theta}(\cdot) \leq \theta \leq 1$), which leads to an increase in the social welfare generated by these DCs.

6. Discussion and Conclusion

Underlying data portability regulation (DPR) are a variety of different policy objectives including compliance, industry concentration, participation, and user data ownership. DPR legislation including the E.U.'s GDPR, California's CCPA, and the U.S.'s ACCESS Act allow for the use of fixed and variable fines as instruments to ensure compliance. We analyze the effect on the above policy objectives in a setting where the policy-maker resorts to the consistent use of such fines, as well as the use of investments to decrease compliance costs.

We model a setting where the policy-maker can choose fixed and variable fines to enforce DPR and can invest to decrease compliance costs. Whereas non-compliant DCs face fines, they also face a loss of revenue from non-compliance due to users moving to DCs that comply with DPR because portability is viewed by users as an additional feature. In addition to any compliance costs, DCs that comply can gain from users moving from other DCs but can also face a loss of users that move to more capable DCs.

Even though DPR provides remedies such as warnings, reprimands, and orders to comply prior to imposing fines on non-compliant DCs, the credible threat of fines is ultimately the motivation for DC compliance. Therefore, fines are the focus of our analysis in addition to investments to decrease compliance costs. Our model is formulated using general functions governed by curvature conditions and describes the choices by the policy-maker and incentives of DCs through a two-stage game. In the first stage the policy-maker sets fixed and variable fines for DCs that do not comply with DPR and sets investments to decrease compliance cost. In the second stage DCs choose their output, whether to participate in the market, and whether to comply with DPR.

If fines are consistently applied for non-compliant DCs, then there may be unintended consequences for the structure of the industry. First, resorting to fines or investing in portability standards can decrease participation in the market. This is because more capable DCs comply, less capable DCs do not comply but continue participating, and the least capable DCs cease participating. Thus, for the policy-maker, increasing fines incentivizes non-compliant DCs to comply with

DPR, but also decreases participation by forcing the least capable DCs to exit. Therefore, fines squeeze the set of non-compliant DCs from two sides – more capable non-compliant DCs are motivated to comply, whereas the least capable non-compliant DCs cease to participate. Essentially, fines can decrease DC participation, thereby decreasing options for users to choose from.

Another important consequence of fines and investments is an increase in industry concentration, which occurs due to a decrease in the output of less capable DCs and an increase in the output of more capable DCs. Several mechanisms lead to this consequence. Variable fines decrease the marginal profits for non-compliant DCs thereby decreasing non-compliant DC output, while investments increase the marginal profits for compliant DCs thereby increasing their output. This result is in addition to indirect effects caused by an increase in compliance from each instrument. These effects together result in an increase in the aggregate output of DCs with the largest output and a decrease in the output of DCs with the smallest output. The consequence is an increase in industry concentration, which may be in conflict with the objectives of DPR.

Perhaps of greatest importance to policy-makers and in answering our main research questions, we find that each instrument has different magnitudes of unintended consequences for participation and concentration. We find that fixed fines have the largest collateral effect on participation. Less capable DCs with lower revenues face a proportionately small variable fine, whereas fixed fines can have a large effect on such DCs. Separately, fixed fines have the smallest collateral effect on industry concentration compared to variable fines and investments. Variable fines and investments have direct effects on the marginal profits of DCs, whereas fixed fines do not. Variable fines decrease non-compliant marginal revenues thereby decreasing their output. In contrast, investments decrease compliant DCs' marginal compliance costs thereby increasing their output. In other words, if policy-maker instruments are limited to fixed fines, variable fines or investments, then the policy-maker must choose between decreased participation and increased concentration.

If fines are sufficiently high, then full compliance is reached where all DCs either participate and comply, or do not participate. Once full compliance is reached, increases in fines cease to have any effect but the effect of investments on participation reverses, so that investments now increase participation. In other words, full compliance is necessary for investments to increase participation. However, if the policy-maker's goal is to achieve full participation and full compliance – where all DCs participate and comply, then investments alone cannot accomplish this. A necessary condition for this to occur is market expansion. Market expansion can occur, for instance, with multi-homing when users port their data to another DC, and consume services from more than one DC when they port. This can also happen when there is a net inflow of users along with their data, into the industry.

Our general model yields findings that are robust in a variety of DC competition and portability settings including network effects, multi-homing, and porting effectiveness. Hence, our analysis broadly applies to industries where a set of competing DCs derive value from personal data. Examples of such industries include the travel booking industry within which DCs such as Expedia operate and the financial services industry where initiatives such as open banking represent data portability. These examples are in addition to the social media and fitness apps examples described earlier.

Policy Implications: We show that there may be a disconnect between the policy-makers' goals of increased compliance with DPR, decreased concentration, and increased competition, and the monetary instruments designed to achieve these goals. This disconnect includes regulations that have been implemented such as GDPR and CCPA, and ones currently being discussed such as the ACCESS Act. As we show, the outcomes of DPR may be in direct conflict with these goals if the policy-maker resorts to consistently applied fines, and to investments to decrease compliance costs.

For the policy-maker intent on using fixed fines, variable fines, or investments to enforce data portability, the choice of instrument has different magnitudes of unintended consequences for compliance, participation, concentration, and welfare. Thus, the choice of instrument depends on the policy-maker's tolerance for each of these different collateral effects.

Policy-makers across jurisdictions are concerned about the dominance of a handful of large DCs in today's market and have displayed an interest in creating a more level playing field for competitors. We find that in an environment where users can freely choose DCs for their services and where policy-makers resort to the use of investments, fixed and variable fines that are consistently applied, enforcing DPR can mean users move from less capable DCs to more capable DCs where the latter are usually larger and better resourced. This reinforces the dominance of larger DCs over smaller, less capabale, ones.

Our work has several takeaways for policy-makers. First, the sole use of investments prior to achieving full compliance decreases the profits of the less capable DCs and reduces their participation. Instead, the use of investments can be increased after a high level of compliance is achieved because with high compliance, investments can increase DC participation. Second, DPR-induced market expansion through phenomena such as multi-homing can soften the unintended consequences of fines and investments. Although one form of multi-homing is where users use multiple DCs within the same industry, another form is where users port their data across industries. This occurs, for instance, when users port their data from Facebook (social media) to Expedia (travel booking) in order to get more personalized services from Expedia. A direct policy-maker implication here is on the development of standards. Standards that enable the broad porting of data across different industries are superior to narrow or targeted standards built for specific industries. Third, given that DPR can encourage users to port from less capable to more capable DCs, a simple and direct policy outcome is to focus on improving the capability of smaller and local DCs before implementing DPR. Examples of such interventions include funded regional technology hubs, research and development grants, and innovation funding.

Limitations and Future Research: Even though the effects through porting are modeled using general functions and our general-form results point the policy-maker in the direction of the effects, the magnitude of these effects depend on the specific situation and therefore the parameter estimates from a parameterized model. Future research can focus on parameterizing and estimating the model based on the specific characteristics of each market in question. Moreover, we consider fines that are consistently and fairly imposed across different circumstances of DCs in different industries. In practice, the particular situation of the violating DCs and the nature of violations may play an outsized role in determining the fines. Even though significant deviations are banned in DPR legislation (e.g., both GDPR and the ACCESS Act specify consistency mechanisms and allow for judicial protection and due process to prevent arbitrary imposition of fines), in practice, slight deviations in implementation of the policy are possible. For example, the supervisory authority may decide to be more lenient in imposing a fine on a financially unstable DC. Our model, consistent with the DPR policies currently in place, does not capture such circumstances and idiosyncrasies. Policy-makers may be able to prevent some of the collateral effects that we identify through more nuanced policies or through flexible implementation. Finally, as we incorporate definitions of participation and industry concentration in our analysis that are straightforward analogues of widely-used measures, our analytical results provide testable hypotheses to empirically study the effects of DPR in different jurisdictions.

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References

Asvanund A, Clay K, Krishnan R, Smith MD (2004) An empirical analysis of network externalities in peer-to-peer music-sharing networks. *Information Systems Research* 15(2):155–174.

Australian Banking Association (2025) Open banking. `https://www.ausbanking.org.au/priorities/open-banking`.

Bakos JY, Nault BR (1997) Ownership and investment in electronic networks. *Information Systems Research* 8(4):321–341.

Bhargava HK (2021a) Bundling for flexibility and variety: An economic model for multiproducer value aggregation. *Management Science* 67(4):2365–2380.

Bhargava HK (2021b) Bundling for flexibility and variety: An economic model for multiproducer value aggregation. *Management Science* 67(4):2365–2380.

Bhargava HK (2022) The creator economy: Managing ecosystem supply, revenue sharing, and platform design. *Management Science* 68(7):5233–5251.

Braulin FC, Valletti T (2016) Selling customer information to competing firms. *Economics Letters* 149:10–14.

Brynjolfsson E (1994) Information assets, technology and organization. *Management Science* 40(12):1645–1662.

California State Legislature (2018) California consumer privacy act of 2018. `http://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?division=3.&part=4.&lawCode=CIV&title=1.81.5`.

Chellappa RK, Mukherjee R (2021) Platform preannouncement strategies: The strategic role of information in two-sided markets competition. *Management science* 67(3):1527–1545.

Cho S, Qiu L, Bandyopadhyay S (2016) Should online content providers be allowed to subsidize content?—an economic analysis. *Information Systems Research* 27(3):580–595, ISSN 1047-7047, 1526-5536, URL `http://dx.doi.org/10.1287/isre.2016.0641`.

Christensen L, Colciago A, Etro F, Rafert G (2013) The impact of the data protection regulation in the EU. *Intertic Policy Paper* .

Competition and Markets Authority (2021) Corporate report update on open banking. URL `https://www.gov.uk/government/publications/update-governance-of-open-banking/update-on-open-banking`.

Council of European Union (2016) Regulation 2016/679 of the European Parliament and of the Council (GDPR). `http://data.europa.eu/eli/reg/2016/679/oj`.

Council of European Union (2022) Regulation 2022/1925 of the European Parliament and of the Council (DMA). `http://data.europa.eu/eli/reg/2022/1925/oj`.

Cyphers B, O'Brien D (2018) Facing Facebook: Data portability and interoperability are anti-monopoly medicine. *EFF* URL `https://www.eff.org/deeplinks/2018/07/facing-facebook-data-portability-and-interoperability-are-anti-monopoly-medicine`.

de Corniere A, Taylor G (2020) Data and competition: A general framework with applications to mergers, market structure, and privacy policy. *CEPR Discussion Paper No. DP14446* .

Deshpande V, Narahari N (2014) Statistical modelling approach to estimation of average revenue per user in telecom service-a case study. *International Journal of Scientific Engineering and Technology* 3(5):557–60.

Dixit AK, Stiglitz JE (1977) Monopolistic competition and optimum product diversity. *The American economic review* 67(3):297–308.

Dou Y, Wu D (2021) Platform competition under network effects: Piggybacking and optimal subsidization. *Information Systems Research* 32(3):820–835.

Economides N, Katsamakas E (2006) Two-sided competition of proprietary vs. open source technology platforms and the implications for the software industry. *Management science* 52(7):1057–1071.

European Political Strategy Centre (2017) EU policies for a thriving data ecosystem. *European Political Strategy Centre* (21).

Farboodi M, Mihet R, Philippon T, Veldkamp L (2019) Big data and firm dynamics. *AEA papers and proceedings*, volume 109, 38–42 (American Economic Association 2014 Broadway, Suite 305, Nashville, TN 37203).

Gal-Or E, Gal-Or R, Penmetsa N (2018) The role of user privacy concerns in shaping competition among platforms. *Information Systems Research* 29(3):698–722.

Goldman D (2016) 10 years later, twitter still isn't close to making money. *CNN Business* URL `https://money.cnn.com/2016/03/21/technology/twitter-10th-anniversary/`.

Graef I, Verschakelen J, Valcke P (2013) Putting the right to data portability into a competition law perspective. *Law: The Journal of the Higher School of Economics, Annual Review* 53–63.

Gu B, Konana P, Rajagopalan B, Chen HWM (2007) Competition among virtual communities and user valuation: The case of investing-related communities. *Information systems research* 18(1):68–85.

Hagiu A, Wright J (2023) Data-enabled learning, network effects, and competitive advantage. *The RAND Journal of Economics* 54(4):638–667.

Hart O, Moore J (1990) Property rights and the nature of the firm. *Journal of political economy* 98(6):1119–1158.

Hölmstrom B (1979) Moral hazard and observability. *The Bell journal of economics* 74–91.

Jehle GA, Reny P (2011) *Advanced microeconomic theory* (Financial Times/Prentice Hall), 3rd ed. edition, ISBN 9780273731917.

Katz ML, Shapiro C (1985) Network externalities, competition, and compatibility. *The American economic review* 75(3):424–440.

Kenton W (2022) What is average revenue per unit (ARPU)? URL `https://www.investopedia.com/terms/a/arpu.asp`.

Kim JH, Wagman L, Wickelgren AL (2019) The impact of access to consumer data on the competitive effects of horizontal mergers and exclusive dealing. *Journal of Economics & Management Strategy* 28(3):373–391.

Lam WMW, Liu X (2020) Does data portability facilitate entry? *International Journal of Industrial Organization* 69:102564.

Lambert RA (2001) Contracting theory and accounting. *Journal of accounting and economics* 32(1-3):3–87.

Levi MD, Nault BR (2004) Converting technology to mitigate environmental damage. *Management Science* 50(8):1015–1030.

McGuire J (2021) Strava review: the best training app for stat-obsessed runners. *Tom's Guide* URL `https://www.tomsguide.com/reviews/strava-review`.

Mei X, Cheng HK, Bandyopadhyay S, Qiu L, Wei L (2022) Sponsored data: Smarter data pricing with incomplete information. *Information Systems Research* 33(1):362–382, ISSN 1047-7047, 1526-5536, URL `http://dx.doi.org/10.1287/isre.2021.1063`.

Melitz MJ (2003) The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica* 71(6):1695–1725, ISSN 0012-9682, 1468-0262, URL `http://dx.doi.org/10.1111/1468-0262.00467`.

Meta Platforms Inc (2021) Annual Report. `https://www.sec.gov/Archives/edgar/data/1326801/000132680122000018/fb-20211231.htm`, accessed: 2025-04-14.

Nault BR (1996) Equivalence of taxes and subsidies in the control of production externalities. *Management Science* 42(3):307–320.

Nault BR, Zimmermann S (2019) Balancing openness and prioritization in a two-tier internet. *Information Systems Research* 30(3):745–763.

Nocco A, Ottaviano GIP, Salto M (2014) Monopolistic competition and optimum product selection. *American Economic Review* 104(5):304–309, ISSN 0002-8282, URL `http://dx.doi.org/10.1257/aer.104.5.304`.

OECD (2021) Mapping data portability initiatives, opportunities and challenges (321), URL `http://dx.doi.org/https://doi.org/https://doi.org/10.1787/a6edfab2-en`.

Rodriguez S (2019) Why facebook generates much more money per user than its rivals. *CNBC* URL `https://www.cnbc.com/2019/11/01/facebook-towers-over-rivals-in-the-critical-metric-of-revenue-per-user.html`.

Salop SC (1979) Monopolistic competition with outside goods. *The Bell Journal of Economics* 141–156.

Seamans R, Bytes W (2018) Data portability and competition between technology platforms. *Forbes* URL `https://www.forbes.com/sites/washingtonbytes/2018/03/06/data-portability-and-competition-between-technology-platforms`.

Strava (2024) Exporting your data and bulk export. `https://support.strava.com/hc/en-us/articles/216918437-Exporting-your-Data-and-Bulk-Export`.

Swire P, Lagos Y (2012) Why the right to data portability likely reduces consumer welfare: antitrust and privacy critique. *Md. L. Rev.* 72:335.

Tirole J (1988) *The theory of industrial organization* (MIT press).

United States House Committee on the Judiciary (2021) Augmenting compatibility and competition by enabling service switching (access act 2021). URL `https://www.congress.gov/bill/117th-congress/house-bill/3849`.

United States House of Representatives (2020) Majority staff report and recommendations on investigation of competition in digital markets.
`https://judiciary.house.gov/uploadedfiles/competition_in_digital_markets.pdf`.

Wohlfarth M (2019) Data portability on the Internet. *Business & Information Systems Engineering* 61(5):551–574.

Xie J, Zhu W, Wei L, Liang L (2021) Platform competition with partial multi-homing: When both same-side and cross-side network effects exist. *International Journal of Production Economics* 233:108016.

Yoo B, Choudhary V, Mukhopadhyay T (2007) Electronic b2b marketplaces with different ownership structures. *Management Science* 53(6):952–961.