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Platform Competition and Incumbency Advantage under Heterogeneous Lock-in effects

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ABSTRACT

Digital platform markets perform a myriad of daily transactions, providing internet-mediated exchange possibilities: between consumers, for peer-to-peer exchanges; between businesses, for digital value chains; and between businesses and consumers, in digital marketplaces. It is essential for competition that new entrants are able to join platform markets. However, these markets are often characterised by proprietary innovations, especially in data analytics applied to existing user data. The algorithmic analysis of user data and information might increase incumbency advantages, creating lock-in effects among users and making them more reluctant to join an entrant platform. The individual costs of these lock-in effects may differ between the sides of a platform, e.g., between sellers and buyers, and across users within each side, e.g., between sellers with different costs and/or propensities to join an entrant platform. Moreover, these costs will interact with cross-group network effects, another well-studied source of incumbency advantage. This paper develops a model exploring how different levels of lock-in effects may favour an incumbent platform. The conditions for platforms' coexistence, to avoid market tipping, require lock-in effects to be "stronger" than cross-group effects. However, this condition also provides a market advantage to the incumbent platform compared to the entrant's. Therefore, policies aimed at reducing lock-in effects, such as mandating data portability, may counterintuitively impair entry conditions as the incumbent sets its prices more aggressively with lower lock-in effects.

1. Introduction

The increasing prominence of digital platforms poses challenging questions for new entrants, users, and regulators (Cremer et al., 2019; Furman et al., 2019; OECD, 2018; Scott Morton et al., 2019 and Schweitzer et al., 2018). A platform entering a two-sided market faces a competitive disadvantage due to user expectations about the incumbent's network size (Caillaud and Jullien, 2001, 2003; Hagiu 2006; and Jullien, 2011). The existence of cross-side network effects reinforces entry barriers (Biglaiser et al., 2020; and Halaburda and Yehenzkel, 2016), so that even a platform providing superior services may be unable to enter due to user coordination failures (Halaburda and Yehezkel, 2019; and Halaburda et al., 2020). Biglaiser et al. (2019) identified personal data as a possible cause of incumbency advantage since data are fed into algorithms used by the platforms to improve their matching ability for users across the different sides of the platform. Typical examples of these advantages are provided by Web mapping services, such as Google Maps, which train their algorithms with information sourced from users' geolocations to provide better-quality services to other users. Similarly, search engines develop centrality metrics based on user queries to build both meaningful rankings for search results and targeted advertising. Hence: "If a user has been a client of a platform for some time, the platform knows his or her tastes and can give more prominence to goods or services that he or she prefers. Second, the platform can use the data stemming from other users to increase the quality of the service to each of its users" (Biglaiser et al. (2019) page 44). This might apply to platforms such as Strava, identified as a typical example of a differentiated platform by Jullien and Sand-Zantman (2021). However, within the market of its "niche" users, Strava introduces clear lock-in elements by keeping track of users' progress and comparing achievements against "your friends", that is, other users on selected roads or trails. This platform even allows users to match "runs and rides on the same route so you can see how your performance changes over time." "Over 100 million athletes in 195 countries use Strava, so whatever your activity and goals, you'll have a community at your back." (https://www.strava.com/about). An entrant into this market will have to overcome high lock-in

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effects, and multihoming would not be of particular relevance. Similarly, loans-based crowdfunding platforms such as Kiva, which offers "crowdfunding loans and unlocking capital for the underserved, improving the quality and cost of financial services, and addressing the underlying barriers to financial access around the world" (https://www.kiva.org/about), provide additional examples of how network social capital (Davies and Giovannetti, 2022) might be a crucial element in funding success, generating key lock-in effects. The incumbent's knowledge of its customer data may also induce lock-in effects, particularly if algorithms rely on this data to personalise products and advertisements. Also, when users assess the possibility of moving to a new platform, they may be concerned about the potential loss of their contacts' details, application choices, or other individual data kept in the incumbent's system. On e-commerce platforms, sellers changing marketplaces might lose their reputational histories based on previous customers' ratings and reviews (Franck and Peitz, 2019). Similar effects have been described as platforms increasingly provide integration tools, such as application programming interfaces (API), for third-party content developers that may face increased costs of joining an entrant platform relying on incompatible API standards (see Tan et al., 2020). Hence, this paper focuses on the specific challenge of better understanding the strategic relevance of these lock-in effects for incumbency advantage and competition in digital platform markets. This relevance is analysed in its interaction with the better explored role played by cross-side network effects. It is worth pointing out that these types of lock-in effects in digital platforms can entail a permanent loss of utility, leading to calls to facilitate personal data portability to help facilitate entry into the digital platform markets (Gans, 2018; and Coyle, 2018). Lack of data and identity portability can affect agents to different degrees depending on how much they rely on data stored with the incumbent or indirectly linked to other "matched" users through the incumbent's matchmaking services. This can especially be the case where the same platform provides a bundle of personalised services that hinge on creating a shared, detailed, and multifaceted digital profile of user identities and individual preferences, while the entrant only provides some. Hence, changing platforms could persistently degrade the quality of these personalised services. Arguably, this new type of lock-in effect could have different intensities, both within and between the two sides of a platform, due to various exogenous factors shaping user preferences. The presence of these permanent lock-in effects that favour the incumbent platform can also be thought of as a source of vertical differentiation in the sense that, all else being equal, users would prefer to stay with the incumbent and not incur the corresponding loss due to choosing the entrant. This paper provides novel results on how the interaction between these permanent lock-in effects and cross-side network effects jointly affect market competition and incumbency advantage in two-sided platform markets. These results are obtained by developing a singlehoming model where users on either of the two sides, e. g., application developers and users, or buyers and sellers already affiliated with an incumbent platform, have the choice to switch to a new entrant but not to stay with both. However, by moving to the entrant platform, users face a persistent loss of utility that can differ, both within and between sides, due, for example, to varying degrees of personalization built up within their existing provider. These differences are captured in the model, allowing heterogeneity of the lock-in cost parameters both within and between the two sides. As pointed out by Belleflamme et al. (2022), "in the real world, singlehoming environments may result from indivisibilities and limited resources or from contractual restrictions." In this respect, it is also worth pointing out that the kind of lock-in effects described above would typically give rise to indivisibilities and demand-side frictions underpinning a singlehoming environment. As a general remark, the extent to which lock-in effects differ across users operates as a separating or partitioning device, whereby the new entrant targets those agents on both sides with relatively lower lock-in costs and can do so by charging higher prices as the distance from the high-cost customers targeted by the incumbent platform (on the same side) grows. This is especially the case for those located on the side of the platform with comparatively higher lock-in costs. Therefore, a regulatory intervention aimed at helping locked-in users might unintentionally undermine the entrant's prospect of gaining a sustainable foothold in the market. The incumbent naturally responds to such intervention by setting lower prices, thus squeezing out the entrant. Indeed, our novel results show that the market shares of the incumbent grow (on either side) when the extent of lock-in costs is reduced. We find of particular interest that this, counterintuitive, negative relation between lock-in costs and incumbent market shares remains valid for a reduction in lock-in costs taking place on either side of the platform, so a reduction in lock-in costs on the consumer side would increase the incumbent market share on both the seller and the consumer sides of the platform and vice versa. More fundamentally, though, this source of demand-side frictions and preference heterogeneity is needed to avert the kind of tipping and "winner-takes-all" outcomes that would doom the prospect of sustainable entry. That is to say, the parameter range of the lock-in costs within each side has to be sufficiently larger compared to the importance of network effects for the co-existence between the two rival platforms to be feasible and viable from the entrant's perspective. Our model provides additional insights into subtler but nevertheless interesting effects. We find that a reduction in lock-in costs on one side is detrimental to high-cost users on the opposite side when they care more about cross-group network effects. This effect might arise, for example, with a regulatory intervention aimed at protecting high-cost end-users of an e-marketplace platform (i.e., lock-in costs tend to be higher on the consumer side). In contrast, sellers on the other side are comparatively more concerned about the number of buyers shopping online. Under these circumstances, the incumbent platform can capitalise on the resulting increase in market share on the buyer side, as it becomes more aggressive by charging sellers more to extract the improved network benefits. Our paper also shows that both the new entrant's profit and market shares fall when there is a reduction in lock-in costs. At the same time, from a consumer surplus perspective, we find an inverted-U relationship between the aggregate user surplus and the level of same-side lock-in costs. This finding implies that intervention aimed at lowering the impact of lock-in costs would certainly be positive in terms of consumer surplus when these costs are very high, although the entrant's market shares on both sides would fall. However, at an intermediate level of lock-in costs, further reductions in the entrant's market shares in response to a reduction in these costs would also be detrimental in terms of consumer surplus, i.e., to the extent that the incumbent can retain a larger proportion of customers paying comparatively higher prices. From a distributional perspective, however, users with high lock-in costs (i.e., those retained by the incumbent) always benefit from a reduction in these costs, and this result might be of critical policy relevance. The rest of the paper is structured as follows: Section 2 presents a brief literature review; Section 3 introduces the model and derives the main results, briefly sketched above. Section 4 discusses the welfare analysis. Policy implications, limitations of this analysis, and possible extensions are discussed in the concluding Section 5.

2. Literature review

This paper focuses on the interplay between cross-network externalities and asymmetric lock-in costs when both sides can choose between staying with an incumbent platform and joining an entrant. The permanent lock-in costs represent a form of brand loyalty, which might be due to many sources, and they benefit the incumbent. What matters is that these costs, born by every platform user when joining the entrant, are asymmetric both within and between the two platform sides. Armstrong (2006) provides the key paper on platform competition with subscription fees using a Hotelling (1929) style 'transport' cost reflecting horizontal differentiation, whereby agents derive cross-group benefits proportional to the users on the other side (Kaiser and Wright, 2006). We follow Armstrong (2006) in assuming that cross-group network benefits are specific to the platform side, e.g., between buyers and sellers, without depending on which platform agents are affiliated with (Rochet and Tirole, 2003).[1]

Our modelling assumption resembles the presence of a vertical quality parameter, whereby the incumbent has a quality advantage, and users differ in their preference for higher quality (Shaked and Sutton, 1983).[2] Essentially, the lock-in cost in our model measures a relative preference for the incumbent. This scenario is symmetric to that of Zhu and Iansiti (2011), focussing on the role of indirect network effects on competition between an entrant with superior quality and an incumbent platform with an installed-base advantage.

Our setting can also be seen as a Hotelling (1929) model with two firms of different qualities. Thus, an increase or decrease in lock-in costs could also be interpreted as an increase/decrease in transportation cost across firms with different qualities. However, while the presence of unilateral vertical differentiation improves consumer utility, the lock-in costs we are considering only represent a potential utility loss when choosing to join an entrant.

In an explicit intertemporal setting, Lam (2017) extends Armstrong's (2006) model to a two-period framework where agents face a homogeneous (one-off) switching cost that differs between the two sides. The author finds that platforms set *penetration prices* for users located on the side with lower switching costs to entice more members on the opposite side. Though, in Lam's case, competition is between equal incumbents. Tremblay (2019)[3] studies a two-period model where users differ in the intensity of content fruition, thus resulting in heterogeneous switching costs. The author finds that the incumbent platform subsidises content provision in the first period over the membership fee to strengthen the resulting lock-in effect. Nevertheless, contrary to our case, switching costs are present only on one side of the platform.

Gabszewicz and Wauthy (2014) rely on the cross-group benefit parameter as the source of preference heterogeneity. This assumption, however, does not allow the investigation of the effect of a change in the degree of preference heterogeneity on either side, given that neither equilibrium prices nor market shares depend on the corresponding heterogeneous preference parameters. Our model overcomes this limitation by relying on different, side-specific lock-in cost distributions to introduce preference heterogeneity both between and within platform sides.

Finally, Belleflamme et al. (2022) extend Armstrong's (2006) model by allowing the duopolistic platforms to differ in all the relevant parameters, including the stand alone benefit from joining a platform.[4] This is tantamount to a constant and asymmetric difference in (vertical) quality preferences. When the difference between the stand-alone benefit parameters is large enough to fully offset the largest transport cost with respect to the high-quality platform, this configuration is isomorphic to our setting with heterogeneous preferences for quality. Our focus is, however, on offering a detailed welfare analysis of the potential unintended consequences of policies aimed at facilitating competition in this setting and providing important insights into the effects of alternative regulatory frameworks.

3. The model

There are two sets of users benefiting from trading with each other across a two-sided intermediary platform. In the following, these two sides are indicated as A and B. Normalising the size of each group to one, let $m_j^i \in [0, 1]$, with $i = I, E$, and $j = A, B$, be the market shares of the incumbent's (I) and entrant's (E) platforms, on each one of the two sides (A and B). Both I and E platforms have the unconstrained capacity to serve any proportion of the market. They have a common constant marginal cost normalised to zero, on each side, to provide services to an additional customer. Users on both sides derive positive cross-group network effects. These are linearly increasing with the proportion of users located on the opposite side who choose the same platform. These cross-group positive network effects, α_j, are the same for each user within each side, but may differ between the two sides, $j = A, B$. Platforms compete in prices, typically membership fees. These differ for each platform across the two sides, p_j^i, so we focus on equilibria characterised by four equilibrium prices that can be positive or negative (to entice one side to join given the cross-side benefits that arise to the other side). Each user enjoys a common utility, v, from the services provided by the platform, no matter whether this is I or E, and v is high enough so that both sides (markets) are fully covered, reflecting a typical platform market for commoditised services with saturated demand. Initially, on both sides, users are all customers of I, which provides platform I with the type of incumbency benefits discussed in the introduction due, for example, to the stored personal data used to train its algorithms.

A crucial aspect of our model is that it captures user differences in how loyal they are to the incumbent platform they belong to. We capture this aspect by assuming that agents are heterogeneous with respect to their realisation of the lock-in costs, i.e., if they decide to join the entrant, E, users suffer different lock-in costs, s_j, according to a uniform distribution over the range: $s_j \in [0, \overline{s_j}]$. These lock-in costs differ along two dimensions: *between* sides, $j = A, B$, as we allow for different upper distribution limits, $\overline{s_A} \neq \overline{s_B}$, and *within* each side, as for each user, these costs would fall at different points within the selected ranges: $s_A \in [0, \overline{s_A}]$ and $s_B \in [0, \overline{s_B}]$.

In what follows, we assume *singlehoming* - users can only be members of either E or I. Based on this structure, the two platforms, I and E, set the joining prices simultaneously, p_j^i, one per platform and per side. Users, based on the observed prices, p_j^i, common utility, v, cross-group positive network effects, α_j and their known individual realisation of lock-in cost s_j, select whether to stay with the incumbent platform or join the entrant.

3.1. Demand, market shares and reaction functions

The key decision for platform users is *whether to join* the entrant or *stay with* the incumbent. This decision is taken by

[1] See Jullien et al. (2021) for a comprehensive and up to date literature review covering the details of these models.

[2] Similarly, our model specification is isomorphic to a scenario where users have different degrees of brand loyalty for the incumbent (i.e., a negative term in the utility from leaving the incumbent, in contrast to the symmetric transport cost under the Armstrong (2006) horizontal differentiation specification).

[3] Similarly, in Lam and Liu (2020) users stand to lose the benefits from personalised recommendations and enhanced data services in general upon switching to another platform in the second period. The authors research the impact of data portability whereby the entrant can rely on the data provided by users to the incumbent platform in the previous period, but not match the ability to offer enhanced personalised services.

[4] Similarly, Belleflamme and Toulemonde (2018) extend Armstrong (2006) 's Hotelling framework by assuming that one of the two otherwise symmetric platforms has a unit (per user) cost advantage, which can vary between sides.

comparing the two different utility levels that can be reached. In detail, a user belonging to side j will be equally willing to stay with I or join E, when the difference in utilities, due to the difference in cross-platform effects and prices, equals a threshold in the lock-in effect, i.e., a cost s_j^*, that is:

$$s_j^* = \left(p_j^I - p_j^E\right) + \alpha_j\left(1 - 2m_{-j}^I\right) \tag{1}$$

since s_j^* is the value that equalises the utilities of the two choices:

$$v + \alpha_j\left(1 - m_{-j}^I\right) - p_j^E - s_j^* = v + \alpha_j m_{-j}^I - p_j^I$$

Under the assumption of uniform distribution for the lock-in costs on each side, users having higher lock-in effects, above this critical level, $s_j > s_j^*$, remain with I. From this indifference condition, after identifying the critical threshold, s_j^*, it is possible to derive the incumbent and the entrant's side j market shares m_j^I and m_j^E, as:

$$m_j^I = \frac{\overline{s_j} - s_j^*}{\overline{s_j}} = \frac{\overline{s_j} - \alpha_j\left(1 - 2m_{-j}^I\right) - \left(p_j^I - p_j^E\right)}{\overline{s_j}}; \text{ and}$$

$$m_j^E = \left(1 - m_j^I\right) \tag{2}$$

Solving (2) for m_j^I and m_{-j}^I, it is easy to derive the four market shares, one each for incumbent and entrant on each one of the sides of the platform, as a function of the four different prices chosen simultaneously by the two platforms for each side:

$$m_j^I = \frac{\overline{s_{-j}}\left(\overline{s_j} - \alpha_j + p_j^E - p_j^I\right) + 2\alpha_j\left(\overline{s_{-j}} - \alpha_{-j} + p_{-j}^E - p_{-j}^I\right)}{\overline{s_j s_{-j}} - 4\alpha_j\alpha_{-j}} = 1 - m_j^E \tag{3}$$

Due to the assumption of zero marginal costs of serving a new user, the profits of each platform are equivalent to the sum of revenues a platform raises from each side: $\pi^i = \sum_j p_j^i m_j^i,\ \ j = A, B \text{ and } i = I,\ E.$

Given that prices, p_j^i, are a linear factor in the equation for the market shares equation, Eq. (3), the profit (revenue) functions, π^i, are concave in prices, if and only if the denominator is strictly positive, $\overline{s_j s_{-j}} - 4\alpha_j\alpha_{-j} > 0$. This concavity requirement can be seen as capturing a tension between lock-in effects and cross-group benefits. For example, under the simplifying assumptions that $\overline{s_j} = \bar{s}$ and $\alpha_j = \alpha$ (both for $j = A, B$), this concavity requirement, simplifies into: $\bar{s} > 2\alpha$. This result is similar to a condition derived by Armstrong (2006) in the context of a symmetric horizontal differentiation model. Hence, it is not surprising that the condition developed under our asymmetric framework is more demanding.[5]

From the first-order conditions of the profit functions, under concavity, we can obtain the reaction functions as four strategic price equations, p_j^i, with $i = E, I \text{ and } j = A, B$,

$$p_j^I = \frac{p_j^E + \alpha_j + \overline{s_j}}{2} - \frac{\alpha_{-j}\left(p_{-j}^I + \alpha_j\right)}{\overline{s_{-j}}} - \frac{\alpha_j\left(p_{-j}^I - p_{-j}^E\right)}{\overline{s_{-j}}} \tag{4a}$$

$$p_j^E = \frac{p_j^I - \alpha_j}{2} - \frac{\alpha_{-j}\left(p_{-j}^E + \alpha_j\right)}{\overline{s_{-j}}} + \frac{\alpha_j\left(p_{-j}^I - p_{-j}^E\right)}{\overline{s_{-j}}} \tag{4b}$$

[5] Specifically, the corresponding condition in Armstrong (2006) is: $4t_j t_{-j} - (\alpha_j + \alpha_{-j})^2 > 0$ where $t_j,\ j = 1, 2$ is the source of symmetric demand-side friction. The analogous condition derived in Belleflamme and Toulemonde (2018) is more complex in that it depends on the interaction between three types of parameters: the symmetric transport costs, the cross-group network benefits and the asymmetric cost advantage.

Discussion. These price equations (4a & 4b) offer valuable conclusions. Starting by considering a non-platform setting, i.e., one without cross-group benefits Eqs (4a & 4b) simplify into $p_j^{I*} = \frac{2\overline{s_j}}{3}$ and $p_j^{E*} = \frac{\overline{s_j}}{3}$, confirming that the presence of heterogeneous lock-in costs alone advantages the incumbent (see also Shaffer & Zhang, 2000). The second term of these price Eqs. (4a & 4b) reflects the one Armstrong (2006) identified as the discounting 'adjustment factor'. In detail, $(p_{-j}^I + \alpha_j)$ and $(p_{-j}^E + \alpha_j)$, the brackets in the second terms of Eqs. (4a & 4b), express the incremental benefit on side j, due to the platform recruiting one more subscriber on the opposite side $-j$. Indeed, in addition to the subscription prices p_{-j}^i, a platform is also able to extract a value equal to the cross-group benefits term, $\alpha_{j,}$ for each platform member located on the opposite side, $-j$ (see also Belleflamme and Peitz, 2019). The minus signs of these second terms in the price equations for each side, A or B, capture a lower pricing strategy to entice more users on the opposite side of the platform.

Finally, the third and final element of the price Eqs. (4a & 4b) captures an additional adjustment element due to the interplay between lock-in effects and the intensity of cross-group network benefits. Specifically, the expression $\frac{(p_{-j}^I - p_{-j}^E)}{\overline{s_{-j}}}$ represents the rate at which the incumbent platform, I, loses subscribers on the side $-j$, by charging a higher price than that of the entrant. Thus, the last element of Eq. (4a), $-\frac{\alpha_j(p_{-j}^I - p_{-j}^E)}{\overline{s_{-j}}}$, captures the amount of utility lost by each user on side j when the incumbent's market share on the side -j, declines due to the price manipulation of lock-in effects. It is also interesting to notice the different signs of this third term of the pricing equations. While, indeed, this factor is compensating the customers of the incumbent on side j, as it indicates a reduction of their membership prices, the opposite effect is at work for the entrant's customers on the same side of the platform, hence the different signs of these last terms in the pricing equations.

3.2. Symmetrical cross-group benefits

As a first step, we consider the simpler case of symmetrical cross-group network benefits between the two platform sides ($\alpha_A = \alpha_B = \alpha$). While this assumption might have a strong flavour, the impact of asymmetrical cross-group benefits has been widely studied in the early two-sided platforms literature. This initial assumption of symmetrical cross-group network benefits facilitates understanding a novel set of questions, focusing on asymmetrical lock-in effects with simple analytical solutions. In this setting, Lemma 1 below characterises the equilibrium prices under asymmetric lock-in effects and symmetrical cross-group benefits.

Lemma 1. Equilibrium Prices

Under symmetrical cross-group benefits and asymmetric lock-in effects, the platforms pairs of equilibrium prices, p_j^{i*} are given by:

$$p_j^{I*} = \frac{2\overline{s_j}}{3} - \alpha \text{ and } p_j^{E*} = \frac{\overline{s_j}}{3} - \alpha \tag{5}$$

Discussion. Lemma 1 shows that price differentials between entrant and incumbent on both sides increase linearly with the same side's lock-in costs: $p_j^{I*} - p_j^{E*} = \frac{\overline{s_j}}{3}$. Thus, showing the function of *asymmetric* lock-in effects in generating a competitive advantage from incumbency.

Second, Lemma 1 also shows that equilibrium prices are higher, for both platforms, on the market side where lock-in effects are higher. Moreover, if lock-in costs indicate some form of customer vulnerability, equilibrium prices may raise issues concerning fairness of the resulting allocations. If, indeed, lock-in effects are linked to demographic characteristics or informational disparities, customers of the incumbent platform would also pay higher prices for the same service, as shown by Lemma 1.

The result that prices rise with the range of same-side lock-in effects supports the view that asymmetrical lock-in costs allow better market segmentation, as the entrant focuses on agents with a relatively lower level of lock-in effects, while the incumbent, serving customers with higher lock-in cost, increases its equilibrium prices by twice as much as the entrant in response to an increase in these lock-in costs. Finally, from Lemma 1, it is easily seen that the lock-in effects must be considerably greater than the cross-group benefits for the entrant's equilibrium prices to remain above zero, since $p_j^{E*} = \frac{\overline{s_j}}{3} - \alpha$. This last condition, required for the entrant prices to be non-negative, is stricter than that obtained above for the profit concavity. For example, under the additional simplifying assumption that: $\overline{s_j} = \bar{s}$ (for $j = A, B$), the entrant's equilibrium prices are positive for: $\bar{s} > 3\alpha$. The key point to emphasise is that entry viability strongly rests on a sufficiently wide heterogeneity of lock-in costs. Hence, as long as policy and regulatory intervention try to lower barriers to entry by reducing the range of lock-in costs, as an unintended result, the incentives to entry might be reduced.

Remarkably, from Equation (5), we can see that equilibrium prices do not depend on the lock-in effects experienced on the opposite side of the platform. Lastly, it is relevant to notice that equilibrium prices decrease with the intensity of the cross-platform benefits. This finding is further corroborated by Proposition 1, below, focussing on the equilibrium market shares.

Proposition 1. Lock-in costs and market shares

Under symmetrical cross-group benefits and asymmetric lock-in effects:

a) *Equilibrium market shares, m_j^{i*}, for $i = E, I$ and $j = A, B$ are given by:*

$$m_j^{I*} = \frac{2\overline{s_j s_{-j}} + \overline{s_{-j}}\alpha - 6\alpha^2}{3\left(\overline{s_j s_{-j}} - 4\alpha^2\right)}, \text{ and } m_j^{E*} = 1 - \frac{2\overline{s_j s_{-j}} + \overline{s_{-j}}\alpha - 6\alpha^2}{3\left(\overline{s_j s_{-j}} - 4\alpha^2\right)} \tag{6}$$

b) *The incumbent's market share is larger on the side where lock-in effects are lower: $m_j^{I*} \geq m_{-j}^{I*} \Leftrightarrow \overline{s_j} \leq \overline{s_{-j}}$ while the opposite holds for the entrant, E.*
c) *The market shares of the incumbent platform are at least twice as large as those of the entrant;*[6] *and*
d) *The condition for the entrant's market share to be positive is more demanding than the one for profit concavity.*

Discussion. Regarding point *b)*, this is the case since we have seen in Lemma 1 that higher lock-in effects lead to higher prices and that the price difference between I and E is increasing in $\overline{s_j}$. Hence, the market share of the incumbent is smaller on the platform side, where the lock-in effects, $\overline{s_j}$ are higher. This point is clearly shown in Fig. 1 below, representing the two sides' incumbent's market shares, as declining with lock-in effects on side j, and where the incumbent's market shares' crossing point takes place at $\overline{s_{-j}} = \overline{s_j} = 8$.

Concerning point *c)*, despite the results from Lemma 1 that the incumbent's prices premium increases in the lock-in effects on the same side, the incumbent still manages to retain at least two-thirds of the customer base on each side. This effect is mainly due to asymmetric lock-in effects, since also with very small cross-group network benefits, the incumbent would retain two-thirds of each market. Finally, it is relevant to notice that entry is viable only under the following condition: $m_j^{I*} < 1,\ if\ \overline{s_j s_{-j}} - \overline{s_{-j}}\alpha - 6\alpha^2 \geq 0$. It is interesting to emphasise that this condition is always tighter than the profit concavity condition discussed above: i.e.: $\overline{s_j s_{-j}} - \overline{s_{-j}}\alpha - 6\alpha^2 < \overline{s_j s_{-j}} - 4\alpha^2$ unless $\overline{s_{-j}} = \alpha = 0$.

For example, under the additional simplifying assumption that $\overline{s_j} = \bar{s}$ (for $j = A, B$), the entrant's market shares are positive for: $\bar{s} > 3\alpha$,[7] which coincides with the condition for the positivity of the entrant's prices previously discussed.

Next, in Corollary 1, we address how cross-group network effects affect the incumbent's market share when there are heterogeneous lock-in effects.

Corollary 1. Cross-group benefits and incumbent's market shares

Under symmetrical cross-group benefits and asymmetric lock-in effects:

a) *An increase in cross-group benefits leads to larger market shares for the incumbent on both sides of the platform.*

$$\frac{\partial m_j^{I*}}{\partial \alpha} = \frac{\overline{s_{-j}}\left(\overline{s_j s_{-j}} + 4\alpha\left(\overline{s_j} + \alpha\right)\right)}{3\left(\overline{s_j s_{-j}} - 4\alpha^2\right)^2} > 0 \tag{7}$$

b) *This positive effect on the incumbent market shares is greater on the platform's side with lower lock-in effects.*

Discussion. Regarding *a)*, it is relevant to notice, again, how cross-group benefits increase the competitive advantage of the incumbent platform. Concerning point *b)*, it demonstrates how differences in brand loyalty may help strengthen the incumbent's competitive advantage due to cross-group benefits on the platform side with lower lock-in effects.

In summary, we have seen that under symmetrical cross-group benefits, asymmetric lock-in effects provide an incumbent's competitive advantage. This finding is reflected in the expressions for the equilibrium profits, reported below, showing how the incumbent makes higher profits than the entrant by charging higher prices to a larger market share:

$$\pi^{I*} = \frac{\left(\overline{s_j} + \overline{s_{-j}}\right)\left(4\overline{s_j s_{-j}} - 15\alpha^2\right) - 4\alpha\left(2\overline{s_j s_{-j}} - 9\alpha^2\right)}{9\left(\overline{s_j s_{-j}} - 4\alpha^2\right)} \tag{8a}$$

$$\pi^{E*} = \frac{\left(\overline{s_j} + \overline{s_{-j}}\right)\left(\overline{s_j s_{-j}} - 3\alpha^2\right) - 4\alpha\left(2\overline{s_j s_{-j}} - 9\alpha^2\right)}{9\left(\overline{s_j s_{-j}} - 4\alpha^2\right)} \tag{8b}$$

$$\Delta\pi = \pi^{I*} - \pi^{E*} = \frac{\overline{s_j} + \overline{s_{-j}}}{3} > 0 \tag{8c}$$

Next, we move to analyse the effects of asymmetric lock-in costs on the incumbent's market shares.

Corollary 2. Lock-in effects and incumbent's market shares

Under symmetrical cross-group benefits and asymmetric lock-in effects:

a) *An increase in lock-in effects on one side of the platform leads to smaller incumbent's market shares on the same platform's side:*

$$\frac{\partial m_j^{I*}}{\partial \overline{s_j}} = -\frac{\overline{s_{-j}}\alpha\left(\overline{s_{-j}} + 2\alpha\right)}{3\left(\overline{s_j s_{-j}} - 4\alpha^2\right)^2} < 0 \tag{9a}$$

[6] It is worth noting that: $\lim_{\overline{s_j}\to\infty} m_j^{I*} = \frac{2}{3}$, and $\lim_{\overline{s_{-j}}\to\infty} m_j^{I*} = \frac{2\overline{s_j}+\alpha}{3\overline{s_j}} > \frac{2}{3}$.

[7] The condition simplifies to $\bar{s}^2 - \bar{s}\alpha - 6\alpha^2 \geq 0$. This trinomial with two variables can be factored into $(\bar{s} + 2\alpha)(\bar{s} - 3\alpha)$. As the first multiplier is certainly positive, the condition holds for $\frac{\bar{s}}{\alpha} \geq 3$.

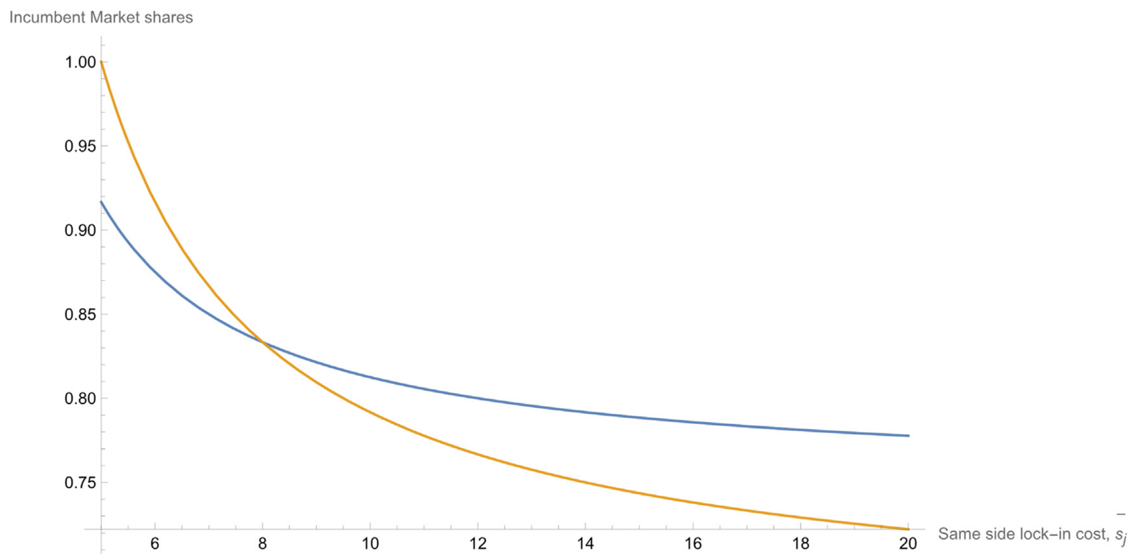

Fig. 1. The two sides' incumbent's market shares, (Blue: Side j, Orange: Side -j) declining with the level of lock-in costs on side j, with symmetric cross-group benefits, $\alpha = 2$, and for opposite side lock-in costs fixed at: $\overline{s_{-j}} = 8$.

b) *An increase in lock-in effects on one side of the platform leads to smaller incumbent's market shares on the opposite platform's side:*

$$\frac{\partial m_j^{I*}}{\partial \overline{s_{-j}}} = -\frac{2\alpha^2\left(\overline{s_j} + 2\alpha\right)}{3\left(\overline{s_j s_{-j}} - 4\alpha^2\right)^2} < 0 \tag{9b}$$

c) *The negative impact of lock-in effects is stronger on the opposite side of the platform than on the same side if:* $\overline{s_{-j}} > \sqrt{2\overline{s_j}\alpha + 5\alpha^2} - \alpha$, *and this critical level for* $\overline{s_{-j}}$ *is increasing in both* $\overline{s_j}$ *and* α.

Discussion. It is interesting to notice that, without cross-group benefits, the lock-in effects do not affect the market shares, $\frac{\partial m_j^{I*}}{\partial \overline{s_j}} = 0$. However, as soon as there are non-negative cross-group benefits, any increase in lock-in costs enables the incumbent to increase the price by two-thirds, as seen in Equation (5), keeping its market share constant. This point helps in viewing the results of Corollary 2 on the impact of lock-in effects on market shares in relation to the cross-group benefits discussed in Corollary 1. In detail, concerning *a)*, we saw that the incumbent mark-up on lock-in costs is double the entrant's one. Thus, the market share of the incumbent declines as lock-in effects *increase* on this side.[8] With regards to point *b)*, the decline in the market share of the incumbent due to an increase in the lock-in effects taking place on the opposite side[9] captures the fact that the reduced incumbent's market share on the side opposite to the increase, reflects the negative impact on the current side, due to the lessening of the cross-group benefits. Lastly, on *c)*, the response discussed in *b)* is greater than the same side effect discussed in point *a)* if cross-group benefits are larger, and the same side lock-in effects are higher.[10]

These findings show that, with high cross-group benefits, policies wanting to reduce lock-in effects will positively impact users. However, these interventions disadvantage the entrant since its market shares decreased, more significantly so, on the opposite platform's side from the one targeted by the policy. This finding has relevant policy implications. Well-motivated calls for stringent regulations on incumbent platforms aim to facilitate entry by reducing the users' lock-in effects, such as facilitating or imposing data and identity portability when changing platform providers. Our results, however, indicated the potential limitations and counterintuitive effects of these interventions, given the increase in the incumbent's market shares associated with a lower value of the lock-in effects parameter.

3.3. Asymmetric cross-group benefits

We now move to the more general case, allowing for different cross-group benefits across the two platform sides ($\alpha_j \neq \alpha_{-j}$). While this case is more complex to analyse, given the increased dimensionality of the parameters' space, we are still able to gain useful insights about the effects of lock-in costs on incumbency advantages in platform competition.

Lemma 2, below, derived from the price reaction function Eqs. (4a & 4b), provides the equilibrium prices for the two platforms, in this *asymmetric cross-group benefits* case.

Lemma 2. Equilibrium prices with Asymmetric cross-group benefits

Under asymmetric cross-group benefits and lock-in effects, the platforms pairs of equilibrium prices, p_j^{i*} *are given by:*

$$p_j^{I*} = \frac{\overline{s_j s_{-j}}\left(6\overline{s_j} - 10\alpha_{-j} + \alpha_j\right) + 2\left(\alpha_{-j} + 2\alpha_j\right)\left[2\alpha_{-j}\left(2\alpha_{-j} + \alpha_j\right) - \ \overline{s_i}\left(3\alpha_{-j} + \alpha_j\right)\right]}{9\overline{s_j s_{-j}} - 4\left(2\alpha_j + \alpha_{-j}\right)\left(\alpha_j + 2\alpha_{-j}\right)} \tag{10a}$$

$$p_j^{E*} = \frac{\overline{s_j s_{-j}}\left(3\overline{s_j} - 8\alpha_{-j} - \alpha_j\right) - 2\left(\alpha_{-j} + 2\alpha_j\right)\left[\ \overline{s_j}\left(\alpha_{-j} + \alpha_j\right) - 2\alpha_{-j}\left(2\alpha_{-j} + \alpha_j\right)\right]}{9\overline{s_j s_{-j}} - 4\left(2\alpha_j + \alpha_{-j}\right)\left(\alpha_j + 2\alpha_{-j}\right)} \tag{10b}$$

Discussion. Even under asymmetric cross-side network benefits,[11] Lemma 2 shows that, as in the previously analysed symmetrical case, the incumbent can still charge higher prices than those set by the entrant. This result holds on both sides of the platform, for the economically relevant set of parameters.[12]

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[8] Notice that the partial derivative of m_j^{I*} with respect to $\overline{s_j}$ is always negative, as it depends on the expression $(-\overline{s_{-j}}\alpha^2 - \overline{s_j s_{-j}}\alpha)$.

[9] Notice that the partial derivative of m_j^{I*} with respect to $\overline{s_{-j}}$ is always negative, as it depends on the expression: $(-\overline{s_j s_{-j}}\alpha - 2\overline{s_j}\alpha^2 - 4\alpha^3)$.

[10] Notice also that the limit for $\overline{s_j} \to \infty$ of the two derivatives equals zero.

[11] It is also interesting to observe how, in contrast to the symmetric Hotelling framework developed in Armstrong (2006), equilibrium prices now depend on both cross-group network benefit parameters.

[12] Specifically, the price difference, $p_j^{I*} - p_j^{E*}$, is given by: $\frac{\overline{s_j}[\overline{s_{-j}}(3\overline{s_j} + 2(\alpha_j - \alpha_{-j})) - 4\alpha_{-j}(2\alpha_j + \alpha_{-j})]}{9\overline{s_j s_{-j}} - 4(2\alpha_j + \alpha_{-j})(\alpha_j + 2\alpha_{-j})}$.This is positive for: $\alpha_j > \frac{-3\overline{s_j s_{-j}} + 2\overline{s_{-j}}\alpha_{-j} + 4\alpha^2_{-j}}{2(\overline{s_{-j}} - 4\alpha_{-j})}$, which

Furthermore, as discussed in the next Proposition 2, both the incumbent's and the entrant's prices increase in the size of the same-side lock-in effects.

Proposition 2. Same-side lock-in effects and equilibrium prices

Under asymmetric cross-group benefits and lock-in effects:

a) *The price of the incumbent's platform increases on side j with lock-in effects on the same side when:*

$$\frac{\delta p_j^{I*}}{\delta \overline{s_j}} = \frac{6\left(3\overline{s_j s_{-j}}\right)^2 + 4\left(2\alpha_j + \alpha_{-j}\right)(\alpha_j + 2\alpha_{-j})\left[2(\alpha_{-j} + 2\alpha_j)\left(3\alpha_{-j} + \alpha_j\right) - \overline{s_{-j}}\left(12\overline{s_j} - \alpha_{-j} + \alpha_j\right)\right]}{\left[9\overline{s_j s_{-j}} - 4\left(2\alpha_j + \alpha_{-j}\right)(\alpha_j + 2\alpha_{-j})\right]^2} \geq 0 \tag{11a}$$

b) *The price of the entrant's platform increases on side j with lock-in effects on the same side when:*

$$\frac{\delta p_j^{E*}}{\delta \overline{s_j}} = \frac{3\left(3\overline{s_j s_{-j}}\right)^2 + 4\left(2\alpha_j + \alpha_{-j}\right)(\alpha_j + 2\alpha_{-j})\left[2(2\alpha_{-j} + \alpha_j)\left(\alpha_{-j} + \alpha_j\right) - \overline{s_{-j}}\left(6\overline{s_j} - \alpha_{-j} + \alpha_j\right)\right]}{\left[9\overline{s_j s_{-j}} - 4\left(2\alpha_j + \alpha_{-j}\right)(\alpha_j + 2\alpha_{-j})\right]^2} \geq 0 \tag{11b}$$

c) *The inequalities in a) and b) are both satisfied in the parameters' region whereby the existence of a non-corner solution is guaranteed: ($\overline{s_j s_{-j}} - 4\alpha_j\alpha_{-j} \geq 0$).*

Discussion. Concerning *a)*, we start by looking at a simplified version of this condition by setting $\alpha_j = \alpha,\ j = A,\ B$ so that the numerator of Equation (11a) is equivalent to $6(3\overline{s_j s_{-j}})^2 + 4(3\alpha)^2(24\alpha^2 - 12\overline{s_j s_{-j}})$. This numerator tends to zero as the product of the maximum values of the lock-in effects, $\overline{s_j s_{-j}}$, approaches four times the square of the symmetric cross-group benefits, $4\alpha^2$ and is positive for $\overline{s_j s_{-j}} > 4\alpha^2$. The same reasoning applies to Equation (11b). Hence, the relevance of lock-in effects declines until the cross-group network benefits thresholds are reached, and, after this point, both platforms stop increasing membership prices in response to an increase in lock-in effect. Moving to the more general case of asymmetric cross-group benefits, for the inequalities described in Equations (11a) and (11b) not to be satisfied, one would need low lock-in effects, close to the critical level: $\overline{s_j s_{-j}} = 4\alpha_j\alpha_{-j}$, together with cross-group network benefits on the side $-j$ higher than those on the side j ($\alpha_{-j} > \alpha_j$). This point confirms again our intuition, since all else being equal, the market share on side $-j$ falls because of a corresponding price increase on the same side. However, this effect negatively affects the platform on its opposite side market since, as discussed, these opposite side users are more sensitive towards reduced cross-group benefits: $\alpha_{-j} > \alpha_j$.

In the next proposition, we explore the relation between equilibrium prices and changes in the lock-in effects on the opposite side of the platform.

Proposition 3. Opposite side lock-in effects and equilibrium prices

Under asymmetric cross-group benefits and lock-in effects:

a) *The price charged by the incumbent's platform on side j is increasing in the lock-in effects on the opposite side if and only if the opposite side cross-group benefits are stronger than the same side ones, if $\alpha_{-j} \geq \alpha_j$, as:*

$$\frac{\delta p_j^{I*}}{\delta \overline{s_{-j}}} = \frac{2\overline{s_j}\left(\alpha_{-j} - \alpha_j\right)\left(\alpha_{-j} + 2\alpha_j\right)\left(3\overline{s_j} + 4\alpha_{-j} + 2\alpha_i\right)}{\left[4\left(2\alpha_j + \alpha_{-j}\right)(\alpha_j + 2\alpha_{-j}) - 9\overline{s_j s_{-j}}\right]^2} \geq 0 \tag{12a}$$

b) *The price charged by the entrant's platform on side j is decreasing in the lock-in costs on the opposite side if and only if the opposite side cross-group benefits are stronger than the same side ones, if $\alpha_{-j} \geq \alpha_j$, as:*

$$\frac{\delta p_j^{E*}}{\delta \overline{s_{-j}}} = -\frac{2\overline{s_j}\left(\alpha_{-j} - \alpha_j\right)\left(\alpha_{-j} + 2\alpha_j\right)\left(3\overline{s_j} + 4\alpha_{-j} + 2\alpha_i\right)}{\left[4\left(2\alpha_j + \alpha_{-j}\right)(\alpha_j + 2\alpha_{-j}) - 9\overline{s_j s_{-j}}\right]^2} \leq 0 \tag{12b}$$

Discussion. The key point in Proposition 3 is that when $\alpha_{-j} \geq \alpha_j$, the entrant's price moves in the opposite direction with respect to movements in lock-in effects taking place on the opposite side of the platform. In contrast, the incumbent's price follows these changes in the opposite side lock-in effects. These results differ from the findings discussed in Lemma 1, whereby changes in lock-in effects did not affect prices set on the opposite sides of the platforms. Furthermore, from Proposition 3, we can see that prices movements in response to changes in opposite side lock-in effects have an opposite sign between the incumbent and the entrant. Thus, it follows that under asymmetric cross-group benefits and lock-in effects, there is an increasing price gap between incumbent and the entrant, entrenching the incumbent competitive advantage, if lock-in effects increase on the opposite platform side, and opposite side cross-group benefits are stronger than the same side ones: $\alpha_{-j} \geq \alpha_j$.

As discussed in Proposition 2, higher lock-in effects on the opposite side, $-j$, incentivise the two platforms to raise prices. Nevertheless, we shall see below, with Corollary 3, that the market share of the incumbent's on the opposite side, $-j$, will be reduced as a consequence. The key message is that pricing reactions on the opposite side hinge on which one of the two sides is more sensitive to cross-group benefits. Considering the entrant, for $\alpha_{-j} > \alpha_j$, we know that users located on the side $-j$ care more about cross-group benefits and hence about variations in the members of the same platform located on the opposite side (now j). If there is an increase in its members' lock-in effects, the entrant will have an incentive to reduce its opposite side price, p_{-j}^{E*},to boost membership on this side, so that we can say that these prices act, in this case, as strategic complements.

If, on the contrary, the users on side j care more about cross-group benefits, so that $\alpha_j > \alpha_{-j}$, then the entrant will be able to leverage that its opposite side market share goes up due to higher exploitation of the customers that are 'locked-in' with the incumbent platform. Thus, in this case, the entrant platform can raise its side j membership price. The reverse reasoning applies to the incumbent platform: a decrease in the market share on the side $-j$, incentives the incumbent to reduce prices on side j of the platform, to offset its users on this side, for the reduced cross-group benefits. On the contrary, if $\alpha_{-j} > \alpha_j$, the incumbent platform does not need to worry about the adverse reaction and hence it can raise its membership prices also on side j of the platform. In conclusion, Proposition 3 demonstrates how competitors' platform prices become strategic substitutes when lock-in effects on the opposite side go up.

holds as the numerator is negative (denominator is positive) for the parameters region whereby we have non corner solutions ($\overline{s_j s_{-j}} - 4\alpha_j\alpha_{-j} \geq 0$).

Because of these results, policies with the objective to lower lock-in effects, for example, on the side $-j$, will exert the unintended consequence of having opposite effects on consumers located on the two different sides of the platform, and these will be based on users' lock-in costs. If, indeed, customers on side j are more sensitive to cross-group benefits ($\alpha_j > \alpha_{-j}$), the entrant platform will lower its same-side price, to compensate the customers with a lower level of brand loyalty due to their reduced cross-group benefits. On the contrary, the incumbent platform can gain from the related increase in its share of the market on the side $-j$; by raising the prices it charges its users on side j, and these will be the the customers with the higher level of lock-in costs. If the side more sensitive to cross-group benefits is the *other side* $(-j)$, i.e., when $(\alpha_{-j} > \alpha_j)$, the incumbent will need to reduce its prices on the side j, to increment its share of the market and keep those customers most at risk of joining the entrant due to their lower brand loyalty. Table A1, in the Appendix, provides a synoptic detailed view of these equilibrium effects for all the relevant different parameters combinations.

Next, we address the implications of Lemma 2 on market concentration.

Proposition 4. Asymmetric cross-group benefits and Market concentration

Under asymmetric cross-group benefits and lock-in effects, the two platforms' sides market shares, m_j^{i*}*(i=I, E) and j= (A, B) are given by:*

$$m_j^{I*} = \frac{6\overline{s_j s_{-j}} + \left(\alpha_j + 2\alpha_{-j}\right)\left[\overline{s_{-j}} - 2\left(2\alpha_j + \alpha_{-j}\right)\right]}{9\overline{s_j s_{-j}} - 4\left(2\alpha_j + \alpha_{-j}\right)\left(\alpha_j + 2\alpha_{-j}\right)},$$

and

$$m_j^{E*} = 1 - \frac{6\overline{s_j s_{-j}} + \left(\alpha_j + 2\alpha_{-j}\right)\left[\overline{s_{-j}} - 2\left(2\alpha_j + \alpha_{-j}\right)\right]}{9\overline{s_j s_{-j}} - 4\left(2\alpha_j + \alpha_{-j}\right)\left(\alpha_j + 2\alpha_{-j}\right)} \tag{13}$$

a) *The market share of the incumbent platform, I, is greater where lock-in effects are relatively lower: i.e.,* $m_j^{I*} \geq m_{-j}^{I*} \Leftrightarrow \overline{s_j} \leq \overline{s_{-j}}\left(\frac{\alpha_j + 2\alpha_{-j}}{2\alpha_j + \alpha_{-j}}\right)$*, the opposite applies to the market share of the entrant platform;*
b) *The entrant's market shares always remain smaller than those of the incumbent platform.*

Discussion. The requirement for the lock-in effects, from *b)*, is not dissimilar to the one derived in Proposition 1*(b)* for the case of symmetrical cross-group benefits, apart from the presence of the additional term: $\frac{\alpha_j + 2\alpha_{-j}}{2\alpha_j + \alpha_{-j}}$. For $\alpha_{-j} < \alpha_j$, the market share detained by the incumbent on side j is greater than the one on the opposite side, also under symmetrical lock-in effects (i.e., $\overline{s_j} = \overline{s_{-j}}$). This finding reflects the intuition that taking advantage of brand loyalty remains more challenging for the market side, where users are more sensitive to cross-group benefits.

Finally, we explore changes in platform market shares for variations in the intensity of lock-in effects on both sides of the platform markets.

Corollary 3. Lock-in effects and the market share of the incumbent platform

Under asymmetric cross-group benefits and lock-in effect:

a) *The market share of the incumbent platform on side j decreases with the intensity of the lock-in effects arising from the same platform side:*

$$\frac{\partial m_j^{I*}}{\partial \overline{s_j}} = -\frac{3\overline{s_{-j}}\left(\alpha_j + 2\alpha_{-j}\right)\left(3\overline{s_{-j}} + 4\alpha_j + 2\alpha_{-j}\right)}{\left(4\left(2\alpha_j + \alpha_{-j}\right)\left(\alpha_j + 2\alpha_{-j}\right) - 9\overline{s_j s_{-j}}\right)^2} < 0 \tag{14a}$$

b) *The market share of the incumbent platform on side j decreases with the intensity of the lock-in effects arising from the opposite platform side:*

$$\frac{\partial m_j^{I*}}{\partial \overline{s_{-j}}} = -\frac{2\left(3\overline{s_j} + 2\alpha_j + 4\alpha_{-j}\right)\left(2\alpha_j + \alpha_{-j}\right)\left(\alpha_j + 2\alpha_{-j}\right)}{\left(9\overline{s_j s_{-j}} + 4\left(2\alpha_j + \alpha_{-j}\right)\left(\alpha_j + 2\alpha_{-j}\right) - 9\overline{s_j s_{-j}}\right)^2} < 0 \tag{14b}$$

Discussion. Regarding *a),* it is easy to see that this result recalls the same results found under symmetrical cross-group benefits. Concerning *b),* we find that this result is coherent with the observed effects on prices, discussed earlier, when $\alpha_{-j} > \alpha_j$. In that case, the incumbent platform maintains its hold on the same side's customers despite the decreased cross-group benefits arising from the shrinking market share held on the opposite side due to the related price increase. Nevertheless, the fact that the market share of the incumbent platform on side j, shrinks if customers on the same side are more reactive to the decline in the incumbent market share on the opposite side of the platform demonstrates how the incumbent platform chooses to recompense its customers, located on side j, for their decrease in cross-group benefits. However, this compensation might be just a partial one.

From a regulatory point of view, these findings are coherent with those obtained under symmetrical cross-group benefit, i.e., that policy initiatives to incentivise market entry by reducing lock-in effects could, instead, raise further barriers to entry, because of the reduction in the market share of the entrant, following the strategic more aggressive pricing implemented by the incumbent.

Finally[13], from Corollary 3, we can see that the critical level of lock-in effects required for the incumbent to maintain the full market share on side j, given by: $s_j^* = \frac{(\alpha_j + 2\alpha_{-j})(\overline{s_{-j}} + 4\alpha_j + 2\alpha_{-j})}{3\overline{s_{-j}}}$, is decreasing[14] in the opposite side lock-in costs $\overline{s_{-j}}$, and increasing in both cross-side benefits α_j and α_{-j}. Fig. 2, below, provides a 3D visualization of these effects.

From Fig 2, we can see that this condition is decreasing in the opposite side switching costs $\overline{s_{-j}}$ but increasing in the cross-side benefits α_j, whereby for visualization benefits we have assumed that the cross benefits on side -j are equal to one half of the cross benefits enjoyed on side j: i.e., $\alpha_{-j} = \frac{\alpha_j}{2}$.

4. Welfare analysis

It is trivial to argue that consumer surplus improves under platform competition since, under the counterfactual scenario absent the entrant, the monopolistic incumbent would be able to extract the entire rent on both sides (i.e., full market coverage). Similarly, total welfare, given by the sum of consumer surplus on both sides and firms' profits, worsens under platform competition due to the presence of lock-in effects. This section focuses on the impact of these lock-in costs, brand loyalty, on consumer surplus considering the customers of the two platforms on either side of these platforms, under symmetrical cross-group benefits.

We start by analysing how the various components of total consumer surplus change with lock-in costs, as $\overline{s_j}$ varies. The first step is to look at the consumer surplus for the mass of customers on side j remaining with the incumbent. Their aggregate consumer surplus is obtained by simply multiplying their common individual

[13] We thank an anonymous reviewer for suggesting analysing this issue.

[14] Since : $\frac{\partial s_j^*}{\partial \overline{s_{-j}}} = -\frac{2(2\alpha_j + \alpha_{-j})(\alpha_j + 2\alpha_{-j})}{3\overline{s_{-j}}^2}$ and $\frac{\partial s_j^*}{\partial \alpha_j} = \frac{8\alpha_j + 10\alpha_{-j} + \overline{s_{-j}}}{3\overline{s_{-j}}}$ and $\frac{\partial s_j^*}{\partial \alpha_{-j}} = \frac{2(5\alpha_j + 4\alpha_{-j} + \overline{s_{-j}})}{3\overline{s_{-j}}}$ To note that the level of individual utility is the same across the incumbent's customer base given that none of them incur *lock-in* costs.

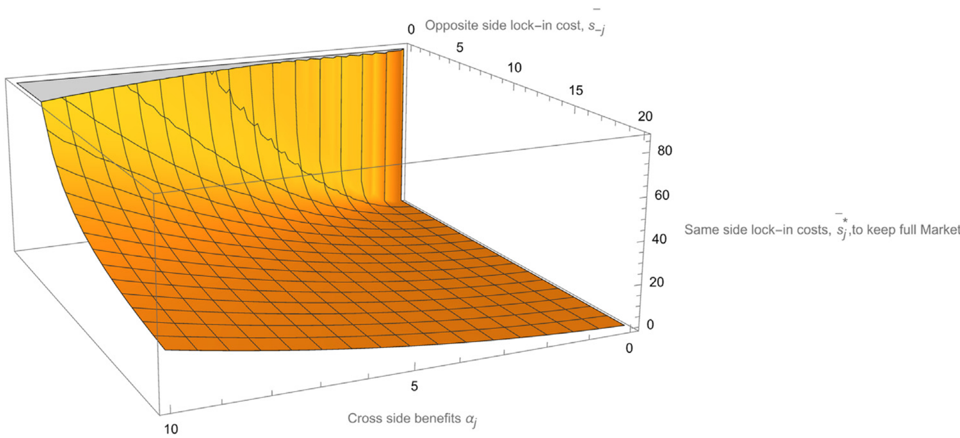

Fig. 2. The critical level of lock-in effects required for the incumbent to maintain the full market share on side j: $s_j^* = \frac{(\alpha_j + 2\alpha_{-j})(\overline{s_{-j}} + 4\alpha_j + 2\alpha_{-j})}{3\overline{s_{-j}}}$

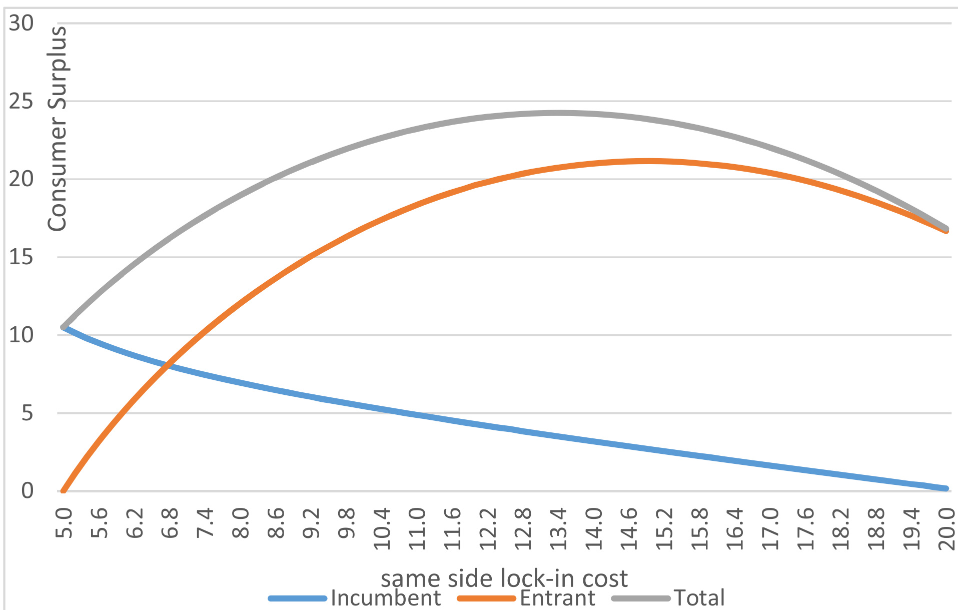

Fig. 3. Consumer surplus on side j, depending on the same side lock-in cost (i.e., for $\overline{s_j} > 5$) with symmetric cross-group network benefits, for $\alpha = 2$, v = 10 and $\overline{s_{-j}} = 8$.[16]

utility, given by $v + \alpha m^{I*}_{-j} - p^{I*}_j$,[15] by the equilibrium market share on the same side, m^{I*}_j. Using the solutions in Eqs (5) and (6) gives:

$$CS^I_j = \frac{\left[\overline{s_{-j}}\left(\alpha + 2\overline{s_j}\right) - 6\alpha^2\right]\left[\overline{s_j s_{-j}}\left(5\alpha - 2\overline{s_j} + 3v\right) - 3\alpha^2\left(6\alpha - 3\overline{s_j} + 4v\right)\right]}{9\left(\overline{s_j s_{-j}} - 4\alpha^2\right)^2} \quad (15)$$

The computation of the aggregate consumer surplus across the customer base of the entrant on the same side is more complex, since individual utilities, given by $v + \alpha(1 - m^{I*}_{-j}) - p^{E*}_j - s_j$, vary with lock-in costs, that are uniformly distributed across users, thus requiring the calculation of the integral over the range $[0, s^*_j]$, where the critical threshold level of the lock-in costs on side j, s^*_j, is given by $s^*_j = (p^{I*}_j - p^{E*}_j) + \alpha_j(1 - 2m^{I*}_{-j})$.

This gives:

$$CS^E_j = \frac{\overline{s_j}\left(\overline{s_j s_{-j}} - 6\alpha^2 - \alpha\overline{s_{-j}}\right)\left(3\alpha + 2v - \overline{s_j}\right)}{6\left(\overline{s_j s_{-j}} - 4\alpha^2\right)} \quad (16)$$

The three welfare curves representing the consumer surplus on side j for those who stay with the incumbent, CS^I_j, those who switch to the entrant, CS^E_j, and their sum, CS_j, are plotted below, in Fig. 3, as a function of the same side lock-in costs, $\overline{s_j}$.

The downward-sloping curve for the incumbent's consumer surplus is mainly the combined result of the increasing price and decreasing market share on side j as the same-side lock-in costs increase.[17] Whereas the inverted-U shapes of both the entrant's and[18] total consumer welfare curves result from contrasting

[15] To note that the coexistence condition $(\overline{s_j s_{-j}} - \overline{s_{-j}}\alpha - 6\alpha^2 \geq 0.)$ is satisfied for $\overline{s_j} > 5$.

[16] In addition, the reduction in the incumbent's market share on side j also triggers the negative feed-back loop due to cross-group network benefits, which induces a similar reduction on the opposite side.

[17] The sign of CS^E_j is determined by the sign of $(\overline{s_j s_{-j}} - 6\alpha^2 - \alpha\overline{s_{-j}})(3\alpha + 2v - \overline{s_j})$. This can be rearranged as a quadratic function in $\overline{s_j}$, where both the coefficient of the quadratic term and the vertical intercept are negative. Accordingly, CS^E_j is positive and with an inverted-U shape within the corresponding two positive roots, which requires the discriminant to be positive: $9\alpha^4 + \overline{s_{-j}}^2(\alpha^2 + v^2) - 6\alpha^2\overline{s_{-j}}(\alpha + v) + 2\alpha v\overline{s_{-j}}^2 > 0$. To fix ideas, under the additional simplifying assumption that $\overline{s_j} = \bar{s}$ (for $j = A, B$), this is always the case over the relevant range of parameters (i.e., $\frac{\bar{s}}{\alpha} > 3$). For $\frac{\bar{s}}{\alpha} = 3$ the two roots are: $6\alpha - 3v$ and $6\alpha - v$.

[18] Conversely to what outlined in the footnote above, this effect is strengthened by the positive feedback loop due to cross-group network benefits.

effects. On the one hand, the entrant's price also increases linearly with same-side lock-in costs (albeit by a third of the increase in the incumbent's price); on the other hand, the entrant's market share increases as the incumbent exploits the resulting stronger brand loyalty effects.[19] The latter effect initially dominates for low lock-in costs, whereas the former prevails for high levels. The reduction in consumer welfare is strengthened to some degree by the higher level of lock-in costs incurred by users choosing the entrant. However, as shown below, this effect fades away, given the asymptotic flattening of the incumbent's market shares over the same range of lock-in costs.

Interestingly, the flattening of the incumbent's market share on the side opposite to where the lock-in costs increase is more pronounced, in line with the result presented in Corollary 1c) (i.e., as the level of exploitation on side j is already elevated). Similarly, the impact of an increase in lock-in costs on side j on the distribution of consumer surplus on the opposite side is muted, given that, under this simplified configuration, the only effect at work is through the resulting change in the corresponding market shares (i.e., equilibrium prices do not depend on the opposite-side lock-in costs).

From a policy perspective, the inverted-U shape entails that interventions aimed at lowering lock-in effects would certainly be positive in terms of consumer surplus for high levels of these costs, although the entrant's market shares on both sides would fall. However, at a medium level of lock-in costs, further reductions in the entrant's market shares in response to a reduction of lock-in costs would also be detrimental in terms of consumer surplus, that is, to the extent that the incumbent can retain a larger proportion of customers paying comparatively higher prices.

5. Conclusions

The competitive advantage of incumbent platforms is one of the key topics of debate in platform regulation and competition policy (Jullien and Sand-Zantman, 2021). When an entrant platform joins a two-sided market held by an existing incumbent, it faces barriers to entry and strategic challenges because of the joint forces of cross-group benefits and brand loyalty. This problem is most pressing for products and services that are not highly differentiated, and where there is a saturation of market demand. These are typical features of mature markets for essential services and products.

Data and identity portability are often advocated as regulatory remedies to remove barriers to entry in two-sided platform markets (Gans, 2018; and Coyle, 2018), especially in interconnected digital markets, dominated by the so-called "Big-Techs." However, as discussed in Biglaiser, Calvano and Cremer (2019) and Jullien and Sand-Zantman, (2021) while "..data can be a source of incumbency advantage … the impact on the platform's initial offer of such a measure - which amounts to giving more ownership rights over data to consumers- is far from being clear" (Jullien and Sand-Zantman, (2021), page 34).

Our contribution addresses this policy issue by modelling the competitive advantage of incumbent platforms in two-sided markets when the degree of lock-in costs, which are the source of incumbency advantage, may differ between the two sides. Such differences, between the two sides, may be due to informational asymmetries, or just be the results of heterogeneous preferences towards change. A typical example can be found in integration tools, such as API for content developers, making it costlier to join an entrant platform without the same APIs that could, otherwise, provide similar functionalities (Tan et al. 2020).

In our model, heterogeneous lock-in effects present both risks and opportunities for the platforms entering these two-sided markets. Heterogeneity in lock-in effects across sides provides the incumbent with an opportunity to capture a greater share of the markets on both sides of the platform while also increasing its customers' prices. Hence, the entrant's profits are higher. The incentives to enter these markets, however, also hinge on the degree of heterogeneity in lock-in costs between the two sides of the platform. In detail, the prevalence of these costs over the cross-group benefits is a necessary condition to prevent equilibria whereby the incumbent will be monopolising the entire platform markets.

Our results have strong policy implications: interventions aimed at lowering search and lock-in costs, especially for those consumers facing higher lock-in costs, could unwillingly render the entrant's competitive stake more challenging. This is because the strategic attitude of the incumbent becomes more aggressive. Maybe counter-intuitively, policy actions aimed at facilitating data portability ought to happen after the entrant platform has already succeeded in gaining a base in the platform markets. Only then, once lock-in costs with the incumbent have decreased beneath the limit where dominance tendencies restart, the entrant will be less likely to be at a competitive disadvantage.

Our welfare analysis discussed how consumer surplus changes in a nonlinear way with the level of lock-in costs. This is due to the strategic effects of lock-in on pricing strategies and their impact on market shares. Policies aimed at increasing data and personal information portability will benefit from considering the complexity of these effects. They will need to be grounded in the estimation of the key parameters characterising the distribution of these lock-in costs both across and within the two sides of the platform participants. This is essential to capturing the differential impact of such policies between and within users on the two sides of the platforms.

5.1. Limitation and further research

Our analysis is based on a one-period game, focusing on the strategic pricing decisions for entrants and incumbents on both sides of a platform. It considers the impact of exogenous parameters capturing asymmetric lock-in costs, whereby the asymmetry appears both within and between the platform's sides. We assumed, however, that cross-side network benefits only differed between, but not within, the two platform sides. We also limited our analysis to a singlehoming setting. Extensions that allow consumers to multihome, or that let platforms endogenise lock-in costs and their distribution across and within sides, while challenging, will require to extend our model into a multiperiod setting. This effort would allow future research to analyse contexts where these assumptions are relevant.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

[19] Conversely to what outlined in the footnote above, this effect is strengthened by the positive feedback loop due to cross-group network benefits.

Appendix 1

Table A1
Synopsis of the effect on platform prices due to brand loyalty changes on the opposite platform's side.

$\uparrow$	$\alpha_{-j} > \alpha_j$	$\alpha_j > \alpha_{-j}$
δp_j^{I*}	$\uparrow$ the incumbent can still retain side $-j$ customers notwithstanding worse network benefits due to lower m_j^{I*}	$\downarrow$ the incumbent needs to recompense side j customers for their reduced cross-group benefits given to smaller market share on the other side m_{-j}^{I*}
δp_j^{E*}	$\downarrow$ entrant must increase m_j^{E*} to poach side $-j$ customers by increasing their cross-group benefits	$\uparrow$ entrant can capitalise on higher cross-group benefits for side j customers thanks to higher m_{-j}^{E*}
$\overline{s_{-j}} \downarrow$	$\alpha_{-j} > \alpha_j$	$\alpha_j > \alpha_{-j}$
δp_j^{I*}	$\downarrow$ incumbent must increase m_j^{I*} to retain side $-j$ customers by improving their cross-group benefits	$\uparrow$ incumbent can capitalise on higher cross-group benefits for users on side j thanks to higher m_{-j}^{I*}
δp_j^{E*}	$\uparrow$ entrant is able to recruit customers on the side $-j$ despite receiving lower cross-group benefits due to a smaller m_{-j}^{E*}	$\downarrow$ entrant needs to recompense customers on side j for their reduced cross-group benefits due to smaller market share m_{-j}^{E*}

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