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The Digital Revolution and COVID-19

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The Digital Revolution and COVID-19

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Abstract

We develop a simple model of digital markets to analyze the impact of Covid-19 on the digital transformation of sectors. The lockdown due to Covid-19 is modeled as a shock that wipes out the physical market, temporarily leaving digital consumption as the only option. Under plausible assumptions on digital demand and supply, the model predicts that such temporary shock produces an irreversible rise of the digital markets. This happens for three distinct reasons. First, by temporarily eliminating the physical market, Covid-19 provides a strong incentive for firms to carry out the fixed investments necessary to venture into the digital market (supply channel). Secondly, by forcing even the most reluctant consumers into the digital market, Covid-19 pushes them to familiarize with digital platforms, and this confidence endures in the post-Covid era (demand channel). Finally, if consumers' taste for digitalization is affected by the size of the digital market, a market may be entrapped into a low-digital equilibrium indefinitely. In such context, the lockdown due to the pandemic is the shock that may unleash the forces of digitalization and tilt the entire sector towards a high-digital equilibrium (network externalities channel).

Keywords: digital transformation, digitalization, Covid-19, pandemic, disruptive technologies.

JEL Classification: O3, L8, D8.

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"COVID-19 is a before-and-after moment in the digital transformation"
Andrew Filev, March 30th, 2020
Forbes, https://www.forbes.com/

1 Introduction

The toll of the COVID-19 pandemic in terms of human lives has been -and still is- huge, and the economic downturn deep and heterogenous. Policies and health prescriptions aimed at limiting the contagion forced producers and consumers' interaction into new modes very quickly. Each one of us -individuals and organizations, on any side of the market- faced the challenge of using digital tools to a much wider extent, adopting smart working, online education, video conferencing, e-commerce, online banking etc. Such intense exploration of digital tools and their applications represented a leap that would have taken years to be realized in normal times (George et al., 2020). But it was also done in an emergency situation, out of restrictions that cancelled *de facto* the existence of the physical market. It was experimenting without any safety net.

Some sectors and firms -especially those providing the infrastructure and services needed for the digital experimentation to take place- were boosted by this change. For example, the video conferencing software sector saw an initial sudden reshuffling of the user bases of different products, with the final growth of Zoom over other tools (CNBC, 2020a). The product was, however, not fully ready for mass usage, and raised security issues that the developers tried to solve "on the fly" (The Guardian, 2020). Also Amazon went through similar phases, mobilizing resources to cope with the sudden increase of the orders well beyond pre-Covid expansion plans (Reuters, 2020). Other sectors, where digital tools were not as widespread, for example small neighbourhood 'ho-re-ca' firms (such as traditional restaurants), struggled during the "Covid phase" to keep up with the changes in demand (The New York Times, 2020; Wine News, 2020). Some experimented innovative solutions, others just waited hoping to go back to normality soon.

Overall, both supply and demand entered an 'era of technological ferment' (Tushman & Anderson, 1986), where consumers' preferences co-evolved with producers' investments to adopt and improve new digital technologies. As adoption of digital technologies has gone through an unprecedented mass experiment, the question we ask in this paper is: what are the medium-to-long run consequences of Covid-19 for the digital transformation of the business-to-consumer (B2C) markets?

As we write, most of the strictest lockdown policies have been waived or softened, and physical interaction as well as more traditional ways of supply-demand matching are again an option that actors can choose. The virus, however, is still unbeaten by any vaccine or therapy, and several markets are still working under specific protocols and restrictions. We then address the above question by building and analyzing a theoretical model of a digital market. Although simple, the model allows us to identify the main channels through which the Covid-19 shock may trigger an irreversible rise of the digital market. It also produces an array of specific predictions on the medium-to-long-run consequences of Covid-19 for the evolution of digital markets, which might be tested in the future.[1]

The model has the following main features. A single commodity exists which may be consumed in two "varieties", a digital (D) and a non-digital (ND) variety, that consumers consider as substitute goods. Firms in a perfectly competitive sector may serve the digital market only after paying a fixed entry cost (the cost of the fixed investment necessary to build the digital infrastructure). A market for the digital variety exists only if consumers' preferences for digitalization are strong enough to compensate for the fixed investments that producers have to sustain. The timing of the model unfolds along the three phases of the pandemic, pre-Covid (period 1), Covid (period 2) and post-Covid (period 3), the only difference being that, during the Covid phase, the non-digital market temporarily disappears. Covid is then interpreted as a positive but temporary demand shock on the digital market.

The first channel through which Covid-19 affects the digital market comes from the supply side of the model. As we show in section 3, if a digital market did not exist in the pre-Covid phase -because consumers' taste for digitalization was too weak to justify the producers' fixed investments necessary to venture into the digital market-, the Covid shock hitting the economy in period 2 may provide a strong enough incentive for firms to carry out those investments, as the non-digital variety is temporarily unavailable. As a result, the digital market arises thanks to this temporary positive demand shock. Crucially, once the digital market has arisen, it remains in place even when Covid disappears (period 3), that is, even when the specific (and temporary) conditions that have favored its emergence cease to exist. In other words, Covid represents a temporary shock which, however, produces a permanent effect on the rise of the digital market.[2]

[1] We will return to these predictions in the concluding section.

[2] If, on the other hand, the digital market already existed in the pre-covid phase, the positive

The previous analysis is conducted under the assumption that consumers' preferences are identical and immutable over time. In reality, it is likely that (i) consumers differ in terms of their attitude towards digitalization; (ii) each consumer's taste for digitalization may be affected by the number of other consumers (direct network effect) and producers (indirect network effect) active on the market. In other words, the number of digital transactions (i.e., the size of the digital market) affects consumers' preferences.

Motivated by these two arguments, we then extend the previous framework along two distinct directions. In section 4, we consider an environment in which two categories of consumers exist, digital and non-digital consumers, where the former are defined as consumers who were already digitally active before the pandemic. When Covid hits the economy, it triggers participation of the non-digital consumers (as they have no alternative), and the digital market booms. Crucially, the non-digital consumers' participation in the digital market remains in place even when Covid retreats. Once again, a temporary shock has a long-lasting effect in boosting the digital market.

In section 5, we build a model with positive network externalities across consumers, in the sense that the taste for digitalization depends positively on how well-developed the digital market is. As it usually happens in the presence of thick market externalities, the model admits multiple equilibria (Cooper, 1999). In particular, we show that two equilibria may exist, a low-digital and a high-digital equilibrium, and that the Covid shock may act as a coordination device that induces market actors to converge towards the high-digital equilibrium.

The rest of the paper is organized as follows. In the next section, we review the theoretical background useful to interpret the "digital revolution" and its possible link with Covid-19. Section 3 introduces the theoretical framework and analyses the supply-side channel of the impact of Covid-19 on digitalization. Sections 4 and 5, respectively, explore the demand side and the network externalities' channel. Finally, in section 6 we further discuss our main findings and draw some conclusions.

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demand shock associated with Covid only has a temporary positive effect on the digital market. This result, however, curcially hinges on the assumption that consumers' digital preferences are identical and unaffected by the Covid shock, an assumption that we remove in the two subsequent model extensions.

2 Background

2.1 Technological change and markets

Technology discontinuities are fundamental turning points in the history of societies (Freeman & Perez, 1988). In particular, General Purpose Technologies (Conti et al., 2019), such as those bundled nowadays under the umbrella of "digital transformation", have been observed spreading in several sectors and through a wide array of applications, changing the very functioning of our economic systems. The 'Fourth Industrial Revolution' (Schwab, 2017) is indeed a revolution, bringing digital technologies into each component of our lives and economies, from people's interaction modes to production processes and global value chains (Floridi, 2014; McAfee & Brynjolfsson, 2017).

Revolutions, however, are rarely linear and predictable events; they often take the form of abrupt discontinuities (Kuran, 1995; Linstone, 2010). Technology-led revolutions are no exception (Kline & Rosenberg, 1986; Freeman & Perez, 1988). Paradigm shifts, or radical and discrete turning points in technological trajectories (Dosi, 1982), depend on several factors, both on the supply and on the demand side. Indeed, the literature on Innovation Studies has investigated both technology-push and demand-pull technological change (Di Stefano et al., 2012; Peters et al., 2012; Nemet, 2009), highlighting the forces that hinder and constrain transformations, as well as those that foster and facilitate them, on both sides. According to this literature, for instance, market equilibria may limit or impede the diffusion of a new technology up to a certain moment in which, suddenly, adoption becomes not only available as an option, but also the best option for the economic actors.

Christensen & Bower (1996) have coded such defining moments *technological disruptions* and explained them by arguing that demand and supply may be misaligned for some new technologies in their early development stages, and then abruptly align when the development of the new technology reaches a certain threshold. More in detail, 'discontinuities' are observed for technologies whose initial adoption is difficult and limited to a niche, as consumers' preferences are still tied to the main feature that the older and still widespread technology provides with greater performance. Producers of the new technology would need to put forward large investments in short time to overcome this consumers' preference bias towards the old technology. The combination of this consumers' bias and the producers' difficulty to bear the large investments needed to meet consumers' taste implies that the new technology is adopted only within the small perimeter of a niche.

Over time, however, the older technology reaches a stage in which innovations along the same trajectory (Dosi, 1982) may be relevant but not valued much by consumers, while parallelly the new technology may improve along its own trajectory enough to satisfy consumers' preferences. Over time, the performance improvement of the new technology in the most requested feature allows producers in the niche to reach the minimum required threshold for that feature, thus becoming finally competitive also on the main market. During the same period of time, consumers gradually learn that the new technology can increasingly satisfy their basic requirements.

Being such new technologies usually cheaper, smaller and simpler (Christensen & Bower, 1996), consumers may finally decide to abandon the old and adopt the new technology right away, 'disrupting' the old market in favor of the new one. Christensen and Bower give a vivid example of this in the disk drive industry: *"Customers in these established markets eventually embraced the new architectures they had rejected earlier, because once their needs for capacity and speed were met, the new drives' smaller size and architectural simplicity made them cheaper, faster, and more reliable than the older architectures"* (p. 210, Christensen & Bower, 1996).[3]

2.2 Consumers' and producers' reciprocal engagement

Disruptive events in the technological development of our societies can be modeled looking at the interplay between consumers' preferences evolution and producers' investments in the new technological trajectory. Consumers and producers represent two sides of the same coin. Consumers' initial lack of preference for the new technology could be overcome by producers' investment in the sudden improvement of the new technology in the main feature the market requests. At the same time, producers would consider such investment only under very peculiar conditions, such as perfect availability of capital, clear evaluation of the expected returns, and certainty about future consumers' preferences. The combination of these conditions is usually very difficult to find in the real world.

For instance, the OECD (2019) study on e-commerce -certainly one of the most disrutptive innovations in distribution- finds that, in the EU in 2015, firms (both those

[3] As we further discuss in subsection 2.4, we interpret the Covid-19 outbreak exactly as a moment of technological disruption, that is, an event capable of shifting the paradigm towards a state of "full digitalization".

selling and those not selling online) identified the following two items as the two key obstacles to e-commerce: "*Costs [of e-commerce] are too high*" (i.e., firms' investments) and "*Products are not suitable [for online purchases]*" (i.e., consumers' preferences).[4]

As a result, breaking the limits of its niche is very difficult for the new technology. It requires a lot of time in which the technology must be learned, valued and adopted by consumers, and improved, adapted, and explored by the producers, whose investment can only unfold piece by piece (Utterback & Suarez, 1993).

The concept of Dominant Design emergence (Tushman & Anderson, 1986; Anderson & Tushman, 1990) clearly captures such dynamics by predicting that, after a phase of broad experimentation by several producers, a technology would become dominant, with producers and consumers converging towards the same technological option (Abernathy & Utterback, 1978; Utterback & Abernathy, 1975). Other technologies, even more competitive, but not in line with the requests of the demand, are selected out (e.g., the well-known VHS vs. Betamax case; Cusumano et al., 1992). At the same time, consumers' preferences undergo a process of discovery: *"consumer attitudes and needs ... change through the course of the industry evolution. ... The closer the industry is to a stage of maturity ... the greater the product knowledge of consumers"* (p. 1125, Giachetti & Marchi, 2010). In other words, consumers learn what can be done with different technologies, become acquainted with their functionalities, and start to figure out the cost of switching to the new technology vis-à-vis its advantages.

Utterback & Suarez (1993) state this clearly: *"A dominant design is the outcome resulting from a series of technical decisions about the product constrained by prior technical choices and by the evolution of customer preferences. A dominant design often does not represent radical change, but the creative synthesis of the available technology and the existing knowledge about customers preferences".* (p. 7, Utterback & Suarez, 1993).

By this gradual process of experimentation and discovery out of uncertainty on both sides of the market, one technological design gets selected and becomes dominant. This is even more true when the new technology radically changes the way the product or the service is produced and delivered to the consumer. The transformation of previously product-centered markets onto service-based markets, i.e. the so called "servitization", represents a case in point (Baines et al., 2009; Frank et al., 2019). Consider for example car sharing (Bardhi & Eckhardt, 2012). This new market is still

[4]Indeed, consumers' strong preference towards in-person purchases is by far (69% in 2017) the most relevant reason for not buying online, with growing importance over time -it was 61% in 2009.

a small niche, but very lively. It revolves around the crucial transformation of the concept of mobility from ‘buying and using the car’ to ‘renting a car to move from A to B’. Such transformation could take place only because consumers and producers engaged in reciprocal experimentation that radically transformed their conception of consumption from ‘producing, selling / buying and then using a product’ to ‘performing / receiving a service’ (Belk, 2014).

This experimentation cannot be done in one shot precisely because investment may be too large, while the uncertainty about the producers’ new technology and consumers’ preferences may persist for a long period of time, following the natural pace of technological improvements and/or consumers’ discovery. A first case in point is the diffusion difficulties of self-driving cars (Maurer et al., 2016). Artificial Intelligence’s (A.I.) main limitations when driving a car are two. The first is a technological problem, weighing on the side of the producers, that calls for improvements of the A.I.’s capabilities to forecast environmental changes, including other (human) drivers’ behavior (Guanetti et al., 2018). The second issue deals with consumers’ acceptance, trust and acquaintance with A.I., and with the development of preferences over a possibility set still to be unfolded (Tussyadiah et al., 2017), also on the ethical side (Lin, 2016; Trappl, 2016). None of the two problems can be solved simply injecting financial capital into the system: it requires time, exploration, and discovery on both sides.[5]

2.3 Network externalities and endogenous evolution of preferences

Reciprocal engagement between demand and supply may be facilitated by the existence of endogenous positive feedbacks across consumers or between consumers and producers. For instance, in markets for which network externalities across consumers are key (e.g., telecom markets, Katz & Shapiro, 1985), the gain each consumer can extract from a new technology is higher the greater the number of other consumers adopting it. As a result, if this number is large enough, the missed gains from not switching may become much higher than the switching costs, pushing consumers to

[5] A well known example is "A Better Place", the enteprise launched in 2007, which was meant to revolutionize the automotive industry towards electric mobility (Loock & Mueller, 2012). While the firm was able to mobilize a huge amount of investments from both corporate and governmental institutions, consumers’ preferences did not evolve consistently and quickly enough. In 2013, "A Better Place" filed for bankruptcy.

experiment the new technology.[6]

Network externalities may also act through the complementarity between demand and supply. Think of two-sided platforms. In the tourism sector, for example, using platforms (such as Booking.com or AirB&B) to program holidays and trips, booking flights etc. is now a widespread consumption mode (Xiang et al., 2017). In these platforms, user-buyers and user-suppliers clearly gain from having a virtual marketplace, where they can match irrespectively of their location and in an asynchronous mode. Clearly, the incentive of the supplier to attend the platform is stronger the greater the number of buyers, and *viceversa*. The nexus between the two sides of the platform generates "indirect network externalities" (Chou & Shy, 1990) that lead to an "indirect network effect" (Mcintyre & Srinivasan, 2017).

The presence of (direct or indirect) network effects clearly affects consumers' choices, and thus convergence to a dominant design (Lee et al., 1995). Indeed, studies of platforms show that installed bases can have strong effects (e.g., Tucker & Zhang, 2010; see also Boudreau & Jeppesen, 2015, for an exception) and that -under certain conditions- may spur a process of self-sustained growth (e.g., Giordani et al., 2017).

2.4 Consumers, producers and the COVID-19 pandemic

Seen from this angle, the outbreak of the COVID-19 pandemic can be seen as the 'disruptive moment' between a "slowly spreading digitalization" and "full digitalization". Before the outbreak, digital technologies were diffusing, but their potential was still greatly underexploited. They were still relegated to certain sectors and usages, adopted mainly by the most advanced, experimenting consumers or producers. Small firms, traditional sectors, and consumers on the lower end of the digital divide were still lagging behind (OECD, 2017; UNCTAD, 2019).

When the policies put in place worldwide to counteract COVID-19 pandemic constrained consumers and producers into the lockdown, restrictions applied not only to physical interaction, but also to mobility and outdoor activities in general (OECD, 2020; The New York Times, 2020). As a result, digitalization became a key channel for

[6] A typical case is the diffusion of social media such as Facebook or WeChat. Consumers not acquainted to instant messaging have found a large incentive to start using it due to its diffusion. Now that most people use such technology, the gain for using it (the opportunity cost of *not* using it) has grown way above the switching costs for almost any type of consumer (Chou, 2016; Kiat & Chen, 2015).

firms to reach consumers, moving investments in digitalization at the center of their strategic plans (e.g., for Italy see data from the Excelsior post-Covid-19 survey data). As 2020 was beginning, an unprecedented experimentation of massive use of digital tools took off, both on the consumers' and the producers' side. Covid-19 'forced' consumers and producers to suddenly abandon the physical markets and adopt digital technologies as widely and deeply as possible, thus fostering a quantum leap in favor of the new technology that would have taken much more investments, time, patience and effort to manifest (Forbes, 2020).

As we write, we are entering a second stage of the outbreak, in which Governments are experimenting policies to move beyond emergency responses. The question we ask is whether or not in this new phase -and, more importantly, in the post-Covid phase- consumers and producers will gradually go back to their previous habits and processes (BBC, 2020). Or, in more precise terms:

- How much of what has been experimented, invested and learned during the Covid phase in terms of digital technology adoption would stick in the medium-to-long run?
- What sectoral features (along both the demand and the supply side) make digitalization more likely to be an irreversible process?

These two questions are those we seek to answer in this paper. In what follows, we build a model able to describe the relationship between consumers' digital preferences and producers' digital investments over the three Covid-related phases. This model will allow us to study the conditions that favor a permanent digital transformation of industries.

3 Covid-19 and digitalization: a supply-side perspective

3.1 Economic environment

The world lasts three periods: (i) period 1, to be interpreted as the pre-Covid phase; (ii) period 2, in which the Covid shock occurs, and the non-digital market temporarily disappears; (iii) period 3, intended as the post-Covid era.

In this timing structure, we analyze the effects of Covid on digitalization in an economic environment with the following features. A single good exists which may be consumed in two "varieties", a digital (D) and a non-digital (ND) variety. Consumers consider the digital and the non-digital varieties of the product as substitute goods, where the marginal rate of substitution captures the relative preference for digitalization. Firms in a perfectly competitive sector may serve the digital market only after paying a fixed entry cost (e.g., the cost of building the digital infrastructure, of training personnel to serve the digital market etc.). We focus on the market for the digital variety, and we now describe its supply and demand in detail.

Digital supply A unit mass of identical firms are active in a perfectly competitive market. Firms' technology for supplying the digital variety entails an entry fixed cost F plus a marginal cost for each unit produced, which is given by $MC = cy_D$, where $c > 0$ and y_D denotes digital output.[7] As a result, the firms' total cost function (TC) can be described as the sum of the fixed (F) and the variable cost function, that is[8]

$$TC = \frac{1}{2}cy_D^2 + F.$$

Let us now characterize the market supply function. A firm maximizes its profits when it prices at marginal cost ($p_D = cy_D$) as long as these profits are positive, that is, as long as

$$\Pi^{\max} = p_D y_D - \frac{1}{2}cy_D^2 - F = \frac{1}{2}cy_D^2 - F > 0 \Longrightarrow y_D > \overline{y_D} \equiv \left(\frac{2F}{c}\right)^{1/2}.$$

Value $\overline{y_D}$ can be interpreted as a threshold on the size of each firm: below $\overline{y_D}$, no firm finds it profitable to venture into the digital market. Defining $\overline{p_D}$ as $\overline{p_D} \equiv c\overline{y_D} = (2Fc)^{1/2}$, and knowing that firms are identical and of unit mass, we can then write

[7] As we have already claimed above, venturing into the digital market implies an early fixed investment in a new technology paradigm. This justifies our current assumption on the fixed cost F. On the other hand, the assumed shape of marginal costs (linearly increasing in output) stems from satisfying the common hypothesis of diminishing marginal returns to the variable input (this can be easily shown upon request).

[8] The variable cost function is the integral sum of the marginal costs, that is:

$$VC(y) = \int cy_D dy_D = \frac{1}{2}cy_D^2.$$

the market supply function of the digital variety as the following piecewise continuous function (figure 1, panel (a)):

$$y_D = \begin{cases} \frac{p_D}{c} \text{ if } p_D \geq (2Fc)^{1/2} \\ 0 \text{ if } p_D < (2Fc)^{1/2}. \end{cases} \tag{1}$$

INSERT FIGURE 1 HERE

As shown in figure 1, panel (a), the digital supply curve coincides with the portion of the marginal cost curve above point M.[9] Note that the shape of the digital supply curve crucially depends on the fixed entry cost F. First, F affects the threshold value below which profits turn negative and supply collapses to zero (point M). Secondly, given that F is a once-and-for-all cost, when F has already been paid, the digital supply curve will coincide with the marginal cost curve even below point M (this will turn out to be useful for the analysis of the post-Covid era).

Digital demand A unit mass of identical individuals populate the economy. Consumers must choose whether to consume the digital (D) or the non-digital (ND) variety of the product (or both). We assume that, for the representative consumer, the non-digital and the digital versions are perfect substitutes 1 to δ with $\delta \in R_+$. The agent's utility function can then be written as

$$U(y_D, y_{ND}) = \delta y_D + y_{ND}, \tag{2}$$

where δ measures the marginal rate of substitution of digital vs. non-digital consumption (the higher δ, the stronger the preference for the digital variety).

The hypothesis of perfect subsitution is meant to capture the behavioral characteristics of the consumption choice under analysis. A perfect substitution utility function, such as (2), implies that the marginal utilities of the two varieties, as well as the marginal rate of substitution, are constant. These features may seem unrealistic when

[9]To show this point more clearly, in figure 1, panel (a) we have also drawn the average total cost curve, whose analytical expression is

$$ATC = \frac{TC}{Y} = \frac{1}{2}cy_D + \frac{F}{Y}.$$

As it is well known, the MC curve crosses the ATC along its minimum point (point M). Below that point, firm's profits are negative and thus supply is null.

describing the agent's choice across any two kinds of ordinary goods (such as food Vs. cloth, consumption today Vs. tomorrow etc.).[10] They are, however, less so in a context in which consumers are frequently deciding, not between two distinct commodities, but on two alternative ways (digital Vs. non-digital) of having the same commodity delivered.[11]

Note that, while reasonable and effective (as it allows us to capture the taste for digitalization in only one parameter, δ), this hypothesis is not strictly necessary. As we will see in the next sections, what ultimately drives our results - in addition to the firms' cost structure described above - is that the Covid shock raises the demand for the digital version (as the non-digital version temporarily disappears). This would also occur in a more general context (for instance, under a CES preference system) in which D and ND were only imperfect substitutes.

Denoting by p_D, p_{ND}, m respectively, the digital and the non-digital price, and the total budget devoted to purchasing the product, we can write the market demand for the digital version of the product as the following piecewise continuous function (figure 1, panel (b)):

$$y_D^* = \begin{cases} \frac{m}{p_D} \text{ if } p_D < \delta p_{ND} \\ [0, \frac{m}{p_D}] \text{ if } p_D = \delta p_{ND} \\ 0 \text{ if } p_D > \delta p_{ND}. \end{cases} \tag{3}$$

The demand for the digital variety can be interpreted as follows. If the price ratio is higher than the marginal rate of substitution ($p_D/p_{ND} > \delta$), the demand for the digital variety is null ($y_D^* = 0$). If it is lower ($p_D/p_{ND} < \delta$), then consumers demand only the digital variety ($y_D^* = m/p_D$). Finally, if the price ratio and the marginal rate of substitution are equal ($p_D/p_{ND} = \delta$), the optimal consumption solution is indeterminate along the interval $[0, m/p_D]$.

[10] The more food the agent consumes, the lower its marginal utility and the higher the marginal utility associated with cloth. The same reasoning applies to intertemporal consumption choice.

[11] For instance, why should one assume that the more one buys music on the digital market, the lower its marginal utility relative to music bought on the traditional non-digital market (such as buying CDs or vinyls)? Or that the more one shops on-line (for cloths, groceries etc.), the lower its marginal utility relative to buying the same goods in physical stores? While the degree of substitution between digital and non-digital consumption may vary greatly across markets and sectors, it seems however reasonable to suppose that it does not vary with the levels of digital and non-digital delivery of the consumed good.

Digital market equilibrium The digital market is in equilibrium when market demand (3) equalizes market supply (1). It can be shown that a digital market equilibrium exists if and only if[12]

$$F \leq \min\left\{\frac{(\delta p_{ND})^2}{2c}, \frac{m}{2}\right\}. \tag{4}$$

Condition (4) sets an upper bound on the firms' digital entry costs above which a digital market does not exist, and depicts four pre-Covid situations: the digital market does not exist, as it fails the first condition (case 1A) or the second (case 1B), or it does, co-existing with the non-digital market (case 2A) or as the only market (case 2B). We now analyze the impact of Covid-19 on the chances that a digital market arises and persists over time following the order of these four cases.

3.2 The impact of the Covid-19 shock

The digital market does not exist in the pre-Covid phase Start from period 1 (the pre-Covid era) in which digital demand and supply are given as in (3) and (1). The digital market does *not* exist either when $F > (\delta p_{ND})^2/2c$ (case 1A) or when $F > m/2$ (case 1B). Let us analyze these two scenarios in order.

Suppose that $F > (\delta p_{ND})^2/2c$ or, solving the inequality by δ, that $\delta < (2cF)^{1/2}/p_{ND}$ (case 1A). Intuitively, this inequality ensures that the taste for digitalization is not strong enough to overcome the barriers to entry posed by the digital entry costs of the producers. Figure 2, panel (a) provides a graphical intuition of this case: the supply curve (1) lies strictly above the demand curve (3), and there is no intersection point. As a result, the number of digital transactions is null.

INSERT FIGURE 2 HERE

[12]The intuition behind condition $F \leq (\delta p_{ND})^2/2c$ is easy to grasp. Rewriting this inequality as $(2Fc)^2 \leq \delta p_{ND}$, we immediately realize that this is a condition for the minimum point of the supply curve (point M in figure 1, panel (a)) to be below the horizontal part of the demand curve. If that were not the case, the two cuves could not have an intersection point. Condition $F \leq 2m$ can instead be explained as follows. The non-linear portion of the demand function ($y_D = m/p_D$) crosses the marginal cost curve encompassing the firms' profit-maxizing pricing strategy ($y_D = p_D/c$) at $p_D = (mc)^{1/2}$. This price is must be higher than the threshold price ($p_D = (2Fc)^{1/2}$), otherwise it would not be an equilibrium. This happens when $(mc)^{1/2} \geq (2Fc)^{1/2}$, that is, when $F \leq m/2$.

When the Covid shock occurs, the non-digital market disappears. This implies that market demand (3) becomes $y_D = m/p_D$, a continuous function defined over the entire domain of p_D. The Covid shock can then be interpreted as a positive demand shock. Figure 2, panel (b) shows how a digital market equilibrium, which did not exist in the pre-Covid era, *arises* in the Covid era (point A). Intuitively, shutting off the non-digital market incentivizes producers to bear the digital entry cost and *forces* the emergence of a digital market.

Now consider what happens when Covid-19 disappears. Period 3 is characterized by the two following changes (compared to period 2): (a) as the entry cost F has already been paid in period 2, the supply curve is now defined over the entire domain as the following linearly increasing function: $y_D = p_D/c$; (b) the non-digital market reappears, and hence the digital market demand returns to be the expression given in (3). Figure 2, panel (c) depicts this scenario. When the pandemic is over in period 3, the digital market equilibrium moves south-west (from A to A'), decreasing both the size of the digital market and the equilibrium price compared to the Covid phase. Importantly, however, once the digital market has taken off thanks to the Covid shock, *it never shuts off* even when the Covid-19 disappears. A temporary shock has a permanent effect.

To give substance to this dynamics, consider the B2C real estate sector, which constitutes the bulk of the whole real estate market (OECD, 2019). Digital transactions never took off: not only the average share of sales via computer mediated networks over total sales across OECD countries was about 5% in 2017; moreover, from 2010 to 2017, the number of firms in the sector engaged in e-commerce increased less than 2%, while sales produced by the digital markets decreased (OECD, 2019). Indeed, buying a real estate property is a very relevant investment, especially in the B2C segment, and the consumers' taste towards digital purchases is probably modest (CNBC, 2020b). Plus, reproducing online the features of a property, providing the same 'touch-and-feel' typical of offline visits, implies a cost for Real Estate providers that probably overcomes their prospects of sales on the online channel. Given this, before the pandemic, e-commerce was almost non-existent for the real estate sector, resembling Figure 2, Panel (a). During the Covid outbreak, real estate operators were forced to invest in moving online their businesses, using drone surveys, virtual walkthroughs, and 3-D mapping (CNBC, 2020b). This allowed the functioning of the sector, creating the basis for the real estate digital market to exist, as in figure 2, panel (b). Our model allows us to formulate an educated conjecture about the future for the real estate sector in the post-Covid era. As suggested by Figure 2, panel (c), the digital real estate market will probably retrench but will not disappear. This may correspond to a situation in which digital modes of interaction are integrated as a complementary channel into the physical market. In the words of the operators of the sector: "*While most of the process of homebuying, from negotiating a deal to writing an offer, can be done electronically, Nick Bailey, chief customer officer at RE/MAX, believes the in-person walkthrough is essential. 'We will continue to see almost all buyers want to step into the home to feel it', said Bailey.*" (CNBC, 2020b).

Other sectors may be considered in a situation similar to the real estate sector. Think about small craftmanship firms and traditional shops, among which neighborhood restaurants are likely the most visible case (The New York Times, 2020). The forced investment in F due to the pandemic (for example, creating a delivery service from scratch) brought the digital market to existence. However, the structural factors behind small δ, such as the importance of building a personal relation with customers, who are mainly local and value the experience in the shop, will inevitably come back after the pandemic, shrinking the digital market. While the market will not disappear (some customers may still like the digital relation, under certain circumstances), it will clearly become an ancillary mode of being on the market.

Let us now analyze the second scenario (case 1B) for a missing digital market, $F > m/2$ (case 1B). If we express this inequality as $m < 2F$, this condition simply tells us that the budget devoted to purchasing the product in either variety (m) is too small to spur the emergence of a digital market. Geometrically, this implies that the non-linear portion of the demand function ($y_D = m/p_D$) crosses the marginal cost curve ($MC = cy_D$) *below* the threshold point M, as in Appendix Figure A2, Panel (a). As it is apparent from Panels (b) and (c) of the same figure, in this case a digital market simply *never* arises because total demand is too weak to cover the firms' fixed entry costs. This may be the case of small craftmanship firms and traditional shops whose local basin of attraction was too small and too unused to digital tools to venture into even home-made e-commerce and delivery service. For this reason, this scenario is relatively uninteresting for our purposes.

The digital market exists in the pre-Covid phase If condition (4) is satisfied, the digital market can either co-exist with the non-digital market (case 2A) or, in the limit, exist as the only market (case 2B). Formally, the equilibrium price and output can be expressed as[13]

$$\{p_D^*, y_D^*\} = \begin{cases} \left\{\delta p_{ND}, \frac{\delta p_{ND}}{c}\right\} \text{ if } m > \frac{(\delta p_{ND})^2}{c} \\ \left\{(mc)^{1/2}, \left(\frac{m}{c}\right)^{1/2}\right\} \text{ if } m \in \left[2F, \frac{(\delta p_{ND})^2}{c}\right] \end{cases}.$$

The first scenario (case 2A) is depicted in figure 3. The digital market equilibrium is initially at point B, where $\{p_D^*, y_D^*\}_1 = \{\delta p_{ND}, \delta p_{ND}/c\}$ (figure 3, panel (a)).

INSERT FIGURE 3 HERE

When the Covid shock occurs, the non-digital market disappears. Again, this implies that market demand (3) becomes $y_D = m/p_D$. Moreover, given that the entry cost F has already been paid in period 1, the supply curve is now defined as $y_D = p_D/c$. This scenario is described in figure 3, panel (b). The equilibrium moves from point B to point B': $\{p_D^*, y_D^*\}_2 = \left\{(mc)^{1/2}, (m/c)^{1/2}\right\}$. Because Covid is essentially a positive demand shock on the digital market, the model predicts an unambiguous rise in both the price and the number of digital transactions during the Covid phase, provided that m does not to change from period 1 to period 2.[14] Finally, when Covid disappears in period 3, the digital market demand returns to be the expression given in (3). As apparent from panel (c) of Figure 3, the equilibrium moves back to where it was under the pre-Covid era (shift from B' back to B), that is, $\{p_D^*, y_D^*\}_3 = \{p_D^*, y_D^*\}_1$.

This may be exemplified by the experiences of distant learning during the lockdown. The sudden entry into the digital world was a traumatic experience for most teachers, parents and students, evident in particular in case of children and primary schools. It surely allowed the discovery of the advantages of distant learning, but it also unveiled all

[13] The threshold $\overline{m} = (\delta p_{ND})^2/c$ contained in the next expression, and determining whether the digital market co-exists or exists as the only market is obtained as follows. Along the horizontal portion of the demand function, the equilibrium must be such that $p_D = \delta p_{ND}$ and $p_D = cy_D$, from which we obtain $y_D = \delta p_{ND}/c$. When this quantity is lower than the threshold quantity $y_D = m/\delta p_{ND}$, the supply curve crosses the demand along the horizontal portion of the demand function and, hence, the digital market co-exists with the non digital market (case 2A). Solving the inequality by m, this happens when $m > (\delta p_{ND})^2/c$. *Viceversa*, when $m < (\delta p_{ND})^2/c$, the digital market exists as the only market (case 2B).

[14] On the contrary, one could imagine that the covid shock implies a fall in m. This negative income effect would run against the positive effect originating from the collapse of the non-digital market. Which effect would dominate would then become an eminently empirical question.

its limitations and challenges. Anecdotal evidence and surveys (New York Times, 2020; Washington Post, 2020; USA Today, 2020. See also the surveys reported by Chalkbeat, 2020) suggest that, let aside some positive specific use and/or audience (e.g., webinars for professionals), most 'consumers' of online education tools and initiatives finally relegated the digital experience to an emergency that they would like to replicate as little as possible.

Note that the conclusion arising from this model, whereby the post-pandemic digital market will exactly return to its pre-pandemic state, relies on the crucial assumption that consumers' preferences do *not* evolve during the pandemic. Both our model extensions developed in the next two sections relax this assumption. In particular, the first extension analyzes the case in which consumers less acquainted with digital tools are however "forced" to experience them (because of Covid-19), gaining confidence, and finally becoming 'digital'. The second extension examines a scenario in which the consumers' taste for digitalization is affected by the size of the digital market (network externalities). In both cases, as we will see, the post-pandemic scenario will look different from the pre-pandemic scenario.

The second scenario for an existing digital market sees no other other option than e-commerce (case 2B), and is represented in Appendix Figure A3. In this rather extreme case, consumers spend their budget m only for the digital version of the product (that is, $y_D^* = m/p_D$) from the very beginning. The initial equilibrium is in point C in Appendix Figure A3, panel (a), in which the digital market was already the only active market in the pre-Covid era. As can be seen from Appendix Figure A3, panels (b) and (c), the Covid shock in period 2 and its retreat in period 3 have no effect on the characteristics of the digital market equilibrium, which remains exactly as in panel (a).

With 75% of purchases online over total sales in the US (RIAA, 2018), the online market was by far the main market for music even before Covid-19 hit the economy. In this sense, it may roughly capture the situation depicted in Appendix Figure A3, panel (a), where digital transactions have already supplanted physical transactions before the shock. While recorded music market did suffer the lockdown, consumers' habits mainly changed within the scope of the current digital offering: the pandemic reshuffled consumption habits (e.g., streaming initially decreased, while on-demand video streams increased, World Economic Forum, 2020), but as the market was already largely digital, it did not change the way consumers and producers met on the market, not as much as in real estate, retail or banking. As shown in Figure A3, panel (c), our model does not predict dramatic changes for this market when the pandemic will be over.

4 Covid-19 and digitalization: a demand-side perspective

Thus far we have assumed that, when evaluating their alternatives, consumers are as "confident" with the non-digital as with the digital variety. In reality, the entry into the digital market may be costly for consumers. Many categories of consumers do not possess the skills, the equipment or the bandwidth to be on the digital markets. Think about digitally marginalized categories such as the elderly population. While Chou (2016) and Kiat & Chen (2015) illustrate the investments needed by -and the advantages for- elderly people to enter the digital world, during the pandemic news reported several cases in which such entry allowed elderly people to survive isolation and loneliness due to the lockdown (Bloomberg CityLab, 2020). This trasformed them *de facto* from non-digital into digital consumers: the new skills will stay with them also when the pandemic will be gone.

To capture this situation, we now introduce in our model a consumers' entry cost in the digital market. This cost, thought of as a utility loss, is modeled as a once-and-for-all cost. Moreover, consumers differ in terms of this entry cost. In particular, consumers may be "digital" (characterized by a low entry cost) or "non-digital" (characterized by a high entry cost). We then focus on a scenario in which, before the pandemic outbreak, the digital market is active only for digital consumers.

The main result of this section can be described as follows. When Covid-19 hits the economy, it wipes away the physical market, thus forcing even the non-digital consumers to pay the entry cost into the digital market. During the pandemic, the digital market is then active for both types of consumers. As a consequence of the positive demand shock, both the price and the number of digital transactions increase. When Covid-19 disappears, the once-and-for-all entry cost into the digital market has already been paid, and hence the digital market remains active for both consumers. Hence, here again, a temporary shock has a permanent effect.

4.1 Consumers' demand with digital entry cost

Suppose that consumers' preferences can be represented by the following utility function:

$$U = \delta y_D + y_{ND} - D \cdot I(y_D) \cdot U \tag{5}$$

where $D \in R_+$ and $I(y_D)$ is an indicator function defined as

$$I = \begin{cases} 0 \text{ if } y_D = 0 \\ 1 \text{ if } y_D > 0. \end{cases}$$

The interpretation of (5) goes as follows: if $y_D = 0$, that is, if a consumer does *not* buy the digital variety, her utility function is identical to (2). If, on the other hand, $y_D > 0$, that is, if a consumer does buy the digital variety, she bears a "cost", expressed in terms of utils, equal to $D \cdot U$.

Once again, denoting by p_D, p_{ND} and m, respectively the prices of digital and non-digital variety and the total budget devoted to purchasing the product, we can express the demand function for the digital variety as the following piecewise continuous function (see appendix A for details on how to derive it):

$$y_D = \begin{cases} \frac{m}{p_D} \text{ if } p_D < \frac{\delta}{1+D} p_{ND} \\ 0 \text{ if } p_D > \frac{\delta}{1+D} p_{ND} \\ \left\{0, \frac{m}{p_D}\right\} \text{ if } p_D = \frac{\delta}{1+D} p_{ND} \end{cases} \tag{6}$$

Now suppose that two unit-mass types of consumers exist which only differ in terms of the entry cost into the digital market: digital consumers (d) have an entry cost which is strictly lower than non-digital (nd) consumers, that is, $D_d < D_{nd}$. A graphical representation of their demand functions is contained in figure 4.

INSERT FIGURE 4 HERE

4.2 The impact of the Covid-19 shock

We are now ready to analyze the characteristics of the digital equilibrium along the three phases of our model, pre-Covid, Covid and post-Covid.[15]

[15] In this section, we assume that $m \geq 2F$. As we have seen in the previous section, if that were not the case, a digital market would simply never arise.

Pre-Covid To obtain the digital market demand, we need to sum up horizontally the digital demands for both types of consumers. The market demand (y_D^M) then writes as

$$y_D^M = y_D^d + y_D^{nd} = \begin{cases} \frac{2m}{p_D} \text{ if } p_D < \frac{\delta}{1+D_{nd}} p_{ND} \\ \frac{m}{p_D} \text{ if } p_D \in \left[\frac{\delta}{1+D_{nd}} p_{ND}, \frac{\delta}{1+D_d} p_{ND}\right] \\ 0 \text{ if } p_D > \frac{\delta}{1+D_d} p_{ND}. \end{cases} \tag{7}$$

Function (7) is easy to interpret. When the digital price is "low" ($p_D < \delta p_{ND}/(1 + D_{nd})$), the digital market is active for both types of consumers. When it is "high" ($p_D < \delta p_{ND}/(1 + D_d)$), the digital market is inactive for both types of consumers. Finally, for all prices in-between ($p_D \in \left[\frac{\delta}{1+D_{nd}} p_{ND}, \frac{\delta}{1+D_d} p_{ND}\right]$) the digital market is active only for the digital consumers but not for the non-digital consumers. This case represents the focus and the starting point of our analysis. Keeping the same supply side structure of the model described in section 3, a graphical intuition of the resulting digital equilibrium in the pre-Covid phase (point 1) is provided in figure 5.

INSERT FIGURE 5 HERE

Covid When Covid-19 hits the economy, the non-digital market disappears and the market demand simply becomes $2m/p_D$ through the entire domain. While this change bears no consequence for the digital consumers, it does have consequences for the non-digital consumers because it triggers their demand for the digital variety. A graphical intuition is provided in figure 6, where point 2 lies north-east of point 1. Intuitively, when the non-digital market disappears, non-digital consumers find themselves "on the fence" and hence are willing to pay the entry cost. This kick-starts their participation into the digital market. As a result, the digital market booms.

INSERT FIGURE 6 HERE

Post-Covid When Covid disappears, both markets are already active, so that in the post-Covid era we have $D_d = D_{nd} = 0$ (as they have already been "paid" in the previous periods). As a result, both market demands are now the same as in the previous model. A graphical intuition is provided in figure 7. The digital equilibrium moves south-west from point 2 to point 3. Crucially, both the price and the number of digital transactions have permanently increased compared to the pre-Covid era.

INSERT FIGURE 7 HERE

The main takeaway is that a temporary demand shock such as Covid-19 triggers the participation of the non-digital consumers, and this participation continues even when the pandemic is over.

This framework may capture the case of the retail sector. In this sector, whose orientation is clearly towards B2C (65% of the value sold on the internet in OECD countries), even before the Covid outbreak, the digital market was active and on the rise, already involving the most digital consumers, as in figure 5. For instance across OECD countries, in 2017 e-commerce accounted on average for almost 10% of the sector sales, while online sales grew by 6% and the number of firms selling online by 11% from 2010 to 2017 (OECD, 2019). Starting from this situation, during the pandemic the digital market grew dramatically, with online sales increases by 6% worldwide, consistently with figure 6.[16]

A recent study by the Polytechnic of Milan on the impact of Covid-19 on the retail sector in Italy offers a vivid picture of this: *"Players that have been online since the beginning of the epidemic have seen an increase in orders attributable to new consumers ..."*; and in another passage: *"During the health emergency Italian consumers have understood the value of this channel as never before... . Growth of web shoppers ... and greater familiarity with and confidence in online transactions and digital payments ... can generate a positive effect on the development of eCommerce"*.[17]

In such context, our model predicts a net expansion of the digital market, (as shown in figure 7 where the post-pandemic equilibrium at 3 is north-east of the pre-pandemic

[16] https://www.statista.com/statistics/1112595/covid-19-impact-retail-e-commerce-site-traffic-global/

[17] Report presentation, "Covid-19: the impact on B2C eCommerce" at https://www.som.polimi.it/en/covid-19-the-impact-on-b2c-ecommerce/. Full Report 'eCommerce: Retail Growth and Innovation Engine' at www.osservatori.net

equilbrium at 1), but consumption baskets are somewhat reshuffled back towards a mix of digital and physical market (i.e., 3 is still south-west of the covid equilbrium at 2). The reason for the turn back is that consumers will again feel the need to go through physical shops. As Andy Watson and Chris Igwe, members of the Retail and Entertainment Council (Uli Europe) state: "*Online retail can't compete on experience. A successful place needs to offer buzz, entertainment, an opportunity to chat, variety, things to touch, things to taste and more. Even in an era of same-day deliveries, only a shop can give you instant gratification. But delivering all of that, making it relevant and keeping it fresh means active management.*" (Internews, 2020).[18]

However, such turn back would not dissolve the whole shift done during the lockdown because of the positive reaction of the non-digital consumers who, as a consequence of Covid-19, become acquainted with digital consumption.[19] The new equilibrium we expect will then be the result of these two opposite forces.

5 Covid-19 and digitalization: the role of network externalities

The models developed so far have treated δ as an exogenous preference parameter. As we have already discussed extensively in the introductory sections, however, positive network externalities across consumers, or between consumers and producers, may be a defining characteristic of a digital market. In this section, we explore the consequences of suh network externalities. We first prove that multiple equilibria may arise, namely, a low-digital and a high-digital equilibrium. We then show that the Covid shock may act as a coordination device towards the high-digital equilibrium.

Consider the model developed in section 3 with the only difference that δ is an endogenous digitalization preference variable which depends on how many digital trans-

[18] Indeed, the study by the Polytechnic of Milan mentioned above sees a compatible but more complex scenario, where the digital and the physical experiences are likely to merge: *"Among the few certainties, in our opinion, are the proximity that the online and physical channels are demonstrating forcefully at this difficult time"*. Retail might go 'back to pre-Covid' quantitatively, but not qualitatively: the digital channel will likely be re-thought towards a higher integration with the physical experience.

[19] Hamilton and Thomson (2007) show that product experiences are crucial for the construction and the evolution of consumers'preferences. In this perspective, the covid-19 shock forces consumers to such experiences and may thus cause significant changes in their preferences.

actions take place. For simplicity, suppose that δ is a piecewise increasing function of total output produced in the digital market, y_D^*, of the following kind:

$$\delta_t = \begin{cases} \delta^L \text{ if } y_D^* < \widetilde{y_D} \\ \delta^H \text{ if } y_D^* > \widetilde{y_D}, \end{cases}$$

where $\widetilde{y_D}$ is an arbitrary threshold and where $\delta^L < \delta^H$. This function captures - in an admittedly simple, binary fashion - the idea that the *thicker* the market (that is, the greater the number of digital transactions), the stronger the consumers' preference for digitalization.

The existence of positive network externalities implies that the digital demand is not anymore (weakly) decreasing as it was in the previous models (recall figure 1, panel (b)). The new, non-monotonic, digital demand is depicted in figure 8, panel (a). Incorporating this digital demand into our theoretical framework generates multiple digital equilibria, as in panel (b) of figure 8, with L and H, respectively, representing a low-digital and a high-digital market equilibrium. We can now interpret these basic findings through the lens of the Covid narrative and timing introduced in the previous sections.

INSERT FIGURE 8 HERE

At the beginning of time, in the pre-Covid era ($t = 1$), the digital market is still underdeveloped, so that the number of digital transactions is lower than $\widetilde{y_D}$. As a result, the preference for digitalization is "low" ($\delta_1 = \delta^L$), and the economy converges to the low-digital equilibrium: $(y_D)_1^* = y_D^{low}$ and $(p_D)_1^* = \delta^L p_{ND}$. This situation is depicted in figure 9, where the economy, starting from an arbitrary $y' < \widetilde{y_D}$, gradually converges towards the low-digital equilibrium in point 1.

INSERT FIGURE 9 HERE

When the Covid shock hits the economy in period 2, the non-digital market disappears, and the demand function becomes the continuous function $y_D = m/p_D$. The new equilibrium shifts abruptly to point 2, where the number of digital transactions and the price are higher. Given that $(y_D)_2^* > \widetilde{y_D}$, the preference for digitalization grows "high" to $\delta_3 = \delta^H$. As a result, in the post-Covid era ($t = 3$), the market converges to the high digitalization equilibrium (point 3 in figure 9), where $(y_D)_3^* = y_D^{high}$. In other words, the temporary Covid shock allows the economy to permanently overcome the low-digitalization inferior equilibrium in which the market was originally trapped.

To have a sense of this mechanism, consider how The Economist (2020) describes the evolution of Fintech: "*These changes in behaviour seem likely to stick. Many customers were unfamiliar with the technology before the pandemic -and surveys suggest they like it. In April nearly a fifth of American adults used digital payments for the first time ... . Since February Nubank has gained 30,000 users over the age of 60 every month. In a global survey Bain, a consultancy, found that 95% of consumers plan to use digital banking post-pandemic. And banks, which had already been planning to shrink their physical footprint, are closing branches more quickly than they had envisaged ... . As physical branches become irrelevant, finance is exposed to the same network economics that have upended other sectors. Huw van Steenis of UBS, a bank, thinks the pandemic is accelerating a winner-takes-most dynamic, where popular platforms attract exponentially more traffic.*"

Another typical example of a market characterized by strong positive network externalities across consumers is that of video-conferencing. Online communication tools were widespread before the Covid, but in many professions and in personal relations, video-conferencing tools were used intensively only by a fraction of users, being face-to-face communication still the preferred tool for many interaction types and tasks. When Covid-19 hit, video-conferencing became basically the only way to communicate. This increased the install base of users. Data for North America confirm the enlargement of the install base both in downloads (i.e., new users, 627% increase between February and April 2020) as well as in usage (i.e., active users, 121% increase in the same period) of video conferencing mobile apps (Visual Capitalist, 2020). Being communication tools, video conferencing apps increase their values for new as well as old consumers the more widely they are adopted as 'standard' communication channels. The larger install base thus changed consumers' preferences.

In post-Covid, however, we do not expect the market for video-conferencing to remain the same as during the pandemic, but to move between the pre-Covid (point 1 in figure 9) and the Covid phase (point 2), that is, somewhere close to point 3. Scott Wharton (Vice President and General Manager of the Logitech video collaboration group) offers a view supporting this point: "*Someone on my team was in India with a salesperson who wanted to take all our meetings in person. They literally sat in traffic* *for three hours missing an in-person meeting. ... [Indeed] the barrier of being able to connect by video has really gone away. The cost and complexity have gone away. All the conditions are in place to make it mainstream. The next thing is cultural. It's not technology or economic anymore. It's how do you get people to actually use it."* (Yale Insights, 2018). The lockdown may have done the job.

6 Discussion and concluding remarks

In this paper, we have built a simple theoretical framework to analyze the long-run effects of Covid-19 on the sectors' level of digitalization. Under plausible assumptions on digital demand and supply, the model predicts that a temporary shock, such as Covid-19, has a long-lasting impact on the likelihood that a market becomes highly digitalized. The model has allowed us to identify three distinct reasons why a transitory shock may have a permanent effect. First, by temporarily eliminating the physical market, Covid-19 provides a powerful incentive for firms to carry out the fixed investments necessary to venture into the digital market (supply channel). Secondly, by forcing even the most "digitally reluctant" consumers into the digital market (for lack of alternatives), Covid-19 pushes them to familiarize with previously unknown digital platforms (demand channel). Finally, when consumers' digital preferences depend on the number of digital transactions, a market may be entrapped into a low-digital equilibrium indefinitely. In such context, however, Covid-19 represents the kind of positive demand shock which may unleash the forces of digitalization and tilt the entire sector towards a high-digital equilibrium (network externalities channel).

In analyzing the relationship between Covid-19 and the digital market, the theoretical framework developed in this paper has abstracted from a number of relevant dimensions, which might be worth analyzing in future research. First of all, we have not tackled the issue of how Covid-19 affects the industrial organization of the sector (for instance, creating winners and losers among firms, fostering or inhibiting market concentration etc.). Analyzing this issue, which would require building a model with a more complex industrial structure and, possibly, technologically heterogenous firms, is out of the scope of this paper, but worth to mention as a fruitful future research line.

Second, in our simple model the price of the non-digital variety is taken as given, thus *de facto* shutting off all general equilibrium effects. This partial equilibrium approach stems naturally from the motivation of our paper, which is understanding the implications of the Covid shock for the digitalization of B2C markets. The implicit assumption is that the digital market is not "too big" to affect the non-digital market. In a world in which digital transactions will constitute the lion's share of the total mass of market transactions, this hypothesis will probably have to be abandoned.

Third, our framework intentionally shuts off the most complex intertemporal interactions: when making their decisions at time t, neither consumers nor producers take into account their future payoffs. For instance, when deciding whether or not to "go digital" (and thus bear the fixed cost, F), producers do not consider the impact of their digital choice on their future profits. While our theoretical framework could be extended to comprehend these dynamic effects, our hypothesis fits both the nature of the phenomenon under analysis, that is, a strong and largely *unpredictable* shock, as well as the producers' strong uncertainty (Knight, 1921) about the evolution of the consumers' preferences for digitalization in the face of that shock.

Finally, we did not consider demand shocks still connected to the Covid shock but not directly to digitalization. For example, the airlines sector entered a deep crisis, as did the hospitality and touristic sector more in general. This shortage of demand due to the sudden drop in people's mobility is not part of our model, but it should be certainly considered when extending our model -now limited to the impact of Covid-19 on sectors' digital transformation- to the general impact of the pandemic on our economies.

We conclude this paper by discussing a number of medium-run implications of our theoretical framework which might be tested empirically against cross-country sectoral data. First, as suggested by the model developed in section 3, if the digital market arises as a result of the Covid shock, it may retrench in the medium run but will *not* disappear. In particular, the Covid shock immediately raises both the price and the number of transactions in the digital markets, while its retreat lowers them. The total *net* effect in the medium run is, however, expected to be positive on both prices and transactions. Moreover, these changes are, *coeteris paribus*, more pronounced (even in relative terms) in more sizeable sectors -that is, in sectors where m is higher.[20] Secondly, as implied by the model analyzed in section 4, the boost to the digital market caused by Covid-19 should also be visible on the *extensive* margin, that is, by involving an ever increasing number of (originally non-digital) consumers. Finally, the

[20] A high m (a sizeable sector) implies that the expansionary effect of the Covid-19 shock on the digital market when the physical market temporarily disappears is strong. The same reasoning applies to the contractionary effect following the retreat of Covid in period 3.

model extension developed in section 5 suggests that markets characterized by positive network externalities (such as digital platforms, digital communication tools etc.) are those in which the effect of Covid will be comparatively stronger. All these theoretical predictions may be tested when sectoral data on digital penetration in the post-Covid era will gradually become available.

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A Appendix

We here show how to derive expression (6) from the constrained maximization of (5). A typical indifference curve generated from (5) and associated with a generic level of utility equal to $\overline{U}$ is given by

$$y_{ND} = \overline{U}\left(1 + D \cdot I\left(y_D\right)\right) - \delta y_D \tag{8}$$

Figure A1 contains a graphical representation of (8) (the blu solid line), which has a discontinuity point when $y_D = 0$. In fact, when $y_D = 0$, $I\left(y_D\right) = 0$ and hence $y_{ND} = \overline{U}$. The consumer is indifferent between $y_D = \overline{U}\left(1 + D\right)/\delta$ and $y_D = \overline{U}$. This makes the "effective" rate of subsititution between these two consumption bundles equal to $\delta/\left(1 + D\right)$, whose slope is captured by the blu dashed line in figure A1. Hence, the rate of relative preference for y_D over y_{ND} is "discounted" by D.

INSERT FIGURE A1 HERE

Let us now analyze the consumer's optimal choice. If $p_D/p_{ND} > \delta$, the budget constraint is unamabiguously steeper than the indifference curve, and the consumer will only consume the non-digital variety, $y_{ND}^{*} = m/p_{ND}$ (as in the benchmark case where $I\left(y_D\right) = 0 \; \forall y_D$). If, on the other hand, $p_D/p_{ND} < \delta/\left(1 + D\right)$, the price ratio is smaller than the "effective" rate of subsititution between the digital and non-digital variety, and hence the consumer will only consume the digital variety, $y_D^{*} = m/p_D$ (again, as in the benchmark case where $I(y_D) = 0\ \forall y_D$). Only when $p_D/p_{ND} \in \left(\frac{\delta}{1+D}, \delta\right)$, the consumer's choice is affected by function $I(\cdot)$. The green dotted line depicted in figure A1 is an example that captures such scenario. If $I(y_D)$ were equal to $0\ \forall y_D$ (as in the benchmark case), the agent would only consume the digital variety ($y_D^* = m/p_D$). Here, however, since $I(y_D) = 1$ when $y_D > 0$, the agent opts for the non-digital variety ($y_{ND}^* = m/p_{ND}$). Finally, if $p_D/p_{ND} = \frac{\delta}{1+D}$, the agent turns out to be indifferent between the two opposite consumption bundles (one in which only the digital variety is consumed, the other in which only the non-digital variety is consumed, represented respectively as points X and Y in figure A1). Combining these arguments, we obtain the demand function as expression (6).

INSERT FIGURES A2, A3 HERE

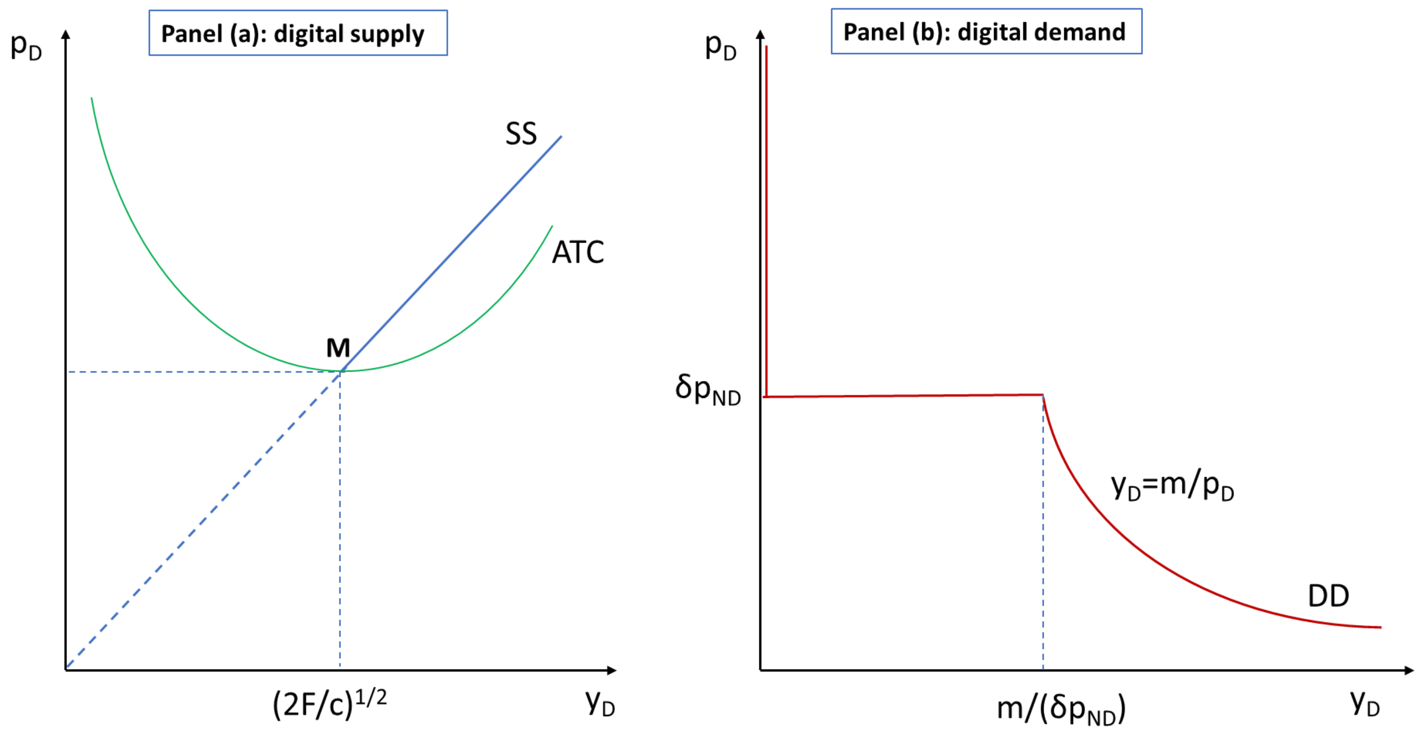

FIGURE 1: DIGITAL SUPPLY AND DEMAND

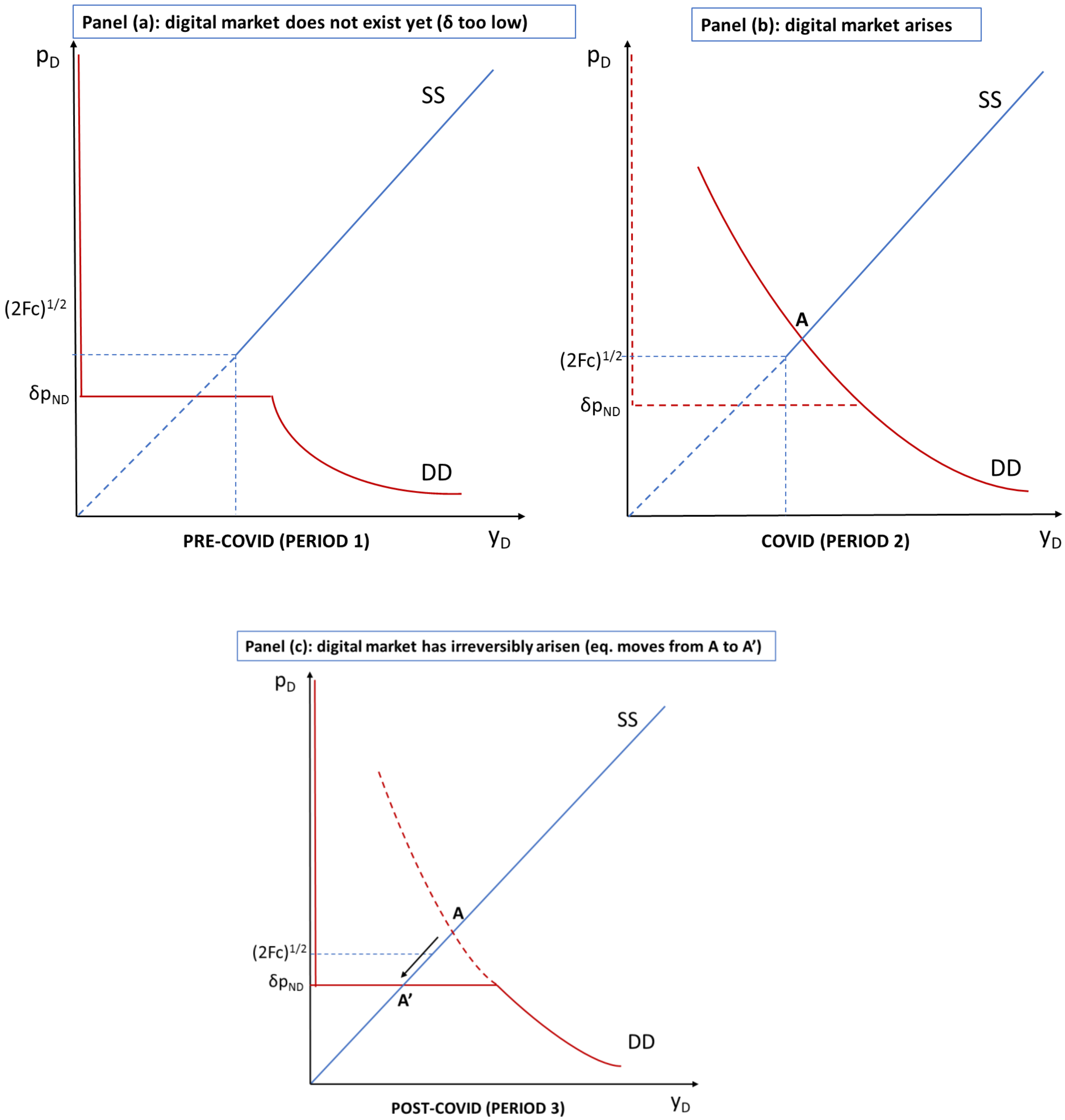

FIGURE 2: THE IRREVERSIBLE RISE OF THE DIGITAL MARKET

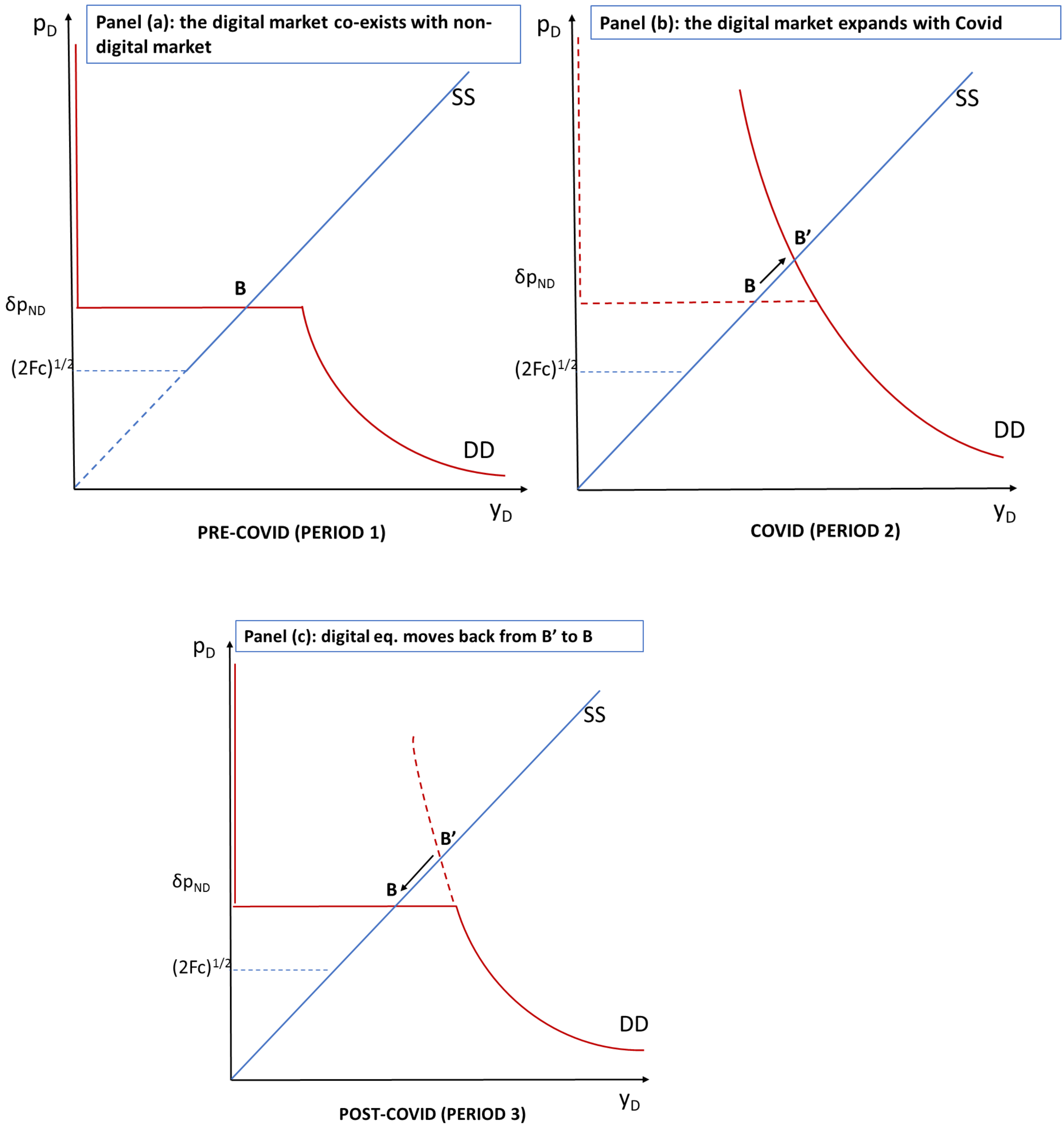

FIGURE 3: THE TRANSITORY EFFECT OF COVID IN DIGITALLY ACTIVE SECTORS

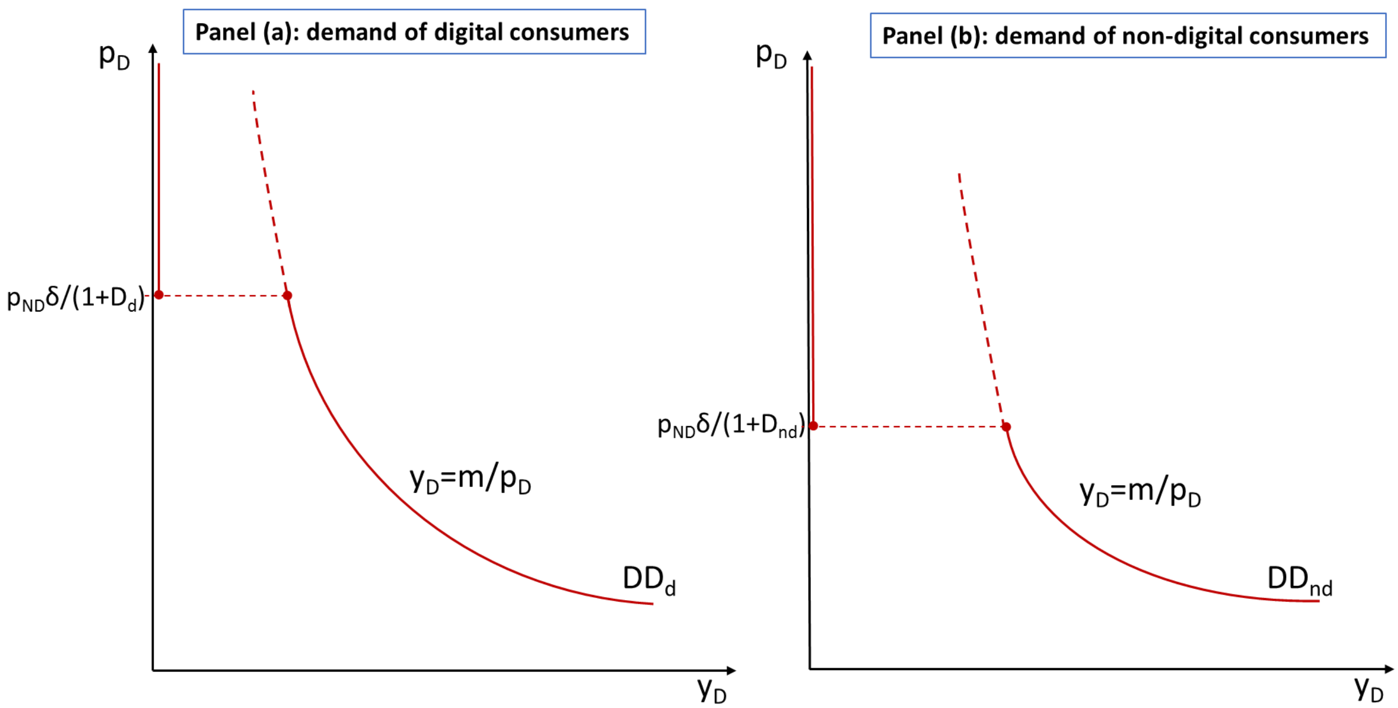

FIGURE 4: DEMAND WITH DIGITAL ENTRY COST

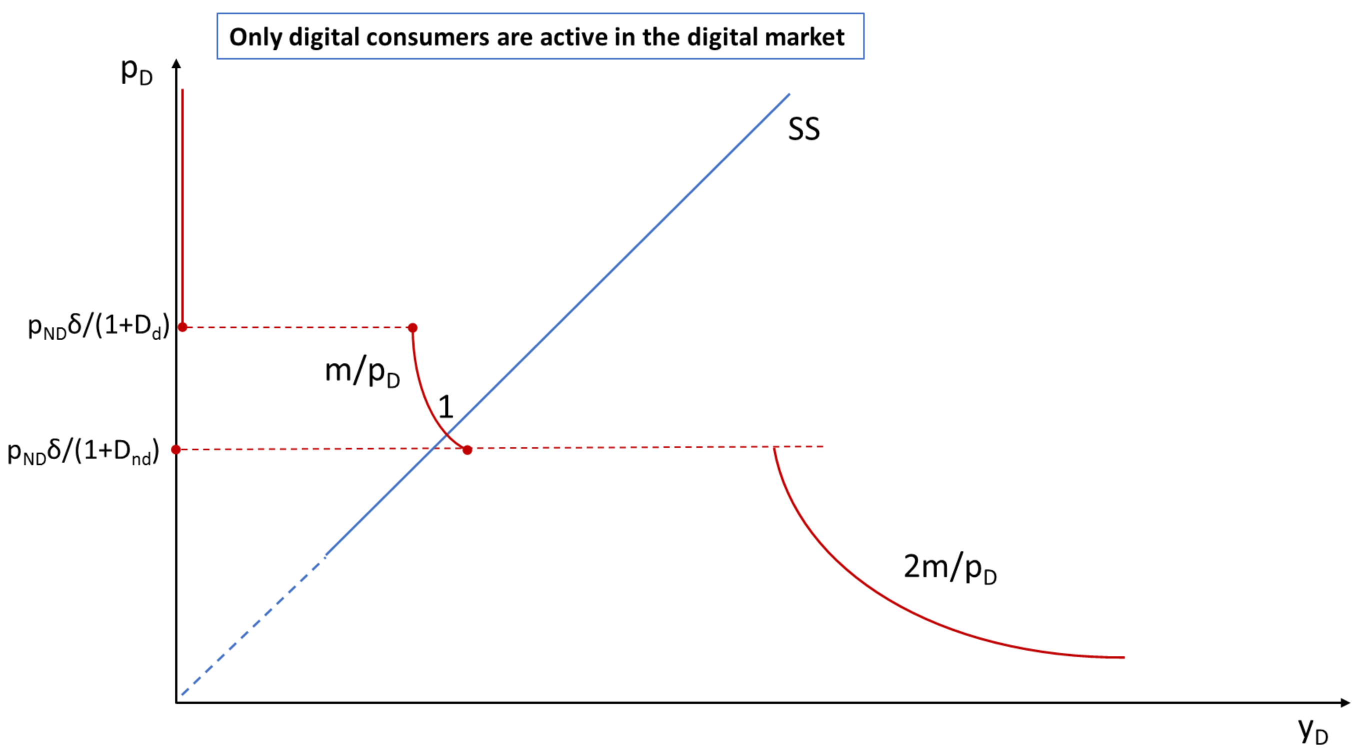

FIGURE 5: DIGITAL EQUILIBRIUM IN THE PRE-COVID ERA

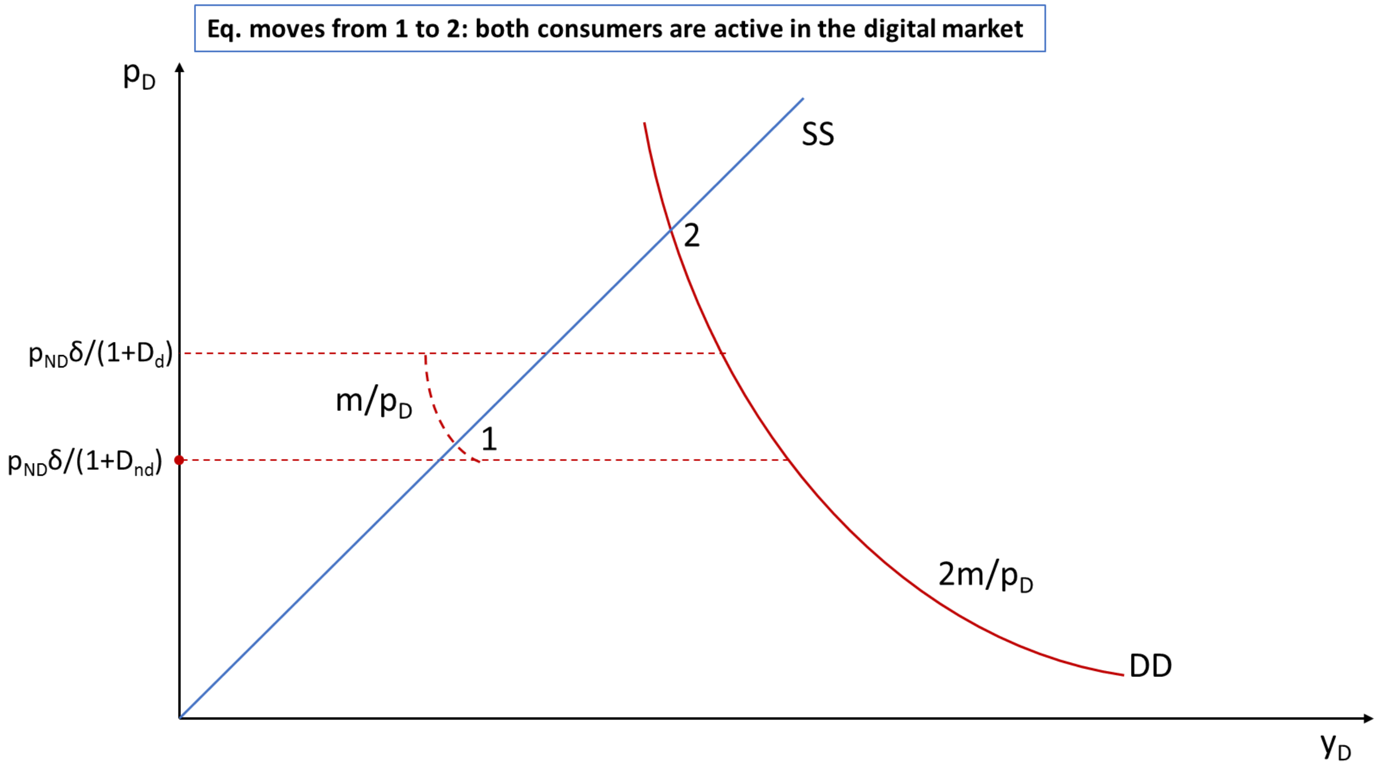

FIGURE 6: DIGITAL EQUILIBRIUM IN THE COVID ERA

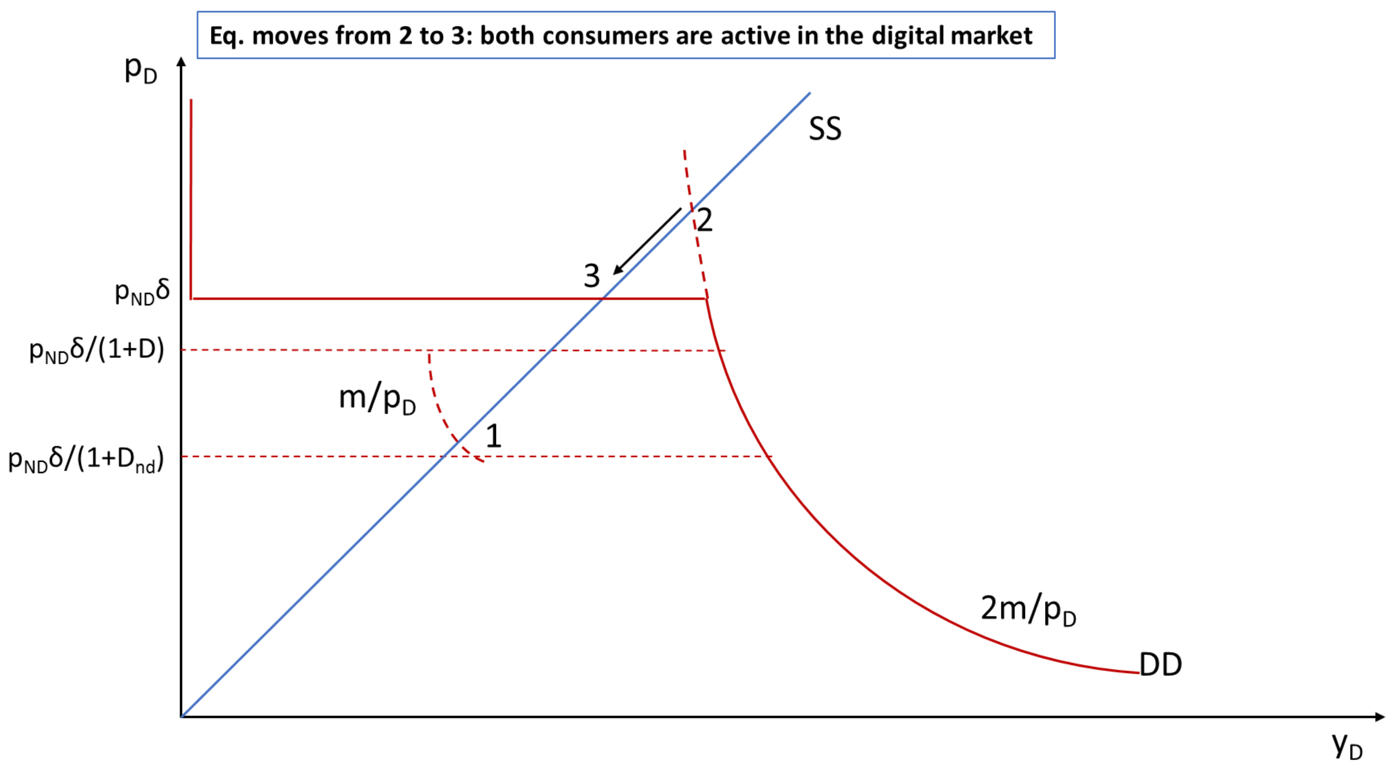

FIGURE 7: DIGITAL EQUILIBRIUM IN THE POST-COVID ERA

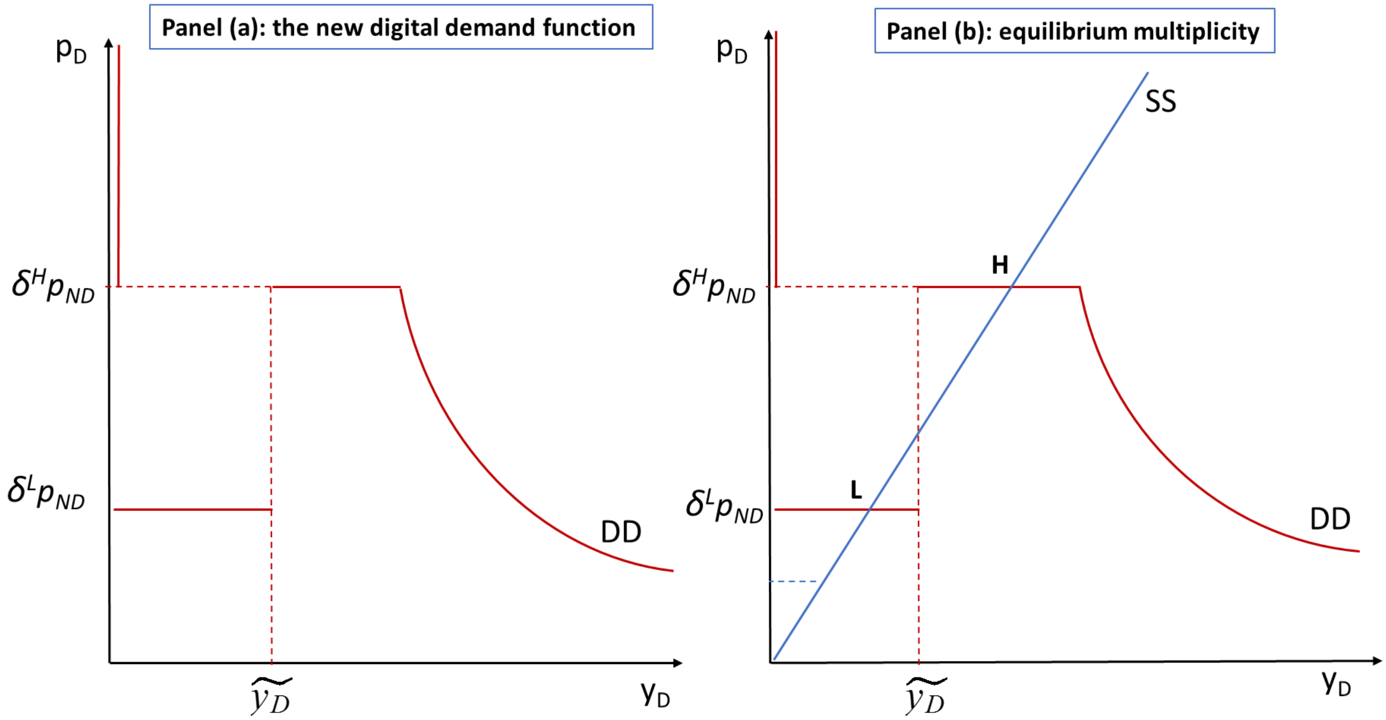

FIGURE 8: ENDOGENOUS PREFERENCES FOR DIGITALIZATION

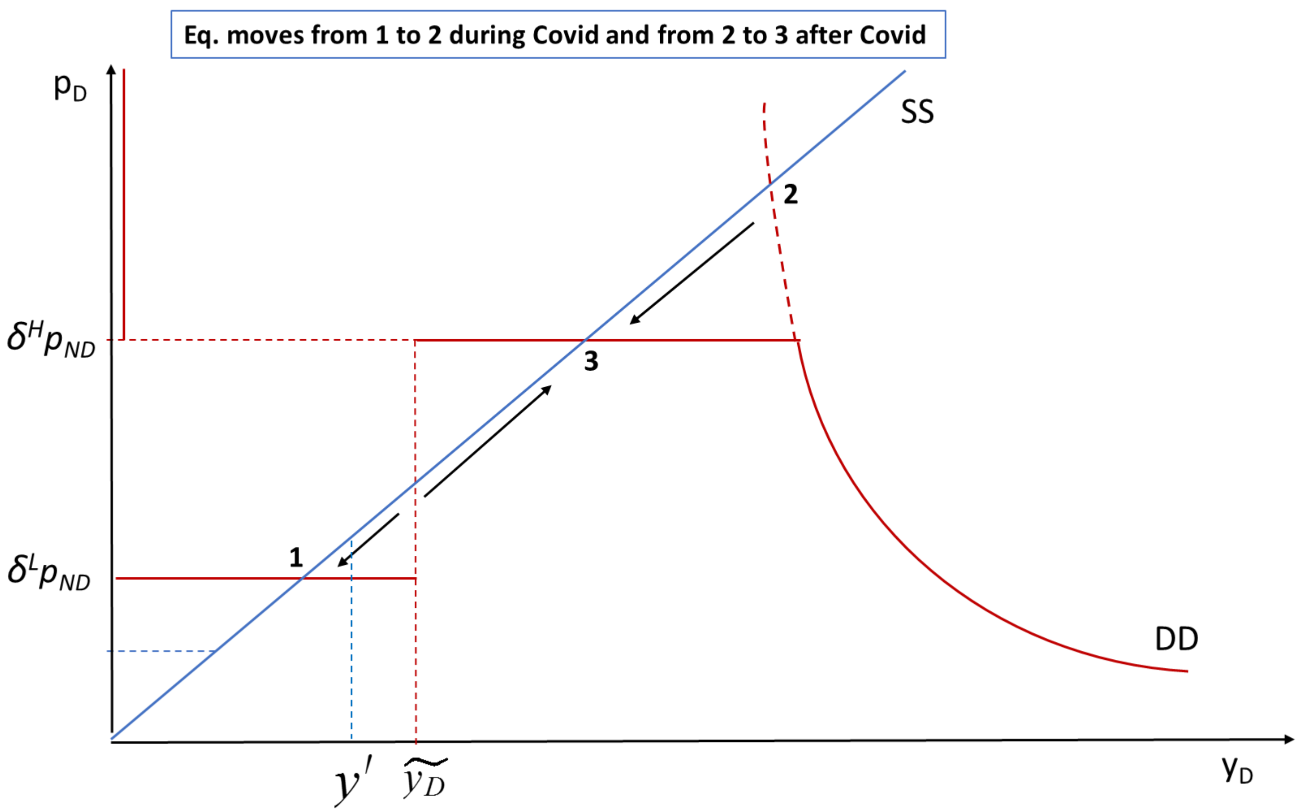

FIGURE 9: LOW- AND HIGH-DIGITAL EQUILIBRIA

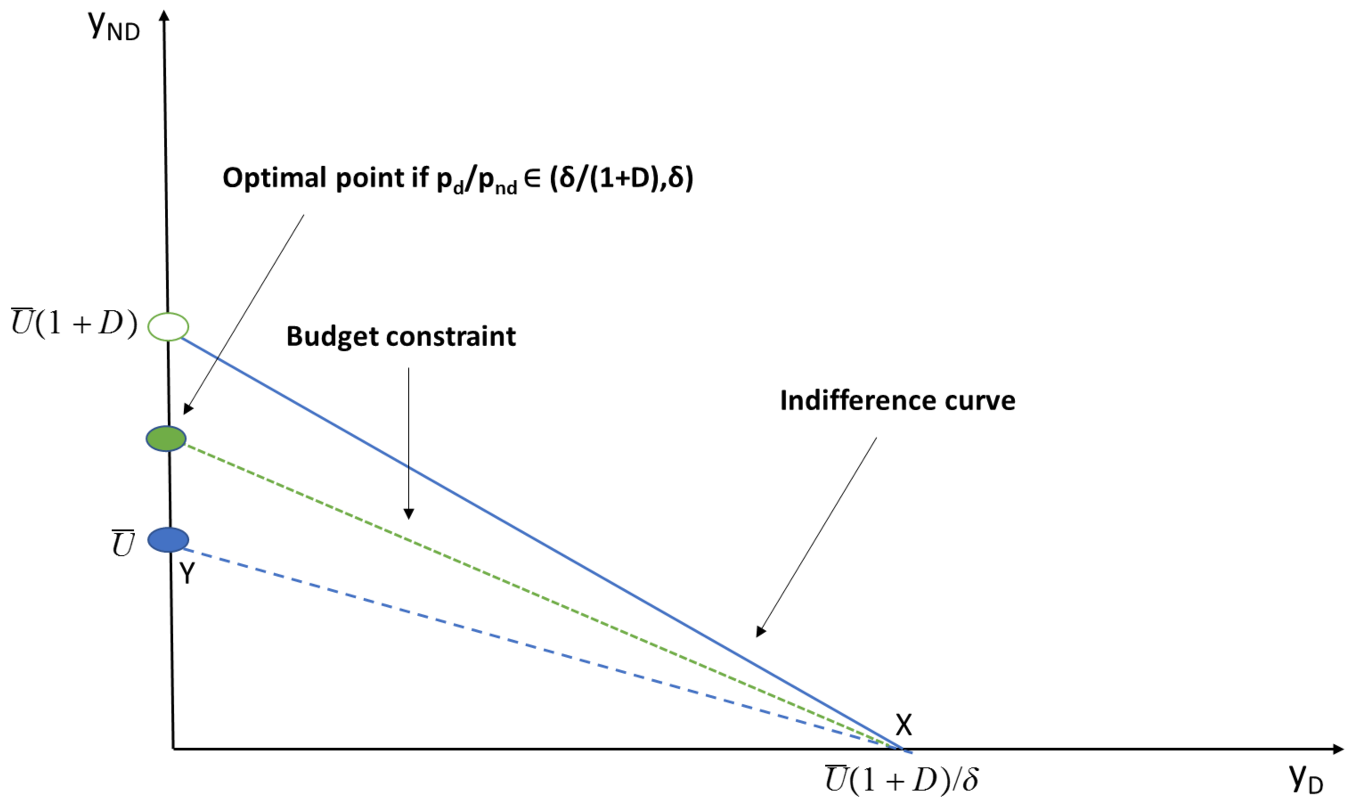

FIGURE A1: CONSUMER MAXIMIZATION UNDER DIGITAL ENTRY COST

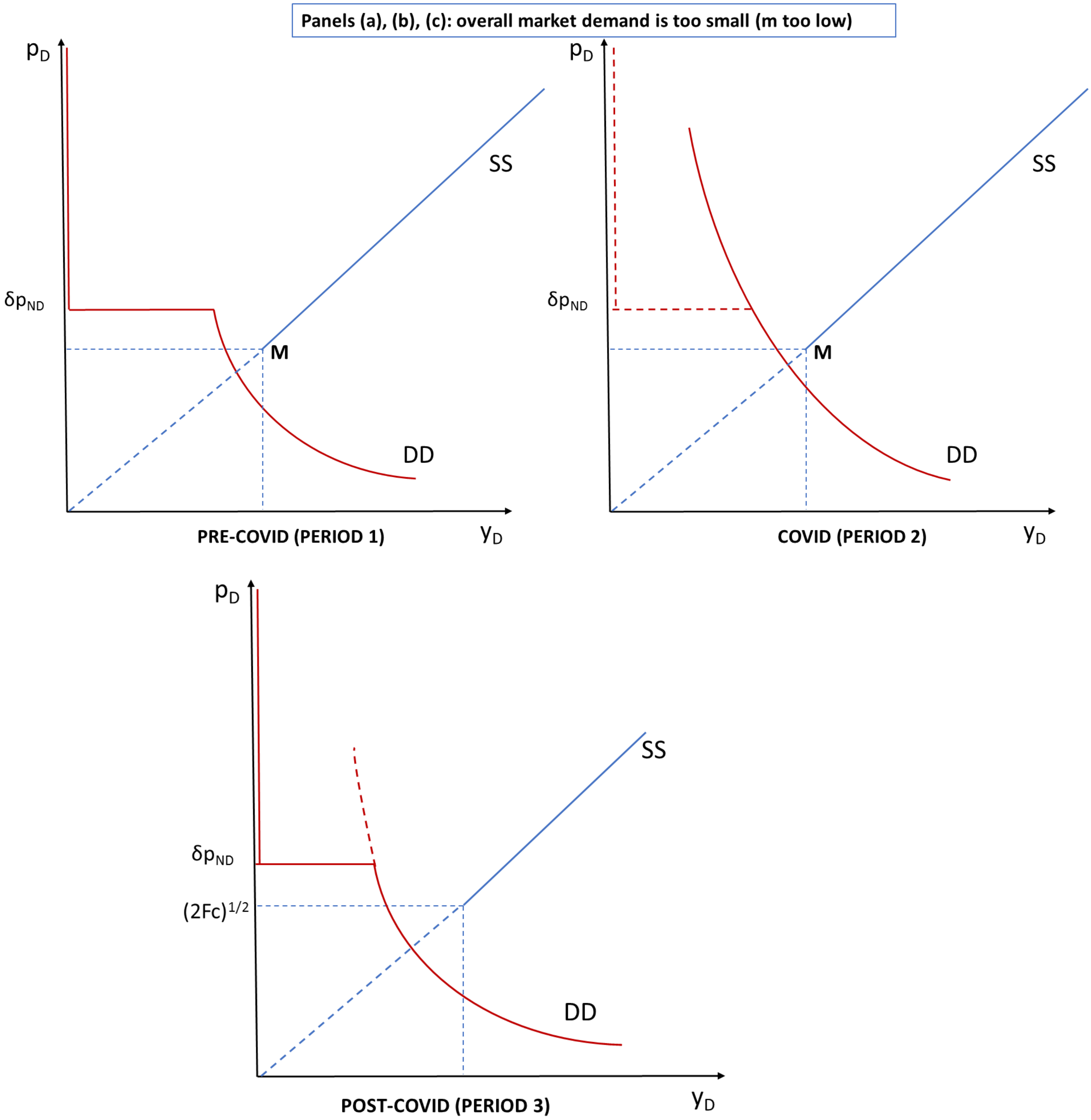

FIGURE A2: DIGITAL MARKET NEVER ARISES

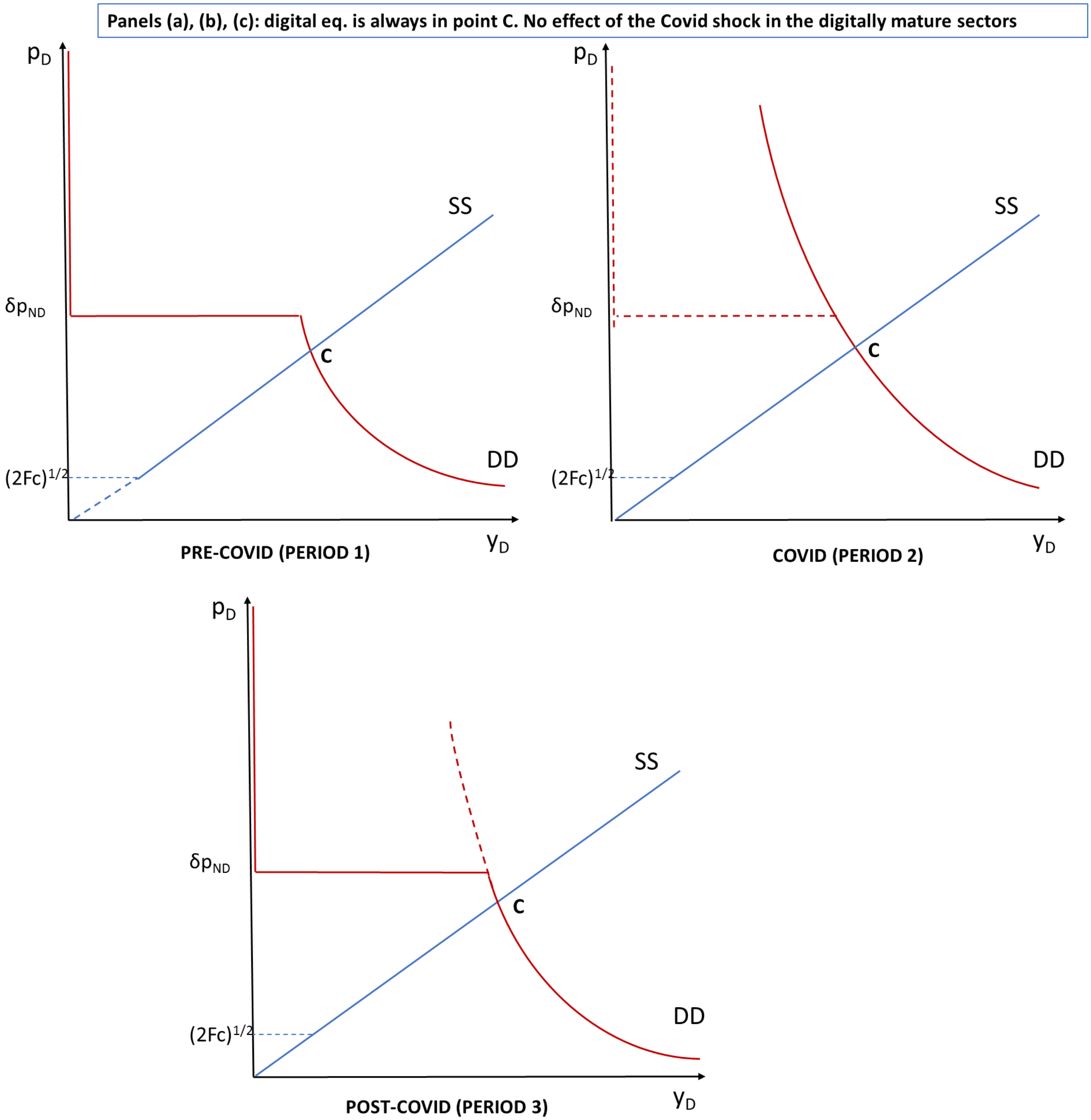

FIGURE A3: THE DIGITAL MARKET IS THE ONLY MARKET