“Assessing Compatibility and Competition Issues in Wearable Markets.”*

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Abstract:

This paper addresses the impact of symmetric and asymmetric compatibility in wearable markets, we assume platforms may be differentiated by endogenous (quality) and exogenous (technology) parameters and they compete in two-sided markets where agents on both sides are heterogeneous in two orthogonal dimensions. We compare two frameworks, one where platforms are incompatible and another where platforms are compatible.

We prove that compatibility leads to higher prices on the opposite side where it is considered but it depends on how compatibility is assumed, and we prove that compatibility changes the investment incentives of platforms.

Keywords: Two-sided Markets, Compatibility, Wearables, Investment, Double-Differentiation Models.

JEL Classification: D42, D92, L11, L12, L86

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1. Introduction.

We are at the gates of a new revolution in information and communication technologies (ICT) based on a new set of technologies that enables advanced services by interconnecting physical and virtual "things" based on existing and evolving ICT technologies. That is the definition of Internet of Things (IoT) given by the International Telecommunication Union[1].

However, a large set of these new technologies is not in mainstream markets at this time, in some cases, we observe that these technologies only reach the market in US[2]. On the other hand, there are examples of mature IoT technologies like wearables and more precisely, fitness trackers that are common gadgets in mainstream technology markets.

The first fitness tracker was launched in 2011[3], three years later, the market worth $2 billion and by 2019 is estimated to reach $5.4 billion and the same pattern is expected in other wearable markets like smart watches[4]. However, wearable markets are smaller than other ICT markets as broadband internet access, search engines, OS software, etc. but they are no longer irrelevant, many of them are large markets that are attracting the attention of bigger agents[5]. In that sense, CB Insights (2015) shows that in "wearable market" has been invested $1.4 billion since 2009 also, IDC states that this market has reached a shipment volume of 18.1 million and it grows at 223.2% from 2014 to 2015.

Although IoT technologies cover a large set of examples and markets, we will focus on fitness trackers case where there is a mature market that we can compare with other devices/technologies less mature related to smart cars or smart driving, i.e. devices that capture data from your vehicle in the same way that a fitness tracker capture data from your body.

These markets have interesting differences with other digital or cutting-edge markets like software because users value not only the quality of the service (QoS) that we can understand also as the functionalities related to the fitness tracker, but also the device design. On the other hand, these devices capture data from the user and, what is interesting about these markets is that companies sell these devices but also they sell the data to other firms interested in such data. For example, sport companies may be interested in sport trends like average intensity, duration or type of activities because that information may be useful to make decisions about a new product.

An interesting feature of these markets is that companies tend to share their data with their competitors however, this feature is not a common one and we observe different patterns from symmetric compatibility structures, i.e. platforms share data with their competitors symmetrically (e.g. Fitbit with Endomondo); to asymmetric ones (e.g. Fitbit with Withings). But also, if we consider other markets less mature but related to fitness tracker like those related to smart cars or smart driving we observe that companies tend to be incompatible among them in the sense of no sharing data.

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[1] See ITU (2012).
[2] https://www.cbinsights.com/blog/iot-smart-cities-market-map-company-list/?utm_source=CB+Insights+Newsletter&utm_campaign=d6de1daf99-Top_Research_Briefs_04_02_2016&utm_medium=email&utm_term=0_9dc0513989-d6de1daf99-86652009
[3] It was the Fitbit Ultra, Bussiness Insider (2015).
[4] http://www.wareable.com/fitness-trackers/fitness-tracker-market-to-top-dollar-5-billion-by-2019-995
[5] http://www.zdnet.com/article/time-to-pay-attention-the-internet-of-things-is-about-to-go-mainstream/

To deal with these markets we propose a dynamic two-sided model with asymmetric externalities where firms value the number of users on the platforms but users do not care about the number of firms on the other side. We will assume that both, firms and users, are differentiated in two orthogonal dimensions, i.e. users value not only the design but also the functionalities of the purchased device and firms value not only the quality of the data but also they have a preference for some kind of data.

Also, we assume two stages: at the first one, platforms choose the quality level and, at the second one, platforms compete in prices. One of the main features of these markets is that we observe different patterns of data sharing among companies, to deal with this idea we propose a compatibility model where platforms share users' data.

Our results point out that: in the total compatibility case may not be optimal to subsidize users as long as both platforms share their dataset. In this case, it may be optimal to behave as a traditional one-sided market without externalities if symmetric network externalities are assumed. Also we have found that two platforms may coexist if there is a strong horizontal differentiation. In this case, even with strong network effects there is not going to be a winner-takes-all-the-market outcome. We observe the effect of vertical differentiation in fees, it is easy to observe that the classical pattern of the high-quality product being more expensive than the low-quality one is also true here, notwithstanding, the difference is in the decision of being low-quality. There is no incentive to be low-quality as it happens in classical vertical differentiation models.

On the other hand, we observe that asymmetric marginal costs mitigate the incentive to invest in the case of the platform with cost advantages. However, we observe a quality race where platforms try to outperform their rival and, if symmetry is assumed, we find a symmetric equilibrium where platform invest the same quantity.

The paper is organized as follows: we discuss the related literature in section 2. In section 3 we present the duopoly case and the main assumptions. In section 4 we analyse the compatibility model. In section 5 we conclude and elaborate some on-going work.

2. Related Literature.

This work is related mainly to multi-sided platforms and compatibility issues but also to digital markets and engineering literature about sensor networks and businesses. There is a large contemporary literature on multi-sided platforms however, there is also a lack of theoretical models based on the recent information and communication technologies (ICTs) like Internet-of-Things (IoT). Economic literature is far behind in understanding these markets, and the questions that are been discussed right now are little connected with the concerns of the new generation of Internet companies like IoT start-ups that have a lack of models to understand the markets they are in.

The first reference to IoT in economic literature is Bohli, et al (2009), they describe how they assume IoT markets will be. What is interesting about their work is not only that they were the first ones in analysing these markets, but also that they describe a multi-sided market without considering it explicitly. They argue that: "*The primary [IoT] service is certainly the provision of sensor data. A higher level service can aggregate data from several sources to produce more accurate data*". In fact, this will be an assumption in this work.

Since then, there is no contribution in economic literature related to multi-sided platforms and IoT technologies however, in engineering literature there are recent examples of multi-sided platforms being applied to analyse IoT markets as Guijarro, et al. (2015), the only work that analyses a market with wireless sensors, users and a platform that coordinates both groups.

There are many published articles from the engineering perspective which are focused on analysing IoT platforms in terms of how the platforms allow users to interact with devices connected to Internet as Mineraud, et al (2015), Benjafaar, Kong and Li (2015) or Guldemond, Keijzer-Broers and De Reuver (2014).

Nevertheless, our paper mainly belongs to the very recent and quickly growing economics literature on multi-sided markets or platforms. It is commonly assumed that this literature started with Rochet and Tirole (2003)[6]. Since Rochet and Tirole (2003), this literature has developed around remarkable topics in industrial economy like tying/bundling strategies (Jullien, 2004; Choi, 2007; Affeldt, 2011), barriers to entry (Bellaflamme and Toulemonde, 2004; Farhi and Hagiu, 2008; Evans and Schmalensee, 2010), collusion incentives (Ruhmer, 2011; Boffa and Filistrucchi, 2014), merger analysis (Filistrucchi, 2008; Alexandrov, et al 2012), asymmetric information in prices (Hagiu and Halaburda, 2014; Sun 2015), etc[7].

However, the recent developments in multi-sided literature, and more specifically, in multi-sided platforms related to digital economy allow us to address wearable markets with relatively confidence. For example, Evans, Hagiu and Schmalensee (2006) point out that information/digital economy is based on network economies and feedbacks; they recognize the fundamental role of network externalities and that justifies the use of multi-sided markets to study digital markets; in fact, Filistrucchi and Klein (2013) state that "*multisided businesses are the most common ownership structure on the Internet*"[8]. Also, Hoelck and Ballon (2015) consider that multi-sided platforms are suitable to analyse ICT markets and Hagiu (2004) and Economides and Katsamakas (2006) adopt this approach to analyse software-hardware markets.

Other interesting contributions are those of Evans (2003a) and Filistrucchi (2008). The former stablishes the first approach to classify multi-sided markets however, the latter is simpler and better from an empirical point of view. Filistrucchi proposes to divide two-sided markets in "payment card type" (e.g. Rochet and Tirole, 2003) and "media type" (e.g. Armstrong, 2006) depending on whether the transaction between sides is present and/or observable. This classification is key from the competitor authorities' point of view as it is also pointed out by the author when analysing the SSNIP test.

Also, our work is related to compatibility issues, but there are two ways to address compatibility: one is the classical way based on the one-sided models proposed by Kazt and Shapiro (1985), Farrell and Saloner (1985 and 1986), Matutes and Regibeau (1985) among others, however, as it is pointed out by Wright (2004) conventional knowledge from one-sided markets may lead to mistakes in two-sided markets. In that sense, conclusions from one-sided literature may not be robust in two-sided markets, however this is not always true. Kazt and Shapiro (1985) prove that total

[6] Caillaud and Jullien (2001 and 2003) are also examples of multi-sided platforms and both works are previous to Rochet and Tirole (2003). However, Rochet and Tirole (2003) proposed the term "two-sided markets" that is used today.

[7] See Sánchez-Cartas and León (2015)

[8] In fact, the pioneering works of Caillaud and Jullien (2001 and 2003) were inspired by what they called "cybermediaries".

compatibility will lead to higher prices compared with the total incompatibility case, a result that is also obtained by Matutes and Regibeau (1988) and by Salim (2009) –a two-sided market model.

On the other hand, we can address this issue based on multi-sided literature. In this case, a remarkable work is Doganoglu and Wright (2006), they analyse a close-related case to our work, and they consider the relationship between compatibility and multihoming. They find that compatibility leads to higher prices however, this is consequence of how they assume users' utility in the compatibility framework. A recent paper that addresses this issue is Salim (2009), she proposes a similar framework than ours but she considers only one differentiation dimension and the extreme cases of compatibility and incompatibility. However, she addresses the same issue of investing in quality and competing in prices but she focuses on the effect of collusion incentives to adopt a standard. She finds that the incentives to invest in quality are higher with compatibility. In the incompatible case she finds that "*platforms only gain from higher qualities [functionalities] by outperforming their rival*". She also finds that compatibility soften competition.

On the other hand, there are works about digital economy that are not based on multi-sided businesses. For example, Shapiro and Varian (1999) highlight that information goods are characterized by high fixed cost and null or very little marginal cost, and that characteristics are key in fixing prices and this idea is also taken by Bohli, et al (2009) when describing IoT markets and by Brousseau and Penard (2007) who also observe that: "*1) Consumable services are […] made up of "packages" of basic functions. 2) Digital activities are characterized by three basic operations: The production of functionalities/modules, the assembling of functionalities, the consumption of services generates value. 3) Users (or consumers) are not neutral in the process of value creation, since they can themselves assemble the functionalities, and since they can generate valuable information or knowledge*".

They also suggest three dimensions to understand digital business models, the economics of intermediation, the economics of assembling and the economics of knowledge management. They consider that these three dimensions are independent, i.e. we can study each dimension separately; in fact, this is the approach followed in this paper where we focus on "the economics of intermediation" dimension.

3. The Duopoly Model.

a. Agents' behaviour.

i. Users.

We assume there is a mass of potential consumers *"n"* that we assume is normalized to 1, each consumer decides about their participation on platforms, a necessary condition is that the utility they receive from being on one platform must be non-negative. The utility of an "*i*" consumer on the platform is given by:

$$U_{i,1} = c^u + \theta_i s(k_1) - v_1 - t^u x_i \qquad\qquad U_{i,2} = c^u + \theta_i s(k_2) - v_2 - t^u(1 - x_i)$$

Where *"v"* is the membership fee, so the higher the price the lower the utility,"c^u" is the intrinsic value users obtain from being on the platform, *"s(k)"* represents the functionalities, we also assume this function is concave[9] and it depends positively on *"k"*, the investment resources; we will assume *"k"* and *"s(k)"* are normalized to 1, "t^u" represents the Hoteling's transportation cost on users' side and "x_i" represents the user's position in Hotelling's segment. The parameter "θ_i"

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[9] We suppose that when there are few functionalities, an increase is noticeable but, as the number of functionalities increases, every new functionality is less noticeable than the previous ones.

represents the value of the functionalities to an *"i"* consumer. This assumption follows the Bohli, Sorge and Westhoff's observation that people care about sensor data, i.e. the sensor network and the functionalities; and not about each individual sensor.

The θ-parameter is also the heterogeneity parameter because every potential consumer on our market will have a different θ-parameter so, a higher θ represents users who love to have a large set of functionalities, they care more about the sensor data; by contrast, a lower θ represents users who are less interested in the functionalities, and they care less about the sensor data. We assume θ is uniformly distributed between [0,1].

On the other hand, the x_i-parameter represents the people's position with respect to the subjective domain like their opinion with respect to users' interface or intuitiveness of the platform. We assume users' position in Hotelling's segment is also uniformly distributed between [0,1].

ii. Firms.

We assume there is a mass of potential firms *M* and we assume is normalized to 1, each firm decides about their participation on platforms, a necessary condition is that the profit they earn from being on one platform must be non-negative. The profit of an "*i*" firm on the platform is given by:

$$\pi_{i,1} = c^f + \delta_i C_1\big(k_1, n_1^e(v_1 v_2)\big) - T_1 - t^f x_i \qquad \pi_{i,2} = c^f + \delta_i C_2\big(k_2, n_2^e(v_1 v_2)\big) - T_2 - t^f(1 - x_i)$$

Where "T" is the membership fee and "c^f" is the intrinsic value from being on the platform. We also assume there is a single fee and platform cannot price discriminate[10], we observe that the higher the fee, the lower the profit. So, our model will be a "media type" in the Filistrucci's classification and a "demand coordinator" in the Evans'. "$C(k, n^e(k, v))$" represents the cost advantages or the extra profit that firms gain from being on the platform, the intuition is the following: platforms provide a service that allows firms to operate in a more efficient way, e.g. information about what trends are starting to arise in sports. Note that we do not assume explicit cost advantages and externalities functions because, in this way, we can deal with more generic frameworks than in other works as Doganoglu and Wright (2006) or Salim (2009) however, later we will point out some assumptions about these functions.

On the other hand, we have assumed agents are rational, so in equilibrium, the firms' expectation about the number of consumers are fulfilled. "t^f" represents the Hotelling's transportation cost on firms' side and "x_i" represents the firm's position in that framework. The intuitive interpretation of Hotelling's framework is the same on both sides.

We assume all firms are provided with an unique service, this service generates cost advantages and we assume firms differ in the valuation of these cost advantages provided by the platforms. The parameter δ represents this idea, i.e. firms will value cost advantages differently, the intuition is that, although they are provided with the same potential cost advantages, each firm exploits them differently because the platform's service is more related to some sectors than others, or because each firm has a different "know-how" about how to exploit this service, so a higher δ represents firms which obtain higher cost advantages. We assume δ is uniformly

[10] This is a common assumption we see throughout multi-sided literature, e.g. Caillaud and Jullien (2001 and 2003), Weyl (2010), Armstrong (2006), etc.

distributed between [0,1] and the firms' position in Hotelling's segment is also uniformly distributed between [0,1].

iii. Platforms

We assume symmetric platforms however, later we will relax this assumption. Each platform will maximize its profits on both sides and the platforms' profit function is given by:

$$\Pi_j = T_j M(T_1, T_2) + (v_j - c_j) n(v_1, v_2) - I(k_j) \qquad \forall\, j \in [1,2]$$

Note that we assume platforms have a zero marginal cost on firms' side, that is a common assumption in multi-sided markets literature (Ambrus and Argenziano, 2004; Reisinger, 2004; Parker and Van Alstyne, 2005; Salim, 2009; etc.) but also in literature about digital economy (Shapiro and Varian, 1999; Bitzer and Schröder, 2004; Katsamakas and Bakos, 2004; Economides and Katsamakas, 2006; Hagiu, 2006a; Njoroge, et al, 2010). However, because we want to reproduce a wearable market where users buy a device, we assume there is a marginal cost on that side related to the production of that device. We assume it is constant.

Also, we assume that both platforms are at the extremes of the Hotelling's segment. This assumption is very common throughout economic literature, Armstrong (2006), Hagiu (2004), Reisinger (2004), Doganoglu y Wright (2006), Choi (2007), Salim (2009), etc.

b. Simplifying assumptions.

During our discussion so far we have made several assumptions however, we have to point out other necessary assumptions.

Assumption 0: $c^u \leq \frac{3}{2}t^u;\ c^f \leq \frac{3}{2}t^f$

This assumption ensures the total participation of users and firms. Armstrong and Wright (2005) or Salim (2009) make a similar assumption. Without it, the interpretation of our results becomes more difficult.

Assumption 1: $C\big(k, n(k,v)\big), c_j \in [0,1]$

This assumption is made to ensure the tractability of our model so, it is not critical one but it is a recommendable one.

Assumption 2: $\frac{dC(\cdot)}{dk} > 0;\ \frac{dC(\cdot)}{dn(k,v)} > 0;\ \frac{dC(\cdot)}{dv} < 0;\ \frac{dv}{dk} < 0\ or\ \frac{dv}{dk} > 0\ \ or\ both.$

We assume cost advantages are increasing with respect to investment, but also with respect to users' demand; however, cost advantages are decreasing with respect to users' fee, although we make no assumption about how users' fee with respect to investment behaves.

The intuition behind these assumptions is the following: the higher the investment or the users' demand, the larger the cost advantages are so, with higher levels of investment or users' demand there are more information to firms about users' habits. However, the higher the users' fee, the lower the costs advantages are because the number of users on the platform is lower. By last, we make no assumptions about fees, it can occur that: the higher the investment, the lower the users' fee because production costs are smaller; by contrast, it can occur that the higher the investment, the higher the added value of the platform and higher the users' fee.

Assumption 3: $\frac{d^2C(\cdot)}{dn(k,v),dk} > 0$

This assumption implies that, from firms' point of view, sensors and users are strategic complements in the sense of Bulow, et al (1985).

Assumption 4: $C\big(0, n(k,v)\big) = C(k,0) = 0$.

Therefore, if there is no investment or there is no users on the platform, there is no cost advantage at all.

Assumption 5: $s'(k) > 0; s''(k) < 0$.

As investment increases, there are more sensors but, as their number grows, the increase is smaller.

Assumption 6: $\frac{dn(k,v)}{dk} > 0$

We assume users' demand is increasing with respect to investment, the intuition is the following: the larger the sensor network, the higher the incentive to join the platform.

Assumption 7: $\frac{d\Pi_j}{dk_j} > 0; \frac{d^2\Pi_j}{dk_j^2} < 0$

We will assume profits are concave with respect to investment, this assumption guarantees that our critical points are maxima.

Assumption 8: $\theta, x \sim f(\theta, x); \delta, x \sim g(\delta, x); f(\theta, x) = f(\theta)f(x) = 1; g(\delta, x) = g(\delta)g(x) = 1$

It is assumed that vertical and horizontal differentiation are orthogonal, e.g. there is no correlation between quality and taste domains.

c. Timing.

Let us specify the timing of the game we consider throughout the paper. There are 2 stages:

- Stage 1: Investment phase, platforms make their investment decision and they maximize their profits.
- Stage 2: multi-sided phase, platforms fix their fees on both sides simultaneously and firms and users make their adoption decisions simultaneously.

There is an important implicit assumption in this model, as long as we assume full information, platforms know what functionalities have been selected by the other platform at the beginning of the second stage. Also, at first stage, platforms decide about their investment knowing that their competitor has selected certain production technology/standard, i.e. the marginal costs.

The intuition is the following: a platform announces its operative system for its devices, e.g. Google Brillo, Samsung Artik or Apple HomeKit; or it announces the connectivity technology, e.g. Bluetooth or WiFi; or it announces the sensor technology for monitoring the heart rate, e.g. infrared or electrodes. This decision is known before the start of the game and, at the first stage, platforms make the decision about quality/functionalities related to that decision already made by all competitors. However, this framework may have sense when there are bigger players with interests in adopting some standard and they share that information also, it explains the behaviour of start-ups when they focus on pointing out their superior technology to attract investors and partners. We also assume there is full information at every stage of the game and all agents are rational.

d. Second Stage.

In our work, firms and users are differentiated in two orthogonal dimensions. This feature implies that demands will be more complex than in a classical Hotelling's model as it is assumed in other works as Doganoglu and Wright (2006) or Salim (2009). It is assumed that each user buys one, and only one, wearable (note that we assume that firms and users are singlehoming), so people that will buy the service are those who obtain a non-negative utility from buying the wearable so if we consider users we define:

$$B \equiv \{(\theta_i x_i);\ c^u + \theta_i s(k_j) - t^u x_i - v_j \geq c^u + \theta_i s(k_{-j}) - t^u(1-x_i) - v_{-j} \geq 0\}$$

Following Weyl (2010) we can define users' demand in platform j as:

$$n_j(v_j, v_{-j}) = \iint_B f(\theta_i x_i) dx_i d\theta_i$$

As it have been pointed out before, we consider the Hotelling's dimension is the subjective domain, e.g. people may be differentiated by design tastes so, there will be people who love big wearables and others who love small ones. On the other hand, we assume that design tastes are uncorrelated with functionality tastes, i.e. people who love big wearables are uncorrelated who those who like sleep monitoring.

What is interesting about this approach is that users will be in a bidimensional world and not in an unidimensional one (the latter is a common assumption in multi-sided markets literature). That implies that the traditional marginal user will not correspond to the users' demand of the platform placed at x=0 because the bidimensional nature of the demand.

Following our assumptions we define users' demands as follows:

$$n_1(v_1, v_2) = \int_0^1 \int_0^{\breve{X}_1} f(\theta, x) dx d\theta = \frac{1}{2} + \frac{s(k_1) - s(k_2)}{4t^u} + \frac{v_2 - v_1}{2t^u}$$

$$n_2(v_2, v_1) = \int_0^1 \int_{\breve{X}_1}^1 f(\theta, x) dx d\theta = \frac{1}{2} + \frac{s(k_2) - s(k_1)}{4t^u} + \frac{v_1 - v_2}{2t^u}$$

Where $\breve{X}_j$; $j = 1{,}2$ is the marginal user in Hotelling's framework. If we compare this demand with the Hotelling's demand, this demand is smaller because the higher heterogeneity on users' side. Note that this is consequence of our normalization assumption because we are considering a subarea of a square of size 1, it is not clear that this result will be robust in non-normalized frameworks.

A common assumption in Hotelling's one-sided models is $v_2 - v_1 < t^u$ to guarantee competition for marginal users however, in this case, that assumption is not enough and we have to assume that: $|v_2 - v_1| + \left|\frac{s(k_2) - s(k_1)}{2}\right| < t^u$

Due to the symmetry with respect to firms' side, firms' demands on that side will be:

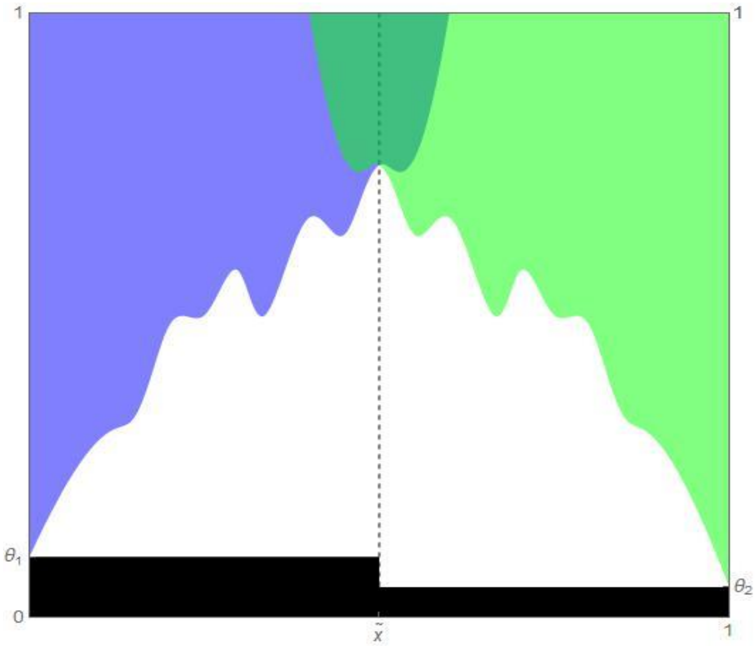
$$M_1(T_1, T_2) = \int_0^1 \int_0^{\breve{X}_1} g(\delta, x) dx d\delta = \frac{1}{2} + \frac{C_1(\cdot) - C_2(\cdot)}{4t^f} + \frac{T_2 - T_1}{2t^f}$$

$$M_2(T_2,T_1)=\int_0^1\int_{X_1}^1 g(\delta,x)dxd\delta=\frac{1}{2}+\frac{C_2(\cdot)-C_1(\cdot)}{4t^f}+\frac{T_1-T_2}{2t^f}$$

And the competition condition will be: $\left|\frac{C_2(\cdot)-C_1(\cdot)}{2}\right|+|T_1-T_2|<t^f$

In Figure 2 we observe in black users that will not adopt the platform, if Assumption 0 holds, this area will no longer exists. Firms' case is symmetric to this one and the conclusions are the same.

FIGURE 2. Bidimensional Market representation.



Source: Author's

So, plugging [1.1] and [1.2] into the platforms' profit functions we have:

$$\max_{T_j,v_j}\Pi_j = T_j\left(\frac{1}{2}+\frac{C_j(\cdot)-C_{-j}(\cdot)}{4t^f}+\frac{T_{-j}-T_j}{2t^f}\right)+(v_j-c_j)\left(\frac{1}{2}+\frac{s(k_j)-s(k_{-j})}{4t^u}+\frac{v_{-j}-v_j}{2t^u}\right)-I(k) \quad [1.3]$$

Using this function we derive optimal prices[11] conditional on expectations. We suppose platforms choose both fees simultaneously which yields:

$$T_1^*=t^f+\frac{C_1\left(k_1,n_1^e(\cdot)\right)-C_2\left(k_2,n_2^e(\cdot)\right)}{6} \qquad T_2^*=t^f+\frac{C_2\left(k_2,n_2^e(\cdot)\right)-C_1\left(k_1,n_1^e(\cdot)\right)}{6}$$

$$v_1^*=t^u+\frac{s(k_1)-s(k_2)}{6}+\frac{2c_1+c_2}{3}-\left(\frac{1}{4}+\frac{C_1(\cdot)-C_2(\cdot)}{72t^f}\right)\left(\frac{dC_1(\cdot)}{dn_1^e(\cdot)}+\frac{dC_2(\cdot)}{dn_2^e(\cdot)}\right)$$

$$v_2^*=t^u+\frac{s(k_2)-s(k_1)}{6}+\frac{2c_2+c_1}{3}-\left(\frac{1}{4}+\frac{C_2(\cdot)-C_1(\cdot)}{72t^f}\right)\left(\frac{dC_1(\cdot)}{dn_1^e(\cdot)}+\frac{dC_2(\cdot)}{dn_2^e(\cdot)}\right)$$

At equilibrium, we assume expectations are fulfilled and the number of active agents is:

[11] Hessian matrix is, at that points, negative semi-definite.

$$M_1^* = \left(\frac{1}{2} + \frac{C_1(\cdot) - C_2(\cdot)}{12t^f}\right) \qquad M_2^* = \left(\frac{1}{2} + \frac{C_2(\cdot) - C_1(\cdot)}{12t^f}\right)$$

$$n_1^* = \left(\frac{1}{2} + \frac{s(k_1) - s(k_2)}{12t^u} + \frac{c_2 - c_1}{6t^u} + \frac{C_1(\cdot) - C_2(\cdot)}{72t^f t^u}\left(\frac{dC_1(\cdot)}{dn_1(\cdot)} + \frac{dC_2(\cdot)}{dn_2(\cdot)}\right)\right)$$

$$n_2^* = \left(\frac{1}{2} + \frac{s(k_2) - s(k_1)}{12t^u} + \frac{c_1 - c_2}{6t^u} + \frac{C_2(\cdot) - C_1(\cdot)}{72t^f t^u}\left(\frac{dC_1(\cdot)}{dn_1(\cdot)} + \frac{dC_2(\cdot)}{dn_2(\cdot)}\right)\right)$$

Note that $n_1^* + n_2^* = M_1^* + M_2^* = 1$, the market is totally covered and competition between platforms leads to a complete participation on both sides. However, this is due to Assumption 0.

If we consider that Assumption 0 does not hold, the market will be smaller because platforms only consider the users and firms they can reach. However, we will have the same equilibrium because platforms rescale the market size to consider only the users they reach.

Proposition 1. *In a market with uncorrelated horizontal and vertical differentiation, the competition will be primarily focused on the marginal-high quality agents when prices are very high but, at equilibrium, it will be focused on almost every agent in the market. On the other hand, fees will have two opposite effects: the classical quality increase of a quality-augmented Hotelling model; and the externality effect that will decrease fees. This decreasing effect will be larger in the platform with the highest quality.*

i. Stability conditions.

In this section we point out the conditions to guarantee positive profits and normalized demands at equilibrium. Without these conditions, the equilibrium fees pointed out before would not be stable, i.e. we could not prove the optimality of that behaviour.

If we consider firms' side, to guarantee $0 \leq M_j(T_j, T_{-j}) \leq 1$, the transportation cost should verify: $t^f \geq \left|\frac{C_j(\cdot) - C_{-j}(\cdot)}{6}\right|$. In fact, this is the same condition to guarantee non-negative profits on firms' side in the case of the follower platform, i.e. when $C_j(\cdot) < C_{-j}(\cdot)$. If we assume $C_j(\cdot) \approx 0; C_{-j}(\cdot) = 1$, it is easy to prove the transportation cost should verify $t^f \geq 1/6$ to guarantee non-negative profits, so both platform will be in the market even at that extreme case.

On the other hand, if we consider the conditions to guarantee $0 \leq n_j(v_j, v_{-j}) \leq 1$. The transportation cost on users' side should verify $t^u \geq \left|\frac{s(k_j) - s(k_{-j})}{6}\right| + \left|\frac{c_{-j} - c_j}{3}\right| + \left|\left(\frac{dC_1(\cdot)}{dn_1^e(\cdot)} + \frac{dC_2(\cdot)}{dn_2^e(\cdot)}\right)\left(\frac{1}{3t^f}\right)\left(\frac{C_j(\cdot) - C_{-j}(\cdot)}{12}\right)\right|$. If we assume there is asymmetry between platforms, it is also interesting to know what conditions should fulfil the transportation cost to verify that the fee fixed by the follower platform is positive. In that case, from the follower's point of view, the condition is: $t^u \geq \left|\frac{s(k_j) - s(k_{-j})}{6}\right| + \left|\left(\frac{dC_1(\cdot)}{dn_1^e(\cdot)} + \frac{dC_2(\cdot)}{dn_2^e(\cdot)}\right)\left(\frac{1}{4} + \frac{C_j(\cdot) - C_{-j}(\cdot)}{72t^f}\right)\right| - \frac{c_{-j} + 2c_j}{3}$

Also, it is easy to prove that the last condition is more restrictive than the previous one as long as the condition about t^f that we have previously pointed out holds. Note that these conditions verify the non-negativity of follower's profits (a non-negative fee and a non-negative demand). In conclusion, as long as both transportation costs are high enough, both platforms will find profitable this market, even a follower platform. It is interesting to point out that there is a lot of worries about IoT technologies becoming a winner-takes-all-the-market, note that this is not the case here.

Proposition 2. *Two IoT platforms may coexist even with one being the leader and the other one the follower. It is only needed a strong differentiation to overcome the network effects.*

The reason is in the horizontal differentiation, as long as agents have different subjective perceptions about each platform, the coexistence is guaranteed without needing decreasing network externalities as it was recently pointed out in the Über vs Lyft case[12].

e. First Stage.

If we assume platforms invest to maximize their profits, their optimal decision is based on the anticipation of their behaviour at the second stage, so the optimal decision of platforms is given by:

$$\max_{k_j} \Pi_j(k_j) = T_j^*(k_j, k_{-j})M_j^*(k_j, k_{-j}) + (v_j^* - c_j)(k_j, k_{-j})n_j^*(k_j, k_{-j}) - I_j(k_j) \qquad [1.8]$$

We assume marginal costs are not related to quality investment, i.e. marginal cost depends on the chosen technology but, in our model, that decision is a discrete and exogenous one, meanwhile quality investment is a continuous and endogenous decision.

Using the previous specifications of fees and demands we can analyse how platforms choose their investment levels. In that sense, the first order conditions (FOC) can be rewritten as:

$$\frac{\mathrm{d}\Pi_j(k_j)}{dk_j} = \left[\frac{\mathrm{d}\Phi}{\mathrm{d}k_j}\right] + \left[\frac{\mathrm{d}\Theta}{\mathrm{d}k_j}\right] + \left[\frac{dn_j^0}{\mathrm{d}k_j}\right]\varepsilon_{cp}^p + n_j^0\left[\frac{d\varepsilon_{cp}^p}{dk_j}\right] - \left[\frac{d\ \varepsilon_{op}^D}{dk_j}\right]\varepsilon_{op}^p - \varepsilon_{op}^D\left[\frac{d\varepsilon_{op}^p}{dk_j}\right] - \frac{c_{-j} - c_j}{6}\left[\frac{d\varepsilon_{op}^p}{dk_j}\right] - \frac{c_{-j} - c_j}{6}\left[\frac{d\varepsilon_{cp}^p}{dk_j}\right] - \frac{dI_j(k_j)}{dk_j} = 0$$

Where Φ and Θ are the platforms' profits that come from firms and users respectively when there is no externalities, n_j^0 is the users' demand without externality effects and ε_{cp}^p and ε_{op}^p are the price-externalities imposed on users' fee by the competitor platform and by the own platform and ε_{op}^D is the externality imposed on the users' demand by the own platform.

If we assume total symmetry, it is reasonable to think that firms will invest the same quantity "k". However, if we assume there is some kind of heterogeneity between platforms in terms of investment or marginal costs, we can reach asymmetric equilibria where one platform will be the leader of the market. However, an interesting result is the following: if the previous stability conditions hold and there is no differences in marginal costs, it is easy to prove that both platforms prefer the symmetric equilibrium, i.e. there is no incentive to be differentiated in a vertical way.

Platforms will start a "quality race", this effect is robust even with asymmetric marginal costs. However, the presence of asymmetric marginal costs mitigate this effect. Note that if a platform has an advantage in terms of marginal costs, it has lower incentives to invest as long as investment is costly and it may prefer not to increase investment because a higher investment implies also a higher subsidy on users' side and that it is also costly. On the other hand, the other platform may have an incentive to invest harder as long as a higher investment may make its wearable more

[12] http://www.latimes.com/business/technology/la-fi-0105-lyft-growth-20160105-story.html

desirable from users' point of view which, at the same time, may increase the number of firms on the platform.

This effect is also found by Salim (2009) that states: "*platforms only gain from higher qualities [functionalities] by outperforming their rival*". However, she does not consider the effect of marginal costs that in our framework play an important role in mitigating investment incentives in the case of the platform with cost advantages.

On the other hand, when we assume total symmetry, agents' decisions no longer depend on quality (investment), this is the same result that we obtain in a classical quality-augmented Hotelling model.

Proposition 3. *Platforms have incentives to increase investment and there is no incentives to invest less as it happens in classical vertical differentiation models however, asymmetric costs lead to asymmetric equilibria. In the total symmetric model, both platforms will try to become leaders so they will reach a symmetric equilibrium where externalities cancel each other out.*

This proposition highlight the fact that, in wearables market, there is a strong competition in launching products with a large set of functionalities. From the first fitness tracker to the last one launched in 2016 there are several products that show a steadily increase in their functionalities like altimeter, sleep monitoring, etc. Also, we observe different patterns of prices among companies, (e.g. Fitbit and Withings), these differences in our model are explained by different cost structures, tastes and functionalities.

4. The Compatibility Model.

In this section we will explore the consequences of adopting compatibility between platforms. In this model, platforms share their users' data, so the information that it is provided to firms is roughly the same, however, the quality of each platform may be different as long as it depends on investment.

We have to consider how this compatibility translates into our model, in this case, we assume that with total and symmetric compatibility firms perceive cost advantages as follows: $\widehat{C}_j(k_j, \widehat{n^e}) = \widehat{C}_j(k_j, n_1^e + n_2^e)$.

As we will prove later, this new feature does not imply larger changes in how the equilibrium is reached. Although it changes fee, demand and profit levels it does not change the way the decisions are made.

a. Second Stage.

Using our previous definition of active agents it is easy to prove that users' demand is the same, however, there is a slightly change in firms' demand related to cost advantages. So we can adopt the previous framework to derive firms' and users' fees and demands at equilibrium.

$$\max_{T_j, v_j} \Pi_j = T_j\left(\frac{1}{2} + \frac{\widehat{C}_j(\cdot) - \widehat{C_{-j}}(\cdot)}{4t^f} + \frac{T_{-j} - T_j}{2t^f}\right) + (v_j - c_j)\left(\frac{1}{2} + \frac{s(k_j) - s(k_{-j})}{4t^u} + \frac{v_{-j} - v_j}{2t^u}\right) - I(k) \quad [1.3]$$

Which yields to:

$$T_1^* = t^f + \frac{\widehat{C_1}(k_1, n_1^e(\cdot)) - \widehat{C_2}(k_2, n_2^e(\cdot))}{6} \qquad T_2^* = t^f + \frac{\widehat{C_2}(k_2, n_2^e(\cdot)) - \widehat{C_1}(k_1, n_1^e(\cdot))}{6}$$

$$v_1^* = t^u + \frac{2c_1 + c_2}{3} - \left(\frac{1}{4} + \frac{\widehat{C_1}(\cdot) - \widehat{C_2}(\cdot)}{72t^f}\right)\left(\frac{d\widehat{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\widehat{C_2}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_1}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_2}(\cdot)}{dn_1^e(\cdot)}\right) + \frac{s(k_1) - s(k_2)}{6}$$

$$v_2^* = t^u + \frac{2c_2 + c_1}{3} - \left(\frac{1}{4} + \frac{\widehat{C_2}(\cdot) - \widehat{C_1}(\cdot)}{72t^f}\right)\left(\frac{d\widehat{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\widehat{C_2}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_1}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_2}(\cdot)}{dn_1^e(\cdot)}\right) + \frac{s(k_2) - s(k_1)}{6}$$

Proposition 4. *Compatibility does not change how the platforms make their pricing decisions however, it changes fee levels. Also, there is an incentive to reduce users' fee because platforms have larger users' bases. An increase in the own users' base it is also an increase of the same magnitude in the competitor's users' base.*

As in Doganoglu and Wright (2006) and Salim (2009), we find that competition is more intense in the incompatible case. However, we prove that standardization or compatibility does not lead necessarily to an one-sided equilibrium as it is pointed out by Salim (2009) or by Doganogly and Wright (2006). In fact, what our model highlights is that one-sided equilibrium may be reached only if there is symmetry in externalities, i.e. if $\frac{d\widehat{C_1}(\cdot)}{dn_1^e(\cdot)} = \frac{d\widehat{C_1}(\cdot)}{dn_2^e(\cdot)}; \frac{d\widehat{C_2}(\cdot)}{dn_2^e(\cdot)} = \frac{d\widehat{C_2}(\cdot)}{dn_1^e(\cdot)}$ holds. So, the way externalities are addressed is key to lead to an one-sided equilibrium and only if there is symmetry we will have such equilibrium.

At equilibrium, we assume expectations are fulfilled and the number of active agents is:

$$M_1^* = \left(\frac{1}{2} + \frac{\widehat{C_1}(\cdot) - \widehat{C_2}(\cdot)}{12t^f}\right) \qquad M_2^* = \left(\frac{1}{2} + \frac{\widehat{C_2}(\cdot) - \widehat{C_1}(\cdot)}{12t^f}\right)$$

$$n_1^* = \left(\frac{1}{2} + \frac{s(k_1) - s(k_2)}{12t^u} + \frac{c_2 - c_1}{6t^u} + \frac{\widehat{C_1}(\cdot) - \widehat{C_2}(\cdot)}{72t^f t^u}\left(\frac{d\widehat{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\widehat{C_2}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_1}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_2}(\cdot)}{dn_1^e(\cdot)}\right)\right)$$

$$n_2^* = \left(\frac{1}{2} + \frac{s(k_2) - s(k_1)}{12t^u} + \frac{c_1 - c_2}{6t^u} + \frac{\widehat{C_2}(\cdot) - \widehat{C_1}(\cdot)}{72t^f t^u}\left(\frac{d\widehat{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\widehat{C_2}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_1}(\cdot)}{dn_2^e(\cdot)} - \frac{d\widehat{C_2}(\cdot)}{dn_1^e(\cdot)}\right)\right)$$

A priori, it is not possible to state whether platforms' profits on firms' side are larger than in the incompatibility case or not, to prove that statement we have to make new assumptions. Let's assume:

- $\widehat{C_j}(k_j, \widehat{n^e}) - C_j(k_j, n_j^e) > \widehat{C_{-j}}(k_j, \widehat{n^e}) - C_{-j}(k_{-j}, n_{-j}^e)$

If the previous condition holds, there will be at least one platform which is better with compatibility however, this condition depends on the optimal investment decision so, it is not clear that there is always a winner with total compatibility in terms of profits from firms' side.

On users' side it is also not possible to determine whether or not there is a winner. Even if we assume the previous condition, it is needed to make assumptions about the externality. An interesting and reasonable assumption in the total compatibility framework is to consider that users' demands are symmetric, i.e. firms valuation of users' data that come from platform 1 and platform 2 is roughly the same[13]. If this assumption holds, it is direct to prove that platforms will fix their users' fee as in the case without externalities, i.e. we will have a one-sided solution.

Proposition 5. *Total compatible platforms may fix the same users' fee that a one-sided platform if both platforms face symmetric users' demand. This implies that when there is compatibility, users should be charged for this service although they do not benefit directly from it.*

This result is an interesting one because, previously, we have pointed out that each side has to be charged in relationship with the value they gain from being on platforms however, in this case, users do not benefit from externality subsidies as before because compatibility makes them disappear.

b. Second Stage. Asymmetric and partial compatibility.

In this section, we will expand the previous model to consider asymmetric and partial compatibility schemes. In that sense, platforms will have access to some data about competitor's users, but they will not have access to all the data as before. Also, platforms may have legal boundaries which allow them to have better/worse access to competitor's datasets.

In fact, this is the most common case in fitness tracker market right now. In this market it is easy to observe that platforms have agreements which allow them to establish asymmetric and partial access to competitors' users' data. For example, the Withings body scale is compatible with Fitbit platform, but the Fitbit platform is not compatible with Withings platform directly[14].

So, we assume cost advantages are given by: $\overline{C_j}\left(k_j, \overline{n^e}\right) = \overline{C_j}\left(k_j, n_j^e + \rho_j n_{-j}^e\right)$ with $\rho_j \in [0,1]$. Note that when $\rho_j = \rho_{-j} = 1$, it is the total compatibility case and when $\rho_j = \rho_{-j} = 0$ it is the basic framework with singlehoming and incompatibility.

Note that the way platforms make their decisions is the same that in previous models, the only change is how cost advantages are defined, so our platforms will behave as follows:

$$\max_{T_j, v_j} \Pi_j = T_j\left(\frac{1}{2} + \frac{\widehat{C_j}(\cdot) - \widehat{C_{-j}}(\cdot)}{4t^f} + \frac{T_{-j} - T_j}{2t^f}\right) + (v_j - c_j)\left(\frac{1}{2} + \frac{s(k_j) - s(k_{-j})}{4t^u} + \frac{v_{-j} - v_j}{2t^u}\right) - I(k) \qquad [1.3]$$

Which yields to[15]:

$$T_1^* = t^f + \frac{\overline{C_1}\left(k_1, n_1^e(\cdot)\right) - \overline{C_2}\left(k_2, n_2^e(\cdot)\right)}{6} \qquad T_2^* = t^f + \frac{\overline{C_2}\left(k_2, n_2^e(\cdot)\right) - \overline{C_1}\left(k_1, n_1^e(\cdot)\right)}{6}$$

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[13] This assumption implies that firms can access to an identical database so, there is neither discrimination nor differences between both platforms in users' database however, platforms may differ in their quality levels (investment levels).

[14] Indirectly, Fitbit platform is compatible with Withings platform, but Withing platform is not direct compatible with Fitbit's.

[15] Hessian matrix is, at that points, negative semi-definite.

$$v_1^* = t^u + + \frac{2c_1 + c_2}{3} - \left(\frac{1}{4} + \frac{\overline{C_1}(\cdot) - \overline{C_2}(\cdot)}{72t^f}\right)\left(\frac{d\overline{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\overline{C_2}(\cdot)}{dn_2^e(\cdot)} - \rho_1 \frac{d\overline{C_1}(\cdot)}{dn_2^e(\cdot)} - \rho_2 \frac{d\overline{C_2}(\cdot)}{dn_1^e(\cdot)}\right) + \frac{s(k_1) - s(k_2)}{6}$$

$$v_2^* = t^u + + \frac{2c_2 + c_1}{3} - \left(\frac{1}{4} + \frac{\overline{C_2}(\cdot) - \overline{C_1}(\cdot)}{72t^f}\right)\left(\frac{d\overline{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\overline{C_2}(\cdot)}{dn_2^e(\cdot)} - \rho_1 \frac{d\overline{C_1}(\cdot)}{dn_2^e(\cdot)} - \rho_2 \frac{d\overline{C_2}(\cdot)}{dn_1^e(\cdot)}\right) + \frac{s(k_2) - s(k_1)}{6}$$

Proposition 6. *Asymmetric and partial compatibility do not modify the way platforms makes their optimal decisions, however it changes fee and demand levels. Also, total compatibility and total incompatibility cases are particular cases of the asymmetric and partial compatibility case.*

We assume that at equilibrium expectations are fulfilled and the number of active agents is:

$$M_1^* = \left(\frac{1}{2} + \frac{\overline{C_1}(\cdot) - \overline{C_2}(\cdot)}{12t^f}\right) \qquad M_2^* = \left(\frac{1}{2} + \frac{\overline{C_2}(\cdot) - \overline{C_1}(\cdot)}{12t^f}\right)$$

$$n_1^* = \left(\frac{1}{2} + \frac{s(k_1) - s(k_2)}{12t^u} + \frac{c_2 - c_1}{6t^u} + \frac{\overline{C_1}(\cdot) - \overline{C_2}(\cdot)}{72t^f t^u}\left(\frac{d\overline{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\overline{C_2}(\cdot)}{dn_2^e(\cdot)} - \rho_1 \frac{d\overline{C_1}(\cdot)}{dn_2^e(\cdot)} - \rho_2 \frac{d\overline{C_2}(\cdot)}{dn_1^e(\cdot)}\right)\right)$$

$$n_2^* = \left(\frac{1}{2} + \frac{s(k_2) - s(k_1)}{12t^u} + \frac{c_1 - c_2}{6t^u} + \frac{\overline{C_2}(\cdot) - \overline{C_1}(\cdot)}{72t^f t^u}\left(\frac{d\overline{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\overline{C_2}(\cdot)}{dn_2^e(\cdot)} - \rho_1 \frac{d\overline{C_1}(\cdot)}{dn_2^e(\cdot)} - \rho_2 \frac{d\overline{C_2}(\cdot)}{dn_1^e(\cdot)}\right)\right)$$

As it has happened before, it is not possible to state whether or not platforms' profits from firms' side are larger than the previous case without making new assumptions. However, in this case, it is interesting to analyse particular cases of asymmetric and partial compatibility.

For example, when $\rho_1 = 1; \rho_2 = 0$ it is only needed to assume $k_1 > k_2$ and it is direct to prove that $\overline{C_1}(\cdot) > \overline{C_2}(\cdot)$ which leads platforms 1 to be the market leader when $c_1 \leq c_2$. However, it is possible that even with $k_1 < k_2$ or $c_2 \leq c_1$ the previous statement holds, i.e. asymmetric compatibility may be a profitably strategy when a platform has lower quality or worse technology and even when this compatibility would lead to symmetric compatibility (it is reasonable to think in that reaction from competitors). However, the profitability of this strategy depends on how cost advantages are considered.

Proposition 7. *Low-quality platforms may have an incentive to try to make competitor's users' database compatible because, in that way, they offer larger cost advantages on firms' side. In that sense, compatibility decreases competition on users' side but increases it on firms' side.*

This incentive to become compatible is also shared by Doganoglu and Wright (2006) and by Salim (2009).

i. Stability conditions.

As before, we point out the conditions to guarantee positive profits and normalized demands at equilibrium. Note that due to the relationship between the compatibility and incompatibility cases, stability conditions are also related. In fact, the conditions on firms' side are quite similar. To guarantee $0 \leq M_j(T_j, T_{-j}) \leq 1$ and non-negative follower's profits, the transportation cost should verify: $t^f \geq \left|\frac{\overline{C_j}(\cdot)-\overline{C_{-j}}(\cdot)}{6}\right|$

On the other hand, if we consider the conditions to guarantee $0 \leq n_j(v_j, v_{-j}) \leq 1$. The transportation cost on users' side should verify $t^u \geq \left|\frac{s(k_j)-s(k_{-j})}{6}\right| + \left|\frac{c_{-j}-c_j}{3}\right| + \left|\left(\frac{d\overline{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\overline{C_2}(\cdot)}{dn_2^e(\cdot)} - \rho_1\frac{d\overline{C_1}(\cdot)}{dn_2^e(\cdot)} - \rho_2\frac{d\overline{C_2}(\cdot)}{dn_1^e(\cdot)}\right)\left(\frac{1}{3t^f}\right)\left(\frac{C_j(\cdot)-C_{-j}(\cdot)}{12}\right)\right|$. It is also interesting to know what conditions should fulfil the transportation cost to verify that the fee fixed by the follower platform is non-negative, in that case, the transportation cost should verify: $t^u \geq \left|\frac{s(k_j)-s(k_{-j})}{6}\right| + \left|\left(\frac{d\overline{C_1}(\cdot)}{dn_1^e(\cdot)} + \frac{d\overline{C_2}(\cdot)}{dn_2^e(\cdot)} - \rho_1\frac{d\overline{C_1}(\cdot)}{dn_2^e(\cdot)} - \rho_2\frac{d\overline{C_2}(\cdot)}{dn_1^e(\cdot)}\right)\left(\frac{1}{4} + \frac{C_j(\cdot)-C_{-j}(\cdot)}{72t^f}\right)\right| - \frac{c_{-j}+2c_j}{3}$

Compared with the incompatible case, the conditions about t^u are weaker, i.e. we need a lower t^u to guarantee non-negative follower's profits. So, as we have pointed out before, compatibility makes easier the coexistence of platforms because it mitigates price competition on the subsidised side, i.e. users' side. On the other hand, the conditions are weaker with total symmetry because transportation cost is only required to be non-negative.

c. First Stage.

We will analyse only the compatible case. However, it is easy to prove that there are no bigger differences in how platforms make their investment decisions when we compare this case with the other ones, it only changes the investment levels.

On the other hand, if we assume platforms will invest to maximize their profits, their optimal decision is based on the anticipation of their behaviour at the second stage, so the optimal decision of platforms is given by:

$$\max_{k_j} \Pi_j(k_j) = T_j^*(k_j, k_{-j})M_j^*(k_j, k_{-j}) + [v_j^*(k_j, k_{-j}) - c_j]n_j^*(k_j, k_{-j}) - I_j(k_j) \qquad [1.8]$$

Using the previous specifications of fees and demands we can analyse how platforms choose their investment levels. In that sense, the first order conditions (FOC) can be rewritten as:

$$\frac{d\Pi_j(k_j)}{dk_j} = \left[\frac{d\widehat{\Phi}}{dk_j}\right] + \left[\frac{d\Theta}{dk_j}\right] + \left[\frac{dn_j^0}{dk_j}\right]\widehat{\varepsilon_{cp}^p} + n_j^0\left[\frac{d\widehat{\varepsilon_{cp}^p}}{dk_j}\right] - \left[\frac{d\,\widehat{\varepsilon_{op}^D}}{dk_j}\right]\widehat{\varepsilon_{op}^p} - \widehat{\varepsilon_{op}^D}\left[\frac{d\widehat{\varepsilon_{op}^p}}{dk_j}\right] - \frac{c_{-j}-c_j}{6}\left[\frac{d\widehat{\varepsilon_{cp}^p}}{dk_j}\right] - \frac{dI_j(k_j)}{dk_j} = 0$$

As it has happened in the incompatible duopoly case, if we assume total symmetry, we expect a symmetric investment equilibrium where platforms invest the same quantity. As before, if the previous stability conditions hold, it is easy to prove that both platforms prefer the symmetric equilibrium when they are in a symmetric framework. Note that the investment level will not necessarily be the same as before as consequence of different network effects. Another interesting result is that compatibility does not imply collusion, i.e. platforms do not behave as a monopoly in any side and, because of that, partnerships cannot be considered as a merger for simplification purposes[16].

On the other hand, if we assume asymmetries between platforms in terms of marginal or investment cost, we will have asymmetric equilibria. However, the nature of those equilibria will be different if the asymmetry comes from marginal or investment cost.

Note that investment costs do not affect the decision-making process at the second stage, by contrast, asymmetric marginal costs modify fees and market shares and, as before, if a platform has a marginal cost advantage, its incentives to invest will be mitigated in comparison with the other platform, i.e. if a platform has chosen a superior technology or it has a more efficient way of producing its devices, it has less incentives to improve its functionalities than the competitor because the competitor will have to overcome the technology-superior platform in some way, and that way is by increasing the investment or the functionalities.

If we compare our results with Salim's (2009) we observe that she find the same competition effect between platforms, i.e. when a platform provides higher quality than its rival, its market shares are also higher. However, she finds quality has a negative impact on market shares that she relates to the feedback loop between sides, she considers that higher investment leads to higher networks effects that, at the same time, intensify competition.

In our model, higher investment leads to a potential higher market share on users' side that, at the same time, leads to a potential higher market share on firms' side. But what we find is that this externality decreases fees on users' side but, in contrast, it does not reduce market shares.

In the case of users' market share, we find the same result than her, i.e. market share depends on own and competitor fees on that side and on the other side. So, the divergence in conclusions related to the effect of externalities in the equilibrium market shares cannot be attributed to externalities as she points out, and probably it is consequence of the model she and we assume and it is not only consequence of externalities by themselves.

If we assume total symmetry, if easy to prove that we reach the one-sided equilibrium with higher profits, so it is reasonable to consider that investment decisions in a total compatibility framework will lead to higher investment levels as long as price competition on users' side is mitigated and a higher investment leads to higher prices without risking losing users as consequence of that mitigated competition, this in fact what Salim (2009) finds and our work highlights the same conclusion.

Proposition 8. *Investment decisions with compatibility may differ from those in incompatibility frameworks. Also, partnerships cannot be considered as only one company when two or more companies operate different platforms in the same market. On the other hand, the main conclusions of the total compatibility/incompatibility cases are valid in the asymmetric compatibility case. However, investment decisions in a total compatibility framework will lead to higher investment levels.*

[16] Note that this conclusion does not imply we cannot find a collusive behaviour, maybe there are other incentives to collude however, those incentives are not coming from compatibility.

5. Conclusions.

Wearables are probably the first IoT market in taking off with respect to the mainstream markets. One of the most characteristic devices is the fitness tracker, these devices are worn on wrist, ankle, etc. and they capture data like heart rate, sleep quality, number of steps, GPS position, etc. that data can be anonymized and sold to companies like sport firms that are interested in sport trends among youth or maybe, life habits of sportsmen. However, as this market evolves, we observe other IoT markets, like smart cars or smart driving, that share a large set of features with wearables market. So, understanding what happens and why in wearables market may be useful to guide the decision making process in other IoT markets.

What makes wearables market interesting is not only its astonishing figures around market size, growth and investment, (by 2020 it is expected to be worth $34 billion[17]) but also they are based on multi-sided markets with asymmetric structures. It is easy to observe that firms are interested in users' data but users only care about the device they buy. So we can understand these high-tech markets with a well-known tool from industrial organization.

To address this issue, we propose a multi-sided model where two platforms sell a device that capture data from users and that data is later sold to firms interested in that data. We assume a two-stage game where at the first stage, platforms choose the functionalities/quality related to their devices and, at the second stage, they compete in prices in both markets. We also assume that previously, platforms have chosen a set of technologies that define the marginal cost of production of the devices however, that decision in our model is exogenous. We assume the set of available technologies is discrete and the differences between each set of technologies can be expressed in terms of marginal costs of production.

We have found that, as long as there is an externality on firms' side, it is optimal to decrease users' fees to attract them (in comparison with the no-externality framework); this also leads to the creation of a more valuable service and higher fees on firms' side. However, in the total compatibility case may not be optimal to subsidize users as long as both platforms share their dataset. In this case, it may be optimal to behave as a traditional one-sided market without externalities if symmetric network externalities are assumed.

We have assumed agents are differentiated in two dimensions, this feature has led us to point out that, in those cases, platforms start competing for high-quality-marginal agents but, in equilibrium, they compete for low-quality users because no agent is priced out of the market. Also, we have found that two platforms may coexists if there is a strong horizontal differentiation. In this case, even with strong network effects there is not going to be a winner-takes-all-the-market outcome.

This result have important consequences from competition authorities' point of view, because differentiation strategies may guarantee the coexistence of several platforms, as it happens in US with Über vs Lyft competition. However, a remarkable outcome of our models is that it is not the vertical differentiation the dimension that allows the coexistence, it is the horizontal one. In fact, many smart services or digital platforms base their existence and their main added value on being

[17] http://www.forbes.com/sites/paullamkin/2016/02/17/wearable-tech-market-to-be-worth-34-billion-by-2020/#4c8ff8833fe3

“different or technological superior than their competitors”[18] and from a vertical differentiation model this seems contradictory because we would expect a low-quality platform and a high-quality one and what we find is two high-quality platforms. Our model points out that these strategies (being different or offering new functionalities) are optimal.

In fact, another interesting result is that, despite vertical differentiation, there is no incentive to invest less than the leader. We observe an incentive to invest more because the horizontal differentiation allows the coexistence of both platforms, in that sense, there is an incentive to invest more because, in that way, platforms can target high-quality users that are also differentiated by tastes.

However, we observe the effect of the vertical differentiation in fees, it is easy to observe that the classical pattern of the high-quality product being more expensive than the low-quality one it is also true here, notwithstanding, the difference is in the decision of being low-quality. There is no incentive to be a low-quality platform as it happens in classical vertical differentiation models, both platforms want to invest more than the competitor because the symmetric investment equilibrium is more profitable than the leader-follower equilibrium. On the other hand, if there is asymmetric marginal/investment costs, there is an incentive to establish an asymmetric quality equilibrium but this equilibrium is different from those in vertical differentiation models.

On the other hand, we observe different patterns of fees between, for example, Fitbit and Withings, these differences in our model are explained by different cost structures, tastes and functionalities. Additionally, we have found a “quality race”, i.e. platforms try to outperform their rival. However, we have pointed out that marginal costs play an important role in mitigating investment incentives in the case of the platform with cost advantages, i.e. the platform with cheaper technology has smaller incentives to invest in quality/functionalities in comparison with the platform with the expensive technology, that is because the latter have to overcome its inherent higher prices with more functionalities or quality.

We also consider what happens when we assume that platforms may become compatible in terms of sharing data and how compatibility may change the market structure. Compatibility has a clear relevance in IoT markets because many companies use public datasets or they have some kind of compatibility among their services as it happens in fitness tracker markets. Our models have highlighted some interesting insights concerning compatibility. Our models points out that compatibility leads to higher prices on users’ side compared with the incompatibility case. When there is compatibility, users should be charged for this service although they do not benefit directly from it. This applies to every compatibility scheme (asymmetric or symmetric; partial or complete).

We prove that standardization or compatibility does not lead necessarily to an one-sided equilibrium as it is pointed out by Salim (2009) or by Doganoglu and Wright (2006), in fact, what our model highlights is that one-sided equilibrium may be reached only if there are symmetric externalities.

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[18] A quick search in webpages of the “56 stratups making cities smarter […]” that CB Insights highlights, it is easy to observe that almost every company points out their better technology and the “experience” of using them.
https://www.cbinsights.com/blog/iot-smart-cities-market-map-company-list/?utm_source=CB+Insights+Newsletter&utm_campaign=d6de1daf99-Top_Research_Briefs_04_02_2016&utm_medium=email&utm_term=0_9dc0513989-d6de1daf99-86652009

Also, we have found that low-quality platforms may have an incentive to make competitor's users' base compatible because, in that way, they offer larger cost advantages on firms' side (and they can charge higher fees). In that sense, compatibility decreases competition on users' side but increases it on firms' side however, as long as firms are horizontal differentiated too, this increase in price competition is mitigated.

If we assume total symmetry and compatibility, if easy to prove that we reach the one-sided equilibrium with higher profits, so it is reasonable to consider that the investment decision in a total compatibility framework will lead to higher investment levels as long as price competition on users' side is mitigated and a higher investment will lead to higher prices without risking losing users as consequence of that mitigated competition. However, it is not clear what levels of compatibility and asymmetry make incompatibility more desirable.

To conclude, these models have some flaws, for example, we have not considered what happens when there is own-network effect on users' side (it is common to create "communities" of users that may influence the adoption of the service); or when a platform sells several services that are in some way interrelated; or, in the case of wearables, we have not considered the impact of intertemporal competition given that those services are durable goods.

In future works we want to extend these models to take into account that features and other ones related to some digital multi-sided platforms like smart cities. In those cases we are interesting in contrasting public and private incentives to invest in smart networks.

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