Digitization and Profitability*

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Abstract

Consider a monopolistic vendor who faces a known demand curve. By setting a price that equates marginal revenue with marginal cost, the vendor will maximize his profit. This logic holds true of both physical and digital products. But since digitization will lower the variable production cost, it will strictly increase the profit to the vendor. Then, can we conclude that digitization always improves the vendor’s profitability? Not necessarily. Now consider what will happen on the next day of the sales. Facing deterministic demand, the physical product vendor must have prepared the exact quantity of the product to sell, and thus would be left with zero inventory. By contrast, the digital product vendor will have more, and infinitely more, “leftover” stock, thanks to the nature of the digital product. Therefore, the rational vendor will try to sell more and achieve a higher profit after the sales date. To this end, the vendor will now lower the price to attract additional customers with lower reservation prices. The process will indefinitely continue. Knowing this would happen, customers will wait for the price reduction. Even the customers who would have purchased on the first day would reconsider buying it now, and instead choose to wait. The digital product vendor will anticipate this and accordingly lower the price on the first day and later, thereby compromising his profitability. Note that this downward spiral takes place as a result of digitization. Thus, digitization may not necessarily improve the profitability to the vendor. We develop an economic model to formally analyze the impact of digitization on the profitability to the vendor.

Key words: Impact of digitization, Strategic customers, subgame perfect equilibrium, digital product pricing, asymptotic exponentiality

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§1. Introduction

Thanks to the Internet, many information goods – such as books, music and movies – are transformed to digital products and distributed over the Internet. Digitization offers numerous benefits – zero variable production cost, no stockouts, no excess inventory, instant deliveries, zero inventory carrying cost, zero shipping cost, and no damages or losses in handling or delivery. It, therefore, achieves an ideal form of make-to-order production-distribution system with unlimited supply, just-in-time delivery and zero variable cost. Most of these benefits directly or indirectly accrue to the vendor. But does digitization guarantee a higher profit? How about social welfare? This paper investigates the questions by using a simple game-theoretic model.

To start with, consider a monopolistic vendor (“he”) who faces a known demand curve. By setting a price that equates marginal revenue with marginal cost, the vendor will maximize his profit. This logic holds true of both physical and digital products. But since digitization will lower the variable production cost, it will strictly increase the profit to the vendor. Then, can we conclude that digitization always improves the vendor’s profitability? Not necessarily. Now consider what will happen on the next day of the sales. Since the demand is known, the physical product vendor must have prepared the exact quantity of the product to sell, and thus would be left with zero inventory. By contrast, the digital product vendor will have more, and infinitely more, “leftover” stock, thanks to the nature of the digital product. Therefore, the rational vendor will try to sell more and achieve a higher profit after the sales date. To this end, the vendor will now lower the price to attract additional customers with lower reservation prices. The process will indefinitely continue. Knowing this would happen, customers will wait for the price reduction. Even the customers (“she” each) who would have purchased on the first day
would reconsider buying it now, and instead choose to wait. The digital product vendor
will anticipate this and accordingly lower the price on the first day and later, thereby
compromising his profitability. Note that this downward spiral takes place as a result of
digitization. Thus, digitization may not necessarily improve the profitability to the vendor.
This casual argument requires a more formal investigation, which is the objective of the
present paper.

We here offer a brief literature survey. There exist three fields of research related
to the present work. First, special characteristics of digital products generated research
with different focuses. For example, Bakos and Brynjolfson (1999) study the effectiveness
of bundling a large number of information goods, in the face of diverse tastes and un-
certainties. Huang and Sundararajan (2011) study optimal nonlinear pricing for a digital
product, when the infrastructure has discontinuous cost. Traditional auction mechanisms
designed for physical products need modification when applied to digital products. In
this area Goldberg, Hartline and Wright (2001) and Bargnoli, et al. (2002) analyze the
auction mechanisms designed for allocating digital products. Our work contributes to the
literature by comparing profitability of physical and digital products.

Second, there exists a well-developed literature on sequential bargaining under informa-
tional asymmetry, and some are closely related to our paper. Sobel and Takahashi
(1983) and Cramton (1984) develop a sequential bargaining model between a buyer and
a seller over infinite time. The authors characterize the limiting sequential equilibrium
in closed form expressions. A similar bargaining model is used by Besanko and Winston
(1990) to compare the performance between strategic and myopic buyers. Horner and
Samuelson (2011) extend the model to $N$ potential buyers in a finite deadline. Our model
is closest to McAfee (2007) who studies sequential bargaining without information asym-
metry. We obtain closed-form trajectories of prices, thresholds and profits. This result is used to compare the profits of the physical and digital products.

Last, the body of work on the Coase conjecture is related to our work. In 1972 Coase conjectured that lack of commitment power and sequential rationality would drive down a durable good monopolist’s profit to zero under certain conditions. The conjecture was formalized by various authors including Stokey (1981), Bulow (1982), Gul, Sonnenschein and Wilson (1986), Orbach (2004), McAfee and te Velde (2007) and McAfee and Wiseman (2008). We show that this conjecture also serves as a distinguishing feature of digital products.

The rest of the paper is organized as follows. In the next section we introduce the model. We analyze the one-period model of physical products in §3. In §4 we study the multi-period sales of digital products and compare the two models. In particular, we encounter the Coase conjecture that arises as a limiting phenomenon for digital products. In §5, we investigate the welfare implications of digitization. The last section offers concluding remarks including the strategy of avoiding the Coase conjecture.

§2. The Model

The main objective of the paper is to analyze the impact of digitization on the profitability to the monopolist vendor. We develop a simple mathematical model to capture the essence of the issue at hand. We consider a market where a monopolistic vendor attempts to sell a product to customers. The product may be either in the physical or digital form. Below is the detailed description of the model.

- (Demand) We assume that the market consists of a continuum of customers with different valuations. A customer with valuation $v$ is called the ‘type-$v$’ customer. The (inverse) demand function is given by $p = \bar{v} - q$ for some positive $\bar{v}$, where $p$ is the price
and $q$ the quantity sold. Equivalently, the valuations of the customers are uniformly distributed in $[0, \bar{v}]$ at unit density. Thus, the initial market size is $\bar{v}$, but will shrink over time as more customers buy.

- (Value Depreciation) A customer’s valuation depreciates in time at a fixed rate of $\delta (\in (0, 1))$ per period. $\delta$ is here called the discount factor. The product valued at $v$ at time 1 becomes worth $\delta^{t-1}v$ in period $t$. Note that customer ‘types’ do not depreciate over time, since types are defined at the initial period. A large discount factor close to 1 means slow depreciation. Cash is not discounted, for simplicity.

- (Production Cost) The variable production cost of the physical product is $c > 0$ per unit, while that of the digital product is set to zero. We assume that the fixed cost is identical in both products.

- (Selling Periods) Physical and digital products operate in different manners. The former has only one selling period, while the latter has an infinite number of selling periods denoted by $t = 1, 2, \ldots$.

- (Strategic Customers) Customers are strategic in the choice of time to buy. Each customer buys in the period that maximizes her (positive) net value of the product – the value earned beyond the cost. She would not buy any if the net value is negative.

- (Vendor’s Pricing) The vendor of the digital product would set the price each period to maximize the residual (gross) profit – the total profit in the present and future periods before the fixed cost is subtracted. The case of the digital product is thus modeled as a multi-period game played by two sets of players, who take turns in making a move. We study the decisions of the players and their resulting outcome as the equilibrium of the game and derive managerial insights.

§3. Physical Product
Consider a physical product vendor who has one period to sell his product. Facing the linear demand we assumed, the vendor will prepare the quantity \( Q^o = (\bar{v} - c)/2 \) at unit cost of \( c \) and set the price at \( p^o = (\bar{v} + c)/2 \) to sell the entire stock. This will generate the total profit of \( \Pi^p = (p^o - c)Q^o = (\bar{v} - c)^2/4 \). Consumer surplus (= the sum of consumers’ net values) will be \( CS^p = (\bar{v} - p^o)Q^o/2 = (\bar{v} - c)^2/8 \). Social welfare \( S^p \) – the sum of the vendor profit and consumer surplus – will equal \( 3(\bar{v} - c)^2/8 \). Note that both the vendor profit and welfare strictly decrease in \( c \).

§4. Digital Product

By its nature, the digital product always has ‘leftover’ stock at the end of each selling period. Knowing this in advance, customers wait to see the price coming down. In response, the vendor adjusts the prices now and for the future. This multi-period game is modeled in the subgame-perfect equilibrium concept. Formally speaking, the equilibrium is the pair of strategies \( \{(p_t, v_t)\}_{t=1,2,...} \), so that taking the history of the game so far as given, in each period \( t \),

(1) each type-\( v \) customer buys a unit if and only if \( v \geq v_t \) for some \( v_t \), meaning that customers in the aggregate choose the ‘threshold’ value \( v_t \); and

(2) the vendor selects the price \( p_t \) to maximize his residual profit \( \pi_t := \sum_{i=t}^{\infty} p_i(v_{i-1} - v_i) \) in expectation of the customers’ strategies.

The strategy in (1) represents the threshold policy in which only high-types of customers buy the product now while the rest wait. It is an optimal policy in our context, but we omit its proof. The vendor’s strategy in (2) is to “cream-skim” the customers by steadily lowering the price and selling to the next interval of customers each period, where the interval is \([v_t, v_{t-1})\) in period \( t = 1, 2, \ldots \), with \( v_0 := \bar{v} \). Thus, in equilibrium the thresholds will form a non-increasing sequence \((v_1, v_2, \ldots)\). Now we seek to find the
explicit values of \( \{ p_t \}, \{ v_t \} \) and \( \{ \pi_t \} \).

### 4.1 Equilibrium

To find the subgame-perfect equilibrium of the game, we work backwards in each period \( t \). That is, given arbitrary values of \( (v_1, v_2, \cdots, v_{t-1}) \) of the previous-period values, the vendor chooses \( v_t \) by solving

\[
\begin{align*}
(P1) & \quad \max_{v_t: v_t \leq v_{t-1}} p_t(v_{t-1} - v_t) + \pi_{t+1}(v_t) \\
(4.1) & \quad \delta^{t-1}v_t - p_t = \delta^t v_t - p_{t+1}, \\
(4.2) & \quad \delta^{t-1}v_t - p_t \geq 0.
\end{align*}
\]

The objective of (P1) tries to maximize the residual profit by selecting the right price \( p_t \) that indirectly controls \( v_t \) (via the constraints). In order to properly assess the impact of his current decision, he has to look ahead and build a prediction on the future equilibrium values \( (p_{t+i}, v_{t+i}) \) for \( i = 1, 2, \cdots \). The prediction should be correct in equilibrium. This correct prediction requirement applies to the customers as well. The above model implicitly assumes that in every period there exists a marginal customer \( v_t (< v_{t-1}) \) who finds accepting the current price equal to waiting in terms of her net value. We will later show that these conditions are indeed met in equilibrium. Eqs (4.1) are the incentive-compatibility (IC) constraints; i.e., each customer in \( [v_i, v_{i-1}) \) buying in period \( i \) does so because she finds the option of buying now is as good as, or better than, the option of waiting, and the marginal customer \( v_i \) will be indifferent between the two options. Eqs (4.2) are the individual rationality (IR) constraints ensuring that each type of customer gets at least zero net value; otherwise, she would not buy the product. See, for example, Mas-Colell, Whinston and Green (1995) for detailed discussions of mechanism design.
The equilibrium of the game is captured by the triplet – the price $p_t$, the threshold $v_t$ and the residual profit $\pi_t$ to the vendor. Below we present the equilibrium in two steps – the first-period equilibrium (Theorem 4.1) and the trajectories of the triplet over time (Theorem 4.3). The equilibrium is given in a surprisingly simple form, even though its derivation is rather complicated.

**THEOREM 4.1** In equilibrium, $(P1)$ of the digital system has the following solution for $t = 1$:

(i) $v_1^* = \frac{1-\sqrt{1-\delta}}{\delta} \bar{v}$

(ii) $p_1^* = \frac{\sqrt{1-\delta}}{\delta} \bar{v}$

(iii) $\pi_1^* (\bar{v}) = \frac{\sqrt{1-\delta}}{2\delta} \bar{v}^2$

**Proof:** Temporarily, we disregard the (IR) conditions. We will later show that these conditions are indeed met in equilibrium. Without loss of generality, we assume $\bar{v} = 1$ for simpler exposition. The vendor’s problem of period 1 is written as

$$(P1) \quad \pi_1(1) = \max_{v_1, p_1} p_1 (1 - v_1) + \pi_2(v_1)$$

s.t.

$$v_1 \leq 1$$

$$v_1 - p_1 = \delta v_1 - p_2(v_1).$$

In the above and below, we define $\pi_t(v_{t-1})$ as the vendor’s residual profit in period $t = 1, 2, \cdots$, and $p_t(v_{t-1})$ as the period-$t$ price, given that the threshold of the previous period is $v_{t-1}$.

Now turning to the problem of finding $\pi_t(v_{t-1})$ for $t = 2, 3, \cdots$, the problem can be formulated as

$$(P2) \quad \pi_t(v_{t-1}) = \max_{v_t, p_t} p_t (v_{t-1} - v_t) + \pi_{t+1}(v_t)$$
s.t.

\[ v_t \leq \delta^{t-1}v_{t-1} \]

\[ v_t - p_t = \delta v_t - p_{t+1}(v_t), \]

where \( v_{t-1} \) and \( \delta^{t-1}v_{t-1} \) were already determined in the previous period and should be treated as constants in this period.

Note that (P1) and (P2) have the same problem structure, differing only in the market size and the distribution of customers’ valuations. The market size in the former is 1, and the customers’ valuations are uniformly distributed on \([0, 1]\). In the latter case, the market size is \( v_{t-1} \), with the customers’ valuations uniformly distributed on \([0, \delta^{t-1}v_{t-1}]\). Therefore, the solutions to (P1) and (P2) become identical if properly adjusted for scale.

Then, the ratios of outputs to input should be identical in the two problems; i.e., for every \( t \),

(4.3) \[ \frac{v'_t}{v'_0} = \frac{v'_1}{\delta^{t-1}v_{t-1}} = \frac{v_1}{v_0} = v_1 \]

(4.4) \[ \frac{p'_t}{v'_0} = \frac{p'_1}{\delta^{t-1}v_{t-1}} = \frac{p_1}{v_0} = p_1, \]

where \( v'_1 \) and \( p'_1 \) are the equilibrium threshold and price in the current \( t \)-th period in (P2), with \( v'_0 \) defined as \( \delta^{t-1}v_{t-1} \). In addition, note that on the absolute term, the threshold value \( v_t \) in period \( t \) in (P1) is given by \( v_t = v'_1/\delta^{t-1} \), since the type-\( v'_1 \) customer in period \( t \) had valuation \( v'_1/\delta^{t-1} \) in period 1. Hence, by applying \( v'_0 = \delta^{t-1}v_{t-1} \) and \( v'_1 = \delta^{t-1}v_t \) to (4.3), we have, for every \( t \),

(4.5) \[ v_t = v_{t-1}v_1 = v_{t-2}v_1^2 = \cdots = v'_1. \]

The first-period price \( p'_1 \) in (P2) is the period-\( t \) price in (P1); i.e., \( p'_1 = p_t \). Thus, from (4.4) and (4.5), for every \( t \),

(4.6) \[ p'_1 = p_t = \delta^{t-1}v_{t-1}p_1 = \delta^{t-1}v_1^{t-1}p_1. \]
The residual profit $\pi_t(v_{t-1})$ is proportional to both the market size $v_{t-1} = v_1^{t-1}$ and the price $p_t = \delta^{t-1}v_1^{t-1}p_1$. Thus,

$$(4.7) \quad \pi_t(v_{t-1}) = \delta^{t-1}v_1^{2(t-1)}\pi_1(1).$$

By applying (4.7) and (4.6), $\pi_2(v_1) = \delta v_1^2\pi_1^*(1)$ and $p_2(v_1) = \delta v_1p_1^*$, which are respectively the predicted residual profit and the predicted price in period 2 when the threshold in period 1 is $v_1$. Thus, (P1) is written as

$$\pi_1(1) = \max_{v_1,p_1} p_1(1 - v_1) + \delta v_1^2\pi_1^*(1)$$

s.t.

$$v_1 \leq 1$$

$$v_1 - p_1 = \delta v_1 - \delta v_1p_1^*.$$

In equilibrium, the prediction should be correct and satisfy:

$$\pi_1(1) = \pi_1^*(1)$$

$$p_1 = p_1^*.$$

From the (IC) constraint of (P1), we have

$$p_1 = v_1(1 - \delta + \delta p_1^*).$$

The objective function is

$$\pi_1(1) = \max_{v_1,p_1} (1 - v_1) + \delta v_1^2\pi_1^*(1)$$

$$= \max_{v_1} v_1(1 - \delta + \delta p_1^*)(1 - v_1) + \delta v_1^2\pi_1^*(1).$$

Invoking our temporary assumption that the inequality constraint (i.e., $v_1^* \leq 1$) is met, we have

$$(4.8) \quad v_1^* = \frac{1 + \delta p_1^*(1) - \delta}{2 - 2\delta(1 + \pi_1^*(1) - p_1^*)}$$

10
\[
\pi_1^*(1) = p_1^*(1 - v_1^*) + \delta v_1^* \pi_1^*(1)
\]

\[
p_1^* = v_1^*(1 - \delta + \delta p_1^*).
\]

Solving (4.8)-(4.10) w.r.t. \(v_1^*, p_1^*\) and \(\pi_1^*(1)\), we have the Theorem. We can also verify that 
\(v_1^* \leq 1\) and that 
\[v_1^* - p_1^* = \frac{2-\delta-2\sqrt{1-\delta}}{\delta} > 0, \forall \delta.\]

The Theorem completely determines the first-period threshold \(v_1^*\), the opening price \(p_1^*\) and total profit \(\pi_1^*\) as a function of the primitive model parameters \(\bar{v}\) and \(\delta\) for the digital system.\(^1\) In particular, note that the total profit \(\pi_1^*\) decreases in the discount factor. We are now in a position to compare the profits of the physical and digital systems as follows (see also Figure 1).

**THEOREM 4.2**

(i) The profit \(\Pi^p\) of the physical product is given by \((\bar{v} - c)^2/4\).

(ii) The profit \(\Pi^d(= \pi_1^*(1))\) of the digital product is given by 
\[\frac{\sqrt{1-\delta} - 1 + \delta}{2\delta} \bar{v}^2.\]

(iii) The digital system is more profitable than the physical system if and only if 
\[\delta \leq \frac{4\bar{v}^2(2\bar{v} - c)}{(\bar{v}^2 - \bar{v}c - 2\bar{v}c)^2}.\]

Profitability of digitization thus depends on the discount factor \(\delta\) and the variable cost \(c\). At a higher \(\delta\), customers do not feel pressured to buy early and instead choose to wait, since most of the original value is retained over time. To counter it, the vendor is forced to lower the price fast to induce them to buy early. Also, if the physical product has a high variable cost, digitization would save more for the digital product vendor. In summary, digitization will favor the vendor when the physical product has high production cost and

\(^1\)See McAfee (2007) who derives a similar form of total profit in a slightly different setting as a fixed point.
the product depreciates fast. Note here that to the digital product vendor, the infinite supply or the lack of scarcity is not a blessing, but a liability.

As a byproduct of the proof of Theorem 4.1, we can derive the trajectories of equilibrium strategies and profits over time. In Eq (4.5) the ratio \( v_t^*/v_{t-1}^* \) for the digital system is constant, independent of time \( t \), so the thresholds take the exponential form in the digital product model. The price \( p_t^* \) and the residual profit \( \pi_t^* \) also follow the exponential form from (4.5) and (4.7). Thus, we have:

**Theorem 4.3** Let \( R := \frac{1-\sqrt{1-\delta}}{\delta} \) and \( K := \frac{\sqrt{1-\delta}-1+\delta}{2\delta} \). Then, for every \( t \),

(i) \( v_t^* = \bar{v} R^t \)

(ii) \( p_t^* = 2K\bar{v}(\delta R)^{t-1} \)

(iii) \( \pi_t^*(\bar{v}) = K\bar{v}^2(\delta R^2)^{t-1} \)

Part (i) confirms that in every period there exists a marginal customer who finds buying now equal to waiting. This result also shows that the (IR) condition (Eq (4.2)) is satisfied in each period \( t \), since \( \delta^{t-1}v_t - p_t = \bar{v}\delta^{t-1}R^t - 2K\bar{v}(\delta R)^{t-1} = \bar{v}(\delta R)^{t-1} \cdot \frac{2-\delta-2\sqrt{1-\delta}}{\delta} > 0 \) for all \( t \). Thus, the net value to each customer exponentially shrinks to zero as \( t \) approaches infinity.

4.2 The Coase Conjecture

We have shown that the digital product vendor will be worse off when the product depreciates slowly. Even worse, Theorem 4.3 (ii) and Figure 1 show a prominent feature of the digital product – both the opening price and total profit continuously decline to zero as \( \delta \) approaches 1. That is, \( \lim_{\delta \to 1} p_1^* = 0 \) and \( \lim_{\delta \to 1} \pi_1^*(\bar{v}) = 0 \). In the limit, the digital product vendor is trapped in the zero-revenue paradox Coase conjectured in his 1972 paper (Coase, 1972). The downward spiral between customers’ deferred purchases and the vendor’s price reduction drives the result in the limit. A large literature on the
Coase conjecture identified and studied the conditions under which the conjecture holds true. The Coase conditions include: (i) the product is durable (not consumable) (Coase 1972, Bulow 1982, and Orbach 2004); (ii) the cost of transacting each deal is zero (Coase 1972); (iii) the price can be instantly changed (Coase 1972); (iv) the discount factor is close to 1 (Gul, Sonnenschein, and Wilson 1986); and (v) the vendor has no power to commit to the future prices (McAfee 2007). One implicit condition only lightly covered in the literature is that the vendor has an infinite (or sufficiently large) supply like “all the land of the United States” as in Coase (1972). Our model highlights the fact that the Coase conjecture may apply to the digital product market with its infinite supply, but not to the physical product market where there is a potential shortage due to its finite supply. Therefore, the Coase conjecture poses a clear and present risk to digitization. Indeed, the digital product vendor should make sure to avoid the Coase conditions. We discuss it further in the final section.

§5. Social Welfare

We turn to the welfare implications of digitization. For the physical product case, social welfare is $S^p = 3(\bar{v} - c)^2/8$, as discussed in §3.

Now consider the welfare in the digital system. Social welfare $S^d$ can be expressed as the total value generated by the purchases. In period $t$ the group of customers belonging to $[v_t, v_{t-1})$ will purchase the product. The size of this group is $v_{t-1} - v_t$ with the average gross value $\delta^{t-1}(v_{t-1} + v_t)/2$ per customer.

The total welfare across all groups is thus given by

$$S^d = \sum_{t=1}^{\infty} \delta^{t-1}(v_{t-1} - v_t)(v_{t-1} + v_t)/2 = \sum_{t=1}^{\infty} \delta^{t-1}(v_{t-1}^2 - v_t^2)/2,$$

where $v_t$ is given in Theorem 4.3. Then, it can be shown that

$$S^d := \frac{1 + \delta - \sqrt{1 - \delta}}{4\delta \bar{v}^2}.$$
Thus, we have:

**THEOREM 5.1**

(i) Social welfare of the physical and digital systems \( S^p \) and \( S^d \) are respectively given by

\[
S^p = \frac{3(\bar{v} - c)^2}{8}
\]

and

\[
S^d = \bar{v}^2 \left( 1 + \delta - \sqrt{1 - \delta} \right)/(4\delta).
\]

(ii) Digitization always improves social welfare.

**Proof of (ii):** Note first that \( S^d \) is monotone increasing in \( \delta \). Also, note that

\[
\lim_{\delta \to 0} S^d = \lim_{\delta \to 0} \frac{\bar{v}^2(1 + \delta - \sqrt{1 - \delta})}{4\delta}
\]

\[
= \lim_{\delta \to 0} \frac{\bar{v}^2(1 + \delta - \sqrt{1 - \delta})(1 + \delta + \sqrt{1 - \delta})}{(4\delta)(1 + \delta + \sqrt{1 - \delta})}
\]

\[
= \lim_{\delta \to 0} \frac{\bar{v}^2(3 + \delta)}{4(1 + \delta + \sqrt{1 - \delta})}
\]

\[
= \frac{3\bar{v}^2}{8}
\]

\[
\geq \frac{3(\bar{v} - c)^2}{8}
\]

\[
= S^p,
\]

which completes the proof.

Why does digitization improve social welfare? Note that there are three factors that determine social welfare – cost of production, market penetration and the timing of sales. The digital system improves welfare through lower production costs. Also, digitization increases the number of customers served. The physical product vendor deliberately limits the quantity and only sell to high types of customers to the detriment of social welfare, while the digital product vendor will ultimately sell to all customers over the infinite
horizon. However, it does not prove that the digital system is better in terms of social welfare, because welfare also depends on how fast sales happen before the product loses its value. In this respect the physical product performs better, since all sales take place in the first period. The Theorem, however, reports that the second effect strictly dominates the third, while the first separately re-enforces the benefit of digitization.

From a broader perspective on the comparison, competition exists between the digital system’s efficiency and the physical system’s scarcity. To the profit-maximizing digital product vendor, efficiency boosts his profit, but lack of scarcity hurts it. On the other hand, both efficiency and lack of scarcity contribute to social welfare. Therefore, digitization may improve or hurt the vendor profit, but it always improves social welfare.

§6. Concluding Remarks

We have investigated if digitization would lead to higher profitability. The answer depends on the variable cost of the physical product and the discount factor of the product. Digitization favors the vendor when the variable cost is high and depreciation is slow. In the extreme case of infinite time horizon and zero depreciation, the digital product vendor will lower the price to zero “in the twinkle of an eye,”\(^2\) and face zero profit.

The digital product vendor should take actions to mitigate the liability of digitization driven by the infinite supply, while maintaining its advantage of low variable cost. In particular, he should by all means avoid the Coase conditions. We consider three approaches to it – a finite time horizon, a small discount factor and a limited number of copies available.

The first approach is to develop a mechanism to artificially end the sales in a finite time, say, \(T\). A finite \(T\), preferably a small \(T\), will benefit the vendor. It may sound counter-

\(^2\) See Coase (1972).
intuitive, since a shorter time horizon may incur loss of sales on the tail end of the time horizon. But it changes the game dynamics as it pressures customers to buy before it is too late. In fact, the finite horizon game shows a completely different pattern of profitability from our infinite horizon case. The profit in the former changes in a U-shaped curve with respect to the discount factor $\delta$ (see Figure 2 for $T = 2$), instead of a monotone-decreasing curve in the latter (see Figure 1 for $T = \infty$). The largest discount factors offer as high profits as the lowest discount factors. The vendor can achieve the maximum profits at the highest discount factors when the time horizon is finite. Moreover, this case will prevent the rise of the Coase conjecture. An example of this approach is to build a reputation of “no markdown” policy. This is equivalent to choosing $T = 1$. Building such a reputation requires multiple rounds of long-term efforts, sometimes risking short-term losses. It will achieve the same profit as a physical product with zero variable cost.

The second approach is to choose a smaller discount factor. A small discount factor (i.e., smaller $\delta$) has a positive effect on profitability similar to a short selling season (smaller $T$). For example, the condition $\delta = 0$ is equal to $T = 1$. In both, the downward spiral will stop before reaching the zero profit level. To execute this strategy, the vendor may shorten the effective product life cycle and introduce a new version of the product at regular intervals. He may continue to offer the current version of product (i.e., keep $T$ at infinity) even after the new product is introduced, but the value of the product will significantly erode, thereby achieving a small discount factor. This way, scheduled obsolescence would keep the discount factor away from 1 and block the Coase conditions.

Lastly, the vendor may create “limited editions” of the digital product. By limiting the supply and creating scarcity, the vendor would overcome the main disadvantage of the digital product. One way is to utilize Blockchain technology. For example, Kodak
(www.kodak.com/kodakone) and a startup Ascribe (www.ascribe.io) offer a Blockchain-based service that enables a digital product vendor to issue a limited number of copies by assigning a unique pair of public and private keys to each copy and tracking its movement on the Blockchain.

The model has several limitations. First, it is a simple stylistic model compromised for tractable analysis. We assumed linear demand, a simplistic market mechanism for physical products and a simple game structure with no uncertainties in the digital system. These simplifying assumptions may admittedly limit the power of the model’s conclusions and applicability. The Coase conjecture, in particular, may be viewed as an artifact of theoretical exercise. However, managers may draw qualitative insights from such extreme results. Second, we have not allowed the physical product vendor to produce extra units to sell over multiple periods and apply dynamic pricing. But it will not generate a higher profit to the vendor. Figure 2 illustrates this point, when we repurpose it for a physical product with two periods of sales and \( c = 0 \). The profit is maximal when \( \delta \) is 0, or equivalently, when \( T = 1 \). That is, even if the vendor is allowed to, it is not optimal for the physical product vendor to sell in multiple periods. Thus, we have not lost optimality with this limitation. Another limitation is, the model captures only two key differentiating features – low production cost and infinite supply – of digital products. It left out of consideration other benefits of digitization such as instant gratification and ease of updating and upgrades. We hope to see more work to complement our deficiencies with more sophisticated models and empirical research.
References


Figure 1. The profit from the digital product is higher than the physical product when $\delta$ is smaller than .73, where $\bar{\sigma} = 1$ and $T=\infty$.

Figure 2. The profit from the digital product is higher than the physical when $\delta$ is either smaller than .45 or larger than .8, where $\bar{\sigma} = 1$ and $T=2$. 