Online Appendix: Multi-Generation Product Diffusion in the Presence of Strategic Consumers

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1. Different Prices for the Two Generations

In the baseline model, we assume that the price of the second generation is the same as the original price of the first generation p. Such a pricing strategy has been widely observed in the consumer electronics industry (e.g., the prices for different generations of iPhones). In this extension, we consider a more general pricing strategy. We assume the price of the second-generation product is higher than the original price of the first generation, possibly to reflect the performance improvement. The reverse case can be similarly analyzed.

We denote the price of the second generation as $p + h$, where the price increment is such that $h \geq 0$. Similar to the baseline model, consumers have five options before the release of the second generation. The main difference is now that the price of the second generation is higher than the price considered in the baseline case. Consumers' payoffs under Adopt, Laggard, and Non-Adopt remain the same as in the baseline case: $v - p$, $e^{-r(\tau - t)}(v - p + \delta)$, and 0, respectively. Under Leapfrog, consumers wait and buy the second-generation product, and the expected payoff becomes $e^{-r(\tau-t)}(\rho v - p - h)$. Under Upgrade, consumers buy the first generation and upgrade to the second generation later, and the expected payoff becomes $v - p + e^{-r(\tau-t)}[(\rho - 1)v - p - h + \mu]$.

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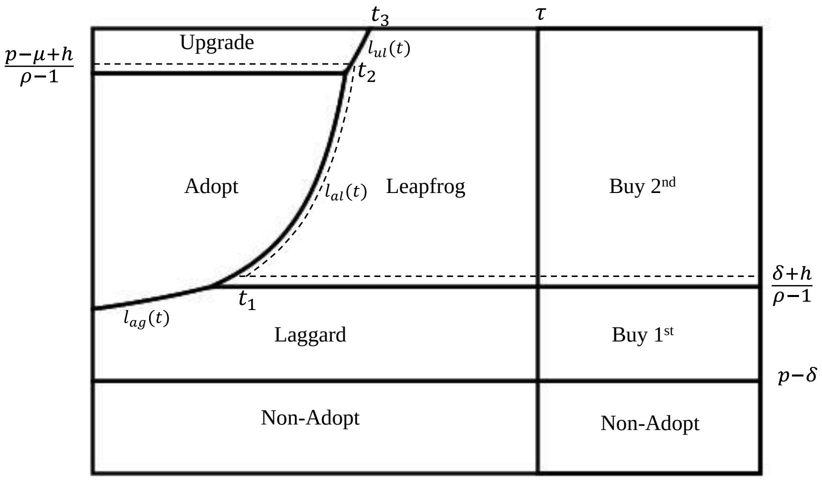

Figure 1: When Two Generations Have Different Prices

We next illustrate the market segmentation by comparing it with the most complicated scenario in the baseline model, presented in Figure 2(c). We can easily replicate all the analyses for the other scenarios and show that all the results qualitatively remain. The indifference curve between Upgrade and Adopt is determined by $l_{ua} = \frac{p+h-\mu}{\rho-1} > \frac{p-\mu}{\rho-1}$. Compared to the baseline case, fewer consumers choose to upgrade because of the price increase of the second generation.

Similarly, the indifference curve l_{ul} is defined by $v - p = e^{-r(\tau-t)}(v-\mu)$, l_{al} is defined by $v - p = e^{-r(\tau-t)}(\rho v - p - h)$, and l_{ag} is defined by $v - p = e^{-r(\tau-t)}(v - p + \delta)$. In fact, only l_{al} shifts to the right. Compared to the baseline case, more consumers choose Adopt, rather than Leapfrog, because of the price increase associated with the Leapfrog option.

Also, compared to the baseline case, the Laggard option becomes relatively more attractive than the Leapfrog option, and more consumers choose the Laggard option because of the price increase associated with Leapfrog. The indifference curve now becomes $l_{lg} = \frac{\delta+h}{\rho-1}$. The consumers who are indifferent between Laggard and Non-Adopt remain the same because the price difference h has no effect on either option.

Figure 1 illustrates the market segments under the general pricing strategy. The dashed lines represent the shifts of indifference curves. Compared to the baseline case, the proportion of consumers who choose the Upgrade and Leapfrog options shrinks, while the proportion of consumers who choose the Adopt and Laggard options expands.

As we can see, the price difference h now plays a role in consumers' adoption choice and thus also affects the diffusion process. Using a similar computation, we find that all the main insights carry over to this extension, as long as the price increase is not dramatic. The overall effect on profit is unclear. The price increase in the second-generation product reduces the total number of adopters of the second generation, and it increases the number of adopters of the first generation because of the inter-generational substitution. Because the second-generation product has its own unique market potential, compared with the baseline case, the smaller number of Leapfroggers may have a significant effect on the diffusion rate of the second-generation product, resulting in more sales loss than can be compensated for by the larger number of adopters of the first-generation product. Therefore, the final effect on profit depends on whether the profit gain from a higher unit price in second-generation product sales can compensate for the profit loss from the cannibalization of second-generation sales from the first-generation product and the profit loss from being unable to attract new sales from the new market. Through our numerical simulation, we find that charging a higher second-generation price usually is unjustified. Although we are not able to analytically characterize the conditions under which the general pricing strategy is optimal, we find that pricing the two products the same usually gives the firm either optimal or close-to-optimal profit. This insight supports the current practice of pricing the new generation of product the same as the previous generation, while discounting the previous generation product price to pick up the remaining market potential.

2. Uncertain Release Time

Now consider the uncertainty involved in the release time of the second-generation product. For simplicity, we assume that with probability θ, the second-generation product will be released at an earlier time $\tau - \varepsilon$, and with probability $1 - \theta$, it will be launched at a later time $\tau + \varepsilon$. The probability of early release, θ, is determined by factors such as a firm's R&D capabilities. We assume θ is ex ante unknown to consumers, and it is uniformly distributed on the interval $[0, 1]$. Accordingly, the expected value of θ is $E\theta = \frac{1}{2}$. Without any information shared between the firm and consumers, and among consumers themselves, consumers make

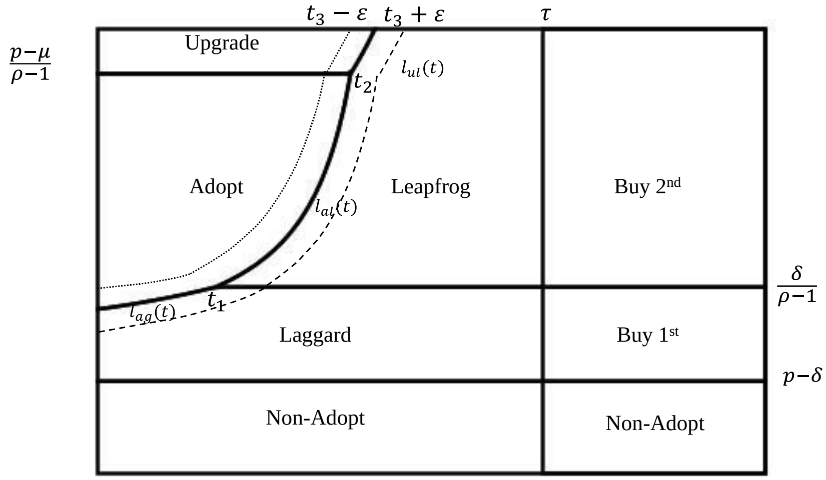

Figure 2: Uncertain Release Time

their wait-or-buy decisions based on their expectation of θ, and the expected release time is $\frac{1}{2}(\tau - \varepsilon) + \frac{1}{2}(\tau + \varepsilon) = \tau$. This is the same expected release time as in the baseline case.

The effect of uncertain release time on market segmentation is illustrated in Figure 2. When the strategic consumers do not have any information about the release time, we have the indifference curves indicated by the solid lines, which is the same as the base model. If the actual release time is $\tau - \varepsilon$ (or $\tau + \varepsilon$), and if the strategic consumers know the actual release time, we have the indifference curves indicated by the dotted lines (or the dashed lines). Note that only in the region where the release time is between the parallel bands defined by the dashed and the dotted lines do consumers make strategic errors because of their lack of information. For example, consider the case that $\theta = 0$; that is, the actual release time is $\tau + \varepsilon$. Consumers who become aware of the first-generation product between the solid lines and the dashed lines (covered in the Leapfrog region) should buy immediately. However, they choose Leapfrog in the absence of true information. In contrast, consumers who become aware of the first-generation product between the dotted lines and the solid lines (covered in the Upgrade and Adopt regions) are not affected.

In contrast to the price commitment, which is purely a strategic decision of the firm, the release time of the newer-generation product is affected by the uncertain R&D process and the newer-generation production technology. Technically, the firm might not be able to fully commit to the release time at the beginning of the planning horizon. In addition, although a commitment to the release time allows the firm to coordinate strategic consumers' actions by synchronizing the expected release time, whether commitment to the release time is beneficial is less clear because its profit consequence is ambiguous. As a result, the firm might choose to commit to its pricing strategy but keep the release time private. This strategy partly reflects the current practices by firms in managing their new product and software releases.

3. Effects of Product Development Cost and Production Cost on Optimal Strategies

New product introduction requires investments in product development and production. In this extension, we look at the effect of product development cost and production cost on the firm's optimal pricing and timing strategies.

When the selling horizon starts, the development cost associated with the first-generation product is sunk. However, the firm incurs some development cost to develop its second-generation product, which can be assumed as a convex function of the product quality improvement ρ. We express the total development cost as $k(\rho-1)^{\gamma}$, where $\gamma \geq 1$ and k is the sensitivity parameter for quality improvement.[1]

To understand the effect of production cost on the firm's strategies and profitability, we make several simplified assumptions. From an operational perspective, especially considering the short product life cycle and the widely adopted practice of international outsourcing, we assume the firm adopts a one-replenishment ordering policy, similar to **?**. Under this policy, the firm places the first order (or completes the production) of a certain amount of the first-generation products to satisfy all demand for the first-generation products at time 0. Then, right before the introduction of the second-generation product (i.e., at time τ), the firm makes the second order (or completes the production) of a certain amount of the second-generation products to satisfy all future demand for the second generation. We let c_1 be the production cost for the first generation. We assume the cost of producing the higher quality second-generation product is more expensive, and the unit production cost is proportional

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[1] We thank the AE and the anonymous reviewer for suggesting this modeling approach.

to its quality improvement. For simplicity, let $c_2 = \rho c_1$. To focus on the insights related to the procurement (or production) cost, we ignore the inventory holding cost because of the short product life cycle. We denote $x_1(T)$ as the total sales of the first-generation product, and $x_2(T)$ and $y_2(T)$ as the total sales of the second-generation product from the competing market and the unique market, respectively. The firm's discounted total profit expression can be modified as:

$$\begin{aligned} \pi_p = \; & \int_0^\tau e^{-rt} p \dot{x}_1(t) dt + e^{-r\tau} (p - \delta) \, g_1(\tau) + e^{-r\tau} p \left[l_1(\tau) + u_1(\tau) \right] + \int_\tau^T e^{-rt} (p - \delta) \dot{x}_1(t) dt \\ & + \int_\tau^T e^{-rt} p [\dot{x}_2(t) + \dot{y}_2(t)] dt - c_1 x_1(T) - e^{-r\tau} c_2 \left[x_2(T) + y_2(T) \right] - k(\rho - 1)^\gamma \end{aligned}$$

Building on the same parameter values as in the main text, we seek to understand how the unit production cost parameters c_1 and c_2 and the quality sensitivity parameter k affect the firm's optimal entry timing and pricing strategies and profit. According to **?**, Apple's \$649 iPhone 6 costs \$200 to make. We assume c_1 =0.05 and 0.08, which account for 20%~35% of the product selling prices in our numerical studies, to represent the low unit production cost and the high unit production cost. For simplicity, let $\gamma = 2$. We assume k =200 and 500 to assess the cost effect of quality improvement, and $\rho = 1.1$ and 1.2, representing a small quality improvement and a large quality improvement.

δ	p	τ (no cost)		τ (with cost)			
		$\rho = 1.1$	$\rho = 1.2$	$\rho = 1.1$		$\rho = 1.2$	
				Low cost	High Cost	Low Cost	High Cost
				$c_1 = 0.05$ $k = 200$	$c_1 = 0.08$ $k = 500$	$c_1 = 0.05$ $k = 200$	$c_1 = 0.08$ $k = 500$
0.02	0.22	4.1	5.6	+0.2	+0.4	+0	+0
	0.23	4.1	4.6	+0.2	+0.3	+0	+0
	0.24	4	4.1	+0.1	+0.2	+0	+0
	0.25	3.8	3.8	+0.1	+0.2	+0	+0
0.05	0.22	4.6	5.3	+0.5	+0.9	+0.5	Never
	0.23	4.4	5.5	+0.6	+1	+0.4	Never
	0.24	3.8	5.7	Now	Now	Never	Never
	0.25	Now	Never	Now	Now	Never	Never

Table 1: Effect of Quality Improvement and Cost Parameters on Optimal Timing Strategies

Table 1 shows the optimal introduction time of the second generation under different price-discount schedules (p, δ). The third and fourth columns present the benchmark case without considering the development cost and production cost. We see that the optimal introduction time decreases as the price increases. As the price discount becomes larger, the rate at which the introduction time decreases in price is faster. Moreover, higher quality improvement favors a later introduction time.

When the cost is considered, the effect of cost parameters on the optimal introduction time is different. A higher unit production cost generally delays the introduction time, while the effect of the quality development sensitivity parameter is insignificant. When both the price and discount are relatively high, a great quality improvement favors a "Never" strategy, while a small quality improvement favors a "Now" strategy, as we see from the last two rows of the table.

δ	p	Revenue (no cost)		Net Profit (with cost)			
		$\rho = 1.1$	$\rho = 1.2$	$\rho = 1.1$		$\rho = 1.2$	
				Low Cost	High Cost	Low Cost	High Cost
				$c_1 = 0.05$ $k = 200$	$c_1 = 0.08$ $k = 500$	$c_1 = 0.05$ $k = 200$	$c_1 = 0.08$ $k = 500$
0.02	0.22	20.79	26.54	14.90	11.12	10.80	12.89
	0.23	21.00	24.81	14.97	11.37	11.42	13.47
	0.24	20.82	23.26	14.66	11.62	11.57	13.72
	0.25	20.41	22.16	14.14	11.81	11.65	13.83
0.05	0.22	18.66	22.01	12.78	11.03	11.16	12.99
	0.23	18.14	22.19	12.18	11.17	11.1	12.96
	0.24	17.53	22.29	11.93	10.54	11.09	12.94
	0.25	17.96	22.33	12.51	10.52	11.07	12.91

Table 2: Effect of Quality Improvement and Cost Parameters on Revenue and Profit

Table 2 shows the the revenue (without considering costs) and the net profit (after taking into account the product development and production costs) corresponding to the optimal introduction times presented in Table 1. When the quality improvement is relatively small (i.e., $\rho = 1.1$) and costs are not considered, the highest revenue is 21 under pricing strategies $p = 0.23$, $\delta = 0.02$, and the introduction time $\tau = 4.1$. When costs are considered, the firm delays the introduction time to $\tau = 4.3$. The optimal pricing strategies remain the same when the unit production cost is relatively low; when the unit production cost is relatively high, the firm charges a higher price, $p = 0.25$, to try to protect its profit margin.

When the quality improvement is relatively large (i.e., $\rho = 1.2$) and costs are not considered, the firm postpones the introduction time of the second generation to near the end of the first-generation life cycle ($\tau = 5.6$ vs. 4.1) and charges a lower price ($p = 0.22$ vs. 0.23). However, if costs are considered, the firm prefers to introduce the second generation earlier ($\tau = 3.8$) and charges a higher price ($p = 0.25$).

In summary, considering cost can significantly affect the firm's optimal pricing and introduction timing. Although the optimal prices might be lower than they are when cost is not considered, the optimal introduction timing tends to be more extreme; that is, more "Now" or "Never" strategies can be found to be optimal.