Provider Output and Downstream Firms' Service Tier Choice

(Authors' names blinded for peer review)

For information and communications technology (ICT) providers, one of the main decisions is output: the menu of service tiers (quality, features, security, and/or reliability) and their corresponding cost to clients. Client firms, on the other hand, need to choose a given service tier from this menu. We study the impact of ICT provider's output on the chosen service tier and profit of downstream firms using a general analytical model. We find that whereas in downstream monopoly (independent firm demands), increased provider output is desirable, this is not necessarily the case if firms have demand externalities. Specifically, a firm's profit decreases with provider's output if firms have large positive externalities (i.e. their demands are complements), as it may drive them to a sub-optimal equilibrium and reduce their profits. In this case, there exists a misalignment of incentives among providers and firms in terms of provider output. Our findings are contrary to the common wisdom and academic literature on provider output and quality, where higher output is always desirable which has important implications for policy makers at the provider level, especially in the context of cybersecurity providers.

Keywords: provider output, ICT provision, service tier, externalities

1. Introduction

Firms often outsource parts of their operations, ranging from product manufacturing and inventory control to enterprise resource planning and customer support. With the proliferation of cloud services, it is convenient for firms to outsource their information and communications technology (ICT) functions, including cloud provision, information security, and customer support. The benefits of using such service providers include efficiencies of scale, access to specialized capabilities, and lower overall cost of services. To appeal to more customer types, providers usually offer a menu of service options made up of several service tier and fee pairs. For example, Google G Suite has three pre-configured tiers (called editions) and additional customized tiers (Google 2020). The quality and/or number of features offered in each tier is determined by the provider output. Providers can improve or deteriorate their output, and thus their offered menu of tiers, by changing their investment in research and development (R&D). Google G Suite, for example, recently added security features such as endpoint management and context aware analysis to it's Enterprise Tier (Table 1). It is generally assumed that, ceteris paribus, as the output of a provider increases, i.e. as it can provide a better service tier for a given fee to downstream firms, it benefits the firms. However, this relationship has not been established in the literature. Using a general economic model, we analytically test this conjecture.

Table 1 New security features offered in Google GSuite in 2020 compared to 2018 (Google 2018, 2020).

	Tier (Edition)		
2020 Feature Additions	**Basic**	**Business**	**Enterprise**
Access control with security key enforcement	New	New	Pre-existing
Advanced Protection Program	New	New	New
Retain, archive and serach data (Vault)		New	New
Endpoint management	New	New	New
Cloud Identity Premium			New
Context aware access			New

An example of such a relationship between firms and providers exists in the context of managed security service providers (MSSPs). Even though many MSSPs provide services in the cloud to their customers, they themselves rely on cloud providers in provisioning their services. For example, threat intelligence platforms make use of a log management tools (such as Logz.io or Sumologic) which themselves are hosted through a cloud provider such as Google Cloud or Amazon Web Services.

In choosing the service tier, firms must balance the extra cost of a higher service tier against the added benefits, such as lower service failures or additional features. In the context of information security, for example, Gordon and Loeb (2002) show that firms should not spend more than $1/e$ of the expected loss to protect vulnerable information assets from breaches; suggesting a threshold where paying more for a higher service tier is inefficient. We examine the impact of demand changes as a result of upstream provider output to determine the conditions under which firms may not benefit from a higher output at the service provider, and how firm profit is impacted by changes in provider output. Contrary to the common wisdom that suggests higher output is always better, we find situations in which firms are hurt by an increase in provider output.

1.1. Literature Review

Quality is an important dimension in supplier selection; however, defining quality is challenging. The quality of a supply chain relationship has been identified as an indicator of firm performance. In this case, better supply chain management or integration activities are seen to lead to better financial outcomes for the contracting firm while specific supplier quality improvement activities (such as Total Quality Management (TQM) at the supplier level) did not have significant impact on firm performance (Al-Abdallah et al. 2014). However, we do not know of any research that specifically shows that a better supplier directly translates to better firm performance.

Quality of the product provided by suppliers is a well-studied dimension in outsourcing. Where firms outsource the complete production of their products, so-called contract manufacturing, there can be a significant degree of ambiguity with respect to quality; ambiguity for which there are no easy quality controls or checks (Gray and Handley 2015). In their work, Gray and Handley (2015) find that while emphasizing quality at the time of supplier selection moderates the quality ambiguity, choosing a single source contract manufacturer increases this ambiguity-quality relationship. "Our findings support the assertion that misalignment (i.e. outsourcing when quality performance ambiguity is high) is associated with inferior performance..." Gray and Handley (2015, p. 51). In essence, Gray and Handley (2015) find that a poorer quality supplier is a bad choice; we are interested in determining whether a higher quality supplier is a good choice. Research has also examined the optimal sourcing policy (single, dual, or multiple suppliers) using aggregate performance measures of both product quality and delivery. For example, where multiple suppliers exist, Shin et al. (2009) are able to identify the optimal set of suppliers to meet quality and delivery requirements.

Researchers have established the use of warranties by businesses to signal quality (Gal-Or 1989). Guarjardo et al. (2016) discuss the impact of product quality and service impacts on consumer demand for that product; illustrating how product quality and the offer of a warranty interact to influence consumer choices, and thus demand, allowing the authors to estimate the willingness to pay for a warranty. Other work examines models of outsourcing and their correlations to product recalls. In particular, Steven et al. (2014) study how supply chain diversification impacts the likelihood of product recalls as a signal of quality failures finding an impact of supply chain design on the likelihood of product recalls and that the nature of the impact is complicated.

Demand changes may occur due to natural disasters, product failures, or even unexpected product popularity; all these factors affect how supply chain members should coordinate to maximize channel profit (Xiao et al. 2007). High-profile breaches such as that experienced by Target have resulted in demand changes, if only for short periods (McGrath 2014). Kolfal et al. (2013) examine how customer demand reaction to security breaches impacts optimal security investment for firms and, in the health care context, breaches of patient records do result in demand changes, but only in a competitive market (Kwon and Johnson 2015). Liu et al. (2015) examine the cloud provider decision regarding the level of security they should offer clients given that security breaches will impact the demand for the provider's service.

In our work, we also examine demand changes and how they impact supply chains. We are interested in the capabilities of a provider and their impact on decisions by downstream client firms.

Extending prior work, we analyze how customer demand for the firm's product and firm profit are affected by the output of service provider. In particular, we address the following questions: How does provider output impact downstream firms' chosen service tier, demand and profit? Is it beneficial for firms to have a high-output provider? Are there conditions under which the provider may want to increase its output, but doing so would hurt the downstream firms' profit?

2. Set-up, Notation and Assumptions

We assume two profit maximizing firms in the downstream, each producing a single product (or service), modeled as a Cournot competition over quality. The firms' products may be independent of each other, that is, each firm may form a monopoly in its market. On the other hand, the products may complement or compete with each other. Consider a simplified example from the information security space. Two MSSP firms sell threat intelligence products to businesses clients (customers). These MSSP firms rely on cloud-hosted infrastructure (ex. log aggregation or data enrichment services) through a service provider such as Amazon Web Services (AWS), Google Cloud, or Microsoft Azure. The provider offers several tiers of service for this infrastructure, where the highest tier has access to the most up-to-date and fully featured version; and the lowest tier has access to less feature-rich version or slower patching. Some providers also allow client firms to select from a marketplace of service offerings, making it possible to define a nearly continuous set of service tier and pricing pairs.

As part of their operation, firms require cloud provision of software or other ICT infrastructure and security services. The provider offers different service tier options, from which each firm chooses. For analytical tractability, we assume the menu to include a continuous set of service tier and fee pairs. The firms choose the tier that maximizes their own profits, based on their customers' demand preferences. The customers do not see the provider's service and make their decision only based on the quality of the firms' products. A higher service tier comes with higher quality of service as captured by a service level agreement (SLA), and is rendered at a higher fee for the service. There is perfect correlation (linear relationship) between service tier and its corresponding fee. For simplicity, we consider service tier and its corresponding fee to be equivalent. Higher service tiers are associated with better quality, for example in terms of delivery, features, support, security, and/or reliability (e.g. service uptime). For clarity of distinction between firm product or service, we consider the provider to produce a service, and the firm to produce a product, noting that these can be either products or services, given that they satisfy our assumptions.

We define the firms' product quality (roughly) as a product characteristic that increases the desirability (willingness to pay) of that product to their target customers and, therefore, the demand for the product. Provider output is defined as the baseline service that a provider can produce. A higher-output provider renders a higher service tier (quality, delivery, features, security and reliability) for a given fee. A firm's product quality is determined both by the provider output and the firm's chosen service tier. Customers observe the firms' product quality, but have no information about the provider output or firms' chosen service tiers. In other words, product quality is the only driver of customers' willingness to pay. The provider sets its output to maximize profit based on its production technology. Firms choose the service tier that maximizes their profit. Figure 1 illustrates the players in our model.

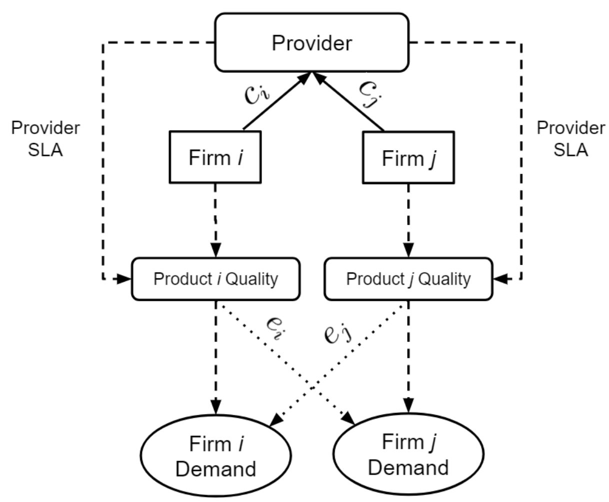

Figure 1 Players and model set-up

Provider output is often a strategic decision. In our model time line, the provider sets its output first, which determines the service menu for firms. Then, the firms choose a service tier from this menu, and the demands are realized. The time line of decisions is depicted in Figure 2.

Provider output can be thought of as the efficiency of the provider in converting firm investment to service tier. We denote provider output as α. All else equal, the higher the provider output, the higher the quality that customers receive. Higher output may be as result of the provider

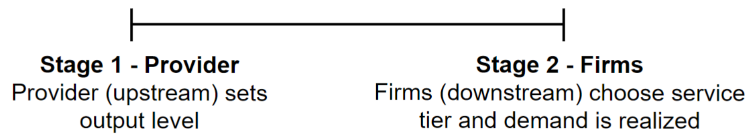

Figure 2 **Time line of decisions**

exerting higher effort and/or through technological progress and R&D. The amount of effort (α), depends on the production technology of the provider (ψ), which is an exogenous characteristic of the provider. The higher the provider's production technology, the lower the cost of achieving a given output. We denote this cost as θ, which is a function of output and production technology.

Assumption 1 (Provider's Cost of Output). Increasing output is costly for the provider, and its cost increases as output increases (convex cost function). Moreover, the higher the production technology of the provider, the lower the cost of achieving a given output.

Using partial derivatives, these can be written as:

$$\theta^{(\alpha)} > 0, \qquad \theta^{(\alpha,\alpha)} > 0, \qquad \theta^{(\psi)} < 0.$$

where $f^{(x)}$ denotes the partial derivative $\partial f/\partial x$ of f with respect to the variable x and $f^{(x,y)}$ denotes the second partial derivative $\partial^2 f/\partial x \partial y$ of f with respect to the variables x and y.

Assumption 2 (Minimum Required Output). There is a minimum required output $\alpha \geq \underline{\alpha} \geq 0$ for the provider.

The minimum requirement may be due to either firms not accepting provider's service with very low output (existence of an outside option or possibility of developing it in-house) or regulation on the minimum service provider quality.

We denote firm i's service tier as $c_i \geq 0$. A higher service tier translates to a higher quality (as dictated in SLA) provided to firm i. This may include higher quality service or additional features. Note that the service tier is not the same as firms' product quality observed by customers. Customers only discover the combined firm product quality, which depends on both provider output and firms' chosen service tier, as illustrated in Figure 1.

The service tier that firms choose, along with the provider output, determines the firms' product quality. Denoting firm i's product quality as Q_i, we have $Q_i = Q_i(c_i, \alpha)$, where $f(x,y)$ denotes that variable f is a function of variables x and y. Due to the interdependency of firms' demand (competition or complementarity), each firm's demand also depends on the other firm's product quality. Therefore, a firm's demand depends on the quality of both firms' products. Demand also depends on the price or gross margin for the product, denoted as p. Therefore, firm i's demand can be characterized as $D_i = D_i(Q_i(c_i, \alpha), Q_j(c_j, \alpha), p)$, $\forall i, j = 1, 2$, $i \neq j$. In order to simplify our notation, we reduce our demand function and incorporate product quality into the demand function. In other words, we take demand as a function of provider output and firms' service tiers, without directly considering the firms' product quality:

$$D_i = D_i(c_i, c_j, \alpha, p), \qquad \forall i, j = 1, 2 \ , \ i \neq j, \tag{1}$$

This simplification is without loss of generality. Our results hold as long as our assumptions on the demand function are satisfied.

A higher service tier enables firms to deliver a higher quality product to customers, which is assumed to monotonically increase the demand due to an increase in customers' willingness to pay.

Assumption 3 (Firm Service Tier). Each firm's demand is a non-decreasing and concave function of its chosen service tier.

Using partial derivatives, this can be described as $D_i^{(c_i)} \geq 0$ and $D_i^{(c_i, c_i)} < 0$, $\forall i = 1, 2$.

Assumption 4 (Provider Output and Firm Demand). Keeping firm's chosen service tier fixed, a firm's demand increases with provider output.

This can be shown as $D_i^{(\alpha)} > 0, \forall i = 1, 2$. Note that this is assuming everything else, including firm's service tier, is held constant (note the use of partial derivative). However, firms react to changes in provider output (α) by changing their service tier (c_i). The relationship of provider output and demand is, therefore, an indirect one, which we discuss in this paper.

Assumption 5 (Provider Output and Service Tier). The marginal increase in demand from a firm's own investment in service tier diminishes as provider output increases. In other words, the provider output and firms' chosen tier are substitutes.

This is due to decreasing marginal returns as output increases, similar to the impact of own investment in service tier on the rate of increase in demand. A firm's product quality and demand improve if either provider output or its service tier increase, i.e. these are substitutes. Using cross-partial derivatives, this can be described as $D_i^{(c_i,\alpha)} < 0$, $\forall i = 1,2$.

Firms may have *externalities* in their demands. We define externalities as the change in a firm's demand due to the other firm's service tier:

$$e_j = D_i^{(c_j)} = \frac{\partial D_i}{\partial c_j}, \qquad \forall i,j = 1,2\ ,\ i \neq j. \tag{2}$$

Assumption 6 (Demand Externalities). Each firm's demand is an increasing and concave function of the other firm's service tier if firms have *positive externalities* ($e > 0$), and is a decreasing and concave function of the other firm's service tier if firms have *negative externalities* ($e < 0$). If there are no externalities ($e = 0$), then the firms' demands are independent.

Concavity implies $e_j^{(c_j)} = D_i^{(c_j,c_j)} < 0$, $\forall i,j = 1,2\ ,\ i \neq j$. If externalities are positive ($e > 0$), one firm's higher service tier has a positive effect on the demand of the other firm. This is the case where firms' products are strategic complements. When externalities are negative ($e < 0$), one firm's higher service tier has a negative effect on demand of the other firm, which is the case where firms' products compete or are strategic substitutes. If there are no externalities ($e = 0$), firms' service tiers do not impact one another's demand, in other words, firms operate in monopoly markets in terms of their demands.

We extend this assumption to include the impact of the other firm's service tier on the marginal change in own demand. We assume the marginal increase or decrease in demand due to own service tier as the other firm's service tier increases to be decreasing. Using cross-partial derivatives, this can be described as $e_j^{(c_i)} = D_i^{(c_i,c_j)} \leq 0$, $\forall i,j = 1,2\ ,\ i \neq j$.

Assumption 7 (Dominance of Own Service Tier). The demand effect of one firm's own service tier is larger than the effect of the other firm's service tier.
This implies $D_i^{(c_i)} > |e_j|$, $\forall i,j = 1,2\ ,\ i \neq j$.

Assumption 8 (Demand Symmetry). The firms face the same demand function.

In other words, we have $D_1 = D_2$. This implies:

$$e_i = e_j \equiv e, \quad D_i^{(c_i)} = D_j^{(c_j)}, \quad D_i^{(c_i,c_i)} = D_j^{(c_j,c_j)},$$
$$D_i^{(c_i,c_j)} = D_j^{(c_j,c_i)}, \quad D_i^{(c_i,\alpha)} = D_j^{(c_j,\alpha)}, \quad \forall i,j = 1,2\ ,\ i \neq j. \tag{3}$$

We assume the price or gross margin of the firms' product to be fixed. This is the case where the firms do not have market power and are price-takers.

Assumption 9 (Fixed Gross Margin). The gross margin of both firms' products are fixed at p. Gross margin is larger than equilibrium service tier as a participation constraint.

The margin for a firm is derived by subtracting its investment in service tier from its gross margin. Even though it is often interesting to analyze price-making firms, we fix the gross margin for tractability of the model and in order to analyze interactions between providers and firms in terms of output and service tier. We show that for firms to participate, we need to have $p \geq D_i/D_i^{(c_i)},\ \forall i = 1,2$.

Assumption 10 (Complete Information). All model parameters are known to both firms.

By not considering information asymmetry, we focus on our main research topic, which is the impact of provider output on downstream firms.

Firms are profit maximizers. Each firm's profit is derived as:

$$\Pi_i = D_i(c_i, c_j, \alpha, p)[p - c_i], \qquad \forall i,j = 1,2\ ,\ i \neq j, \tag{4}$$

In our notation, for brevity, we suppress the function variables in some equations, and depending on the function, use $(.) \equiv (c_i, c_j, \alpha, p)$ or $(.) \equiv (\alpha, p)$, and $(.^*) \equiv (c_i^*, c_j^*, \alpha, p)$.

As we take investment in service tier and service tier to be equivalent, the service tier from firms is the revenue that the provider receives. The provider profit is therefore derived as:

$$\Pi_S = \sum_{i=1,2} D_i^*(\alpha, p) c_i^* - \theta(\alpha, \psi), \tag{5}$$

where $\theta(\alpha, \psi)$ is the cost of output level α, which depends on the production technology of the provider (ψ). Our notation is provided in Table 2.

Table 2 Notation

Variable	Description
c_i	Firm i's service tier, $i = 1, 2$
α	Provider output, $\alpha \geq \underline{\alpha} \geq 0$
ψ	Provider's production technology
θ	Cost of output
D_i	Firm i's demand (demand for firm i's product)
Q_i	Firm i's product quality
$e_j = D_i^{(c_j)}$	Demand externality
p	Gross margin: unit profit for firm's products before service tier investment
Π_i	Firm i's profit, $i = 1, 2$
Π_S	Provider's profit

3. Analysis and Results

The provider sets its output in Stage 1, and firms choose their service tier in Stage 2. We use backward induction to find the equilibrium solution to this problem, i.e. first find the equilibrium firm service tiers, and then the provider output.

3.1. Firms' Chosen Service Tier (Stage 2)

The firms choose the service tier (c_i) that maximizes their profit. Note that gross margin (p) is exogenous and symmetric in our model (Assumption 9). The first-order conditions at the optimal service tier $c_i^*(\alpha, p)$, when they exist, are as follows:

$$\frac{d\Pi_i(.^*)}{dc_i(.)} = [p - c_i^*(.)]D_i^{(c_i)}(.^*) - D_i(.^*) = 0, \qquad \forall i, j = 1, 2\ ,\ i \neq j. \tag{6}$$

We assume a non-negative service tier ($c_i \geq 0$). From (6), we have $c_i^*(.) = p - D_i(.^*)/D_i^{(c_i)}(.^*)$, $\forall i, j = 1, 2$. From Assumption 9, we have $p \geq D_i(.^*)/D_i^{(c_i)}(.^*)$, $\forall i, j = 1, 2$.

The second-order conditions are derived as:

$$\frac{d^2\Pi_i(.^*)}{dc_i^2(.)} = [p - c_i^*(.)]D_i^{(c_i,c_i)}(.^*) - 2D_i^{(c_i)}(.^*) < 0, \qquad \forall i,j = 1,2\ ,\ i \neq j. \tag{7}$$

This is negative, because $p - c_i^*(.)$ and $D_i^{(c_i)}(.^*)$ are positive, and $D_i^{(c_i,c_i)}(.^*)$ is negative. Therefore, the profit function is concave. We assume an interior solution. Moreover, due to symmetry (Assumption 8), we have:

$$c_i^*(.) = c_j^*(.) = p - \frac{D_i(.^*)}{D_i^{(c_i)}(.^*)}, \qquad \forall i,j = 1,2\ ,\ i \neq j. \tag{8}$$

This implies that in the symmetric setting, as expected, firms choose the same service tier. The simultaneous first-order conditions in (6) define a Nash equilibrium in firms' service tiers.

LEMMA 1 **(Firms' Chosen Service Tier)**. *Firms' chosen service tier decreases with provider output.*

Proofs are provided in Appendix A.

Firms choose a lower service tier in response to higher provider output, due them being substitutes. The intuition for this is that firms have an objective for the final product quality (that the customers receive), and they adjust the service tier to achieve that quality. As the provider output increases, firms can choose a lower service tier, and keep the product quality at the profit-maximizing level. Because the end customer does not observe the provider's output, they do not expect the improvements to be passed along to them (i.e. the demand curve does not shift).[1] As the provider's output and its menu of service tiers improves, a threat intelligence firm, for example, may not need access to the highest tier of cloud-hosted log processing software to be able to meet the end-client's needs and maximize its profit. Therefore, as the upstream provider's service tiers improve, the firms may select a lower tier to maintain product quality.

[1] One can think about a different scenario in which α represents improvements in technology, and customers which expect better products as a result of this technology improvement. This can be the case, for example, in the smartphone industry, where customers expect improvements in products as a result of increased output over time. In this paper, however, we do not consider such scenarios. We consider the customer demand to be ignorant of the improvements made at the provider level, meaning that their expectations are fixed.

LEMMA 2 **(Demand)**. *Firms' demand increases with provider output if the direct impact of provider output on demand is large ($D_i^{(\alpha)}(.^*) > K$) and decreases with it if the direct impact of provider output on demand is small ($D_i^{(\alpha)}(.^*) < K$), where* $K = \frac{D_i^{(c_i,\alpha)}(.^*)[p-c_i^*(.)][D_i^{(c_i)}(.^*)+D_i^{(c_j)}(.^*)]}{[p-c_i^*(.)][D_i^{(c_i,c_i)}(.^*)+D_i^{(c_i,c_j)}(.^*)]-D_i^{(c_i)}(.^*)}$.

This implies that if $D_i^{(\alpha)}(.^*)$ is sufficiently high, then the demand increases as α increases. However, if $D_i^{(\alpha)}(.^*)$ is low, then the negative effect of reduced service tier on demand is higher than the positive effect of increased provider output on demand, and therefore, the overall effect is that the demand decreases. This finding is intuitive. If the quality of final product that customers receive depends heavily on the quality of service from the provider, then the firms' demand increases with provider output. This also implies that as provider output increases, the quality of firm's product does not necessarily improve (quality drives the demand). In the cybersecurity context, this suggests that the security that customers receive may decrease as the service provider offers an improved menu of service tiers.

LEMMA 3 **(Firm Profit)**. *If there are no externalities (independent firms), externalities are negative (demand substitutes), or externalities are positive but small (weak demand complements), then firm profit increases with provider output. On the other hand, if externalities are positive and large (strong strategic complements), then firm profit decreases with provider output.*

If firms' demands are independent (no demand externality), as provider output increases, whether the optimal demand increases or decreases, the net effect of change in demand and decreased service tier is that firms' profit increases. Further, this increase depends on the direct impact of α on demand ($D^{(\alpha)}$, everything else kept constant) and the marginal profit of the firm at the chosen service tier. Where firms' demands are independent, they prefer higher provider output.

If an externality exists, other than the direct impact of provider output on demand or $D_i^{(\alpha)}$ (everything else, especially service tier, kept constant), the change in profit due to increased provider output also depends on the externality between firm demands. If there is a negative or small positive externality ($e_i < -D_i^{(\alpha)}(.^*)/[dc_j^*/d\alpha]$), then firms' profits increase with provider output. On the other hand, if there is a high positive externality ($e_i \geq -D_i^{(\alpha)}(.^*)/[dc_j^*/d\alpha]$), then profits decrease with provider output. This implies an interesting phenomenon where in some settings with demand complementarity, the positive impact on profit of increased margin (decreased service tier) is overshadowed by the negative impact on profit of decreased demand. This behaviour does not occur if firms' products are substitutes.

3.2. Provider Output (Stage 1)

In Stage 1, the provider sets its output. The provider profit function is given as:

$$\Pi_S =$$
$$c_1^*(\alpha,p)D_1^*(\alpha,p)+c_2^*(\alpha,p)D_2^*(\alpha,p)-\theta(\alpha,\psi)=2c_1^*(\alpha,p)D(c_1^*(\alpha,p),c_2^*(\alpha,p),\alpha,p)-\theta(\alpha,\psi). \quad (9)$$

The provider sets $\alpha^\star$ which maximizes its profit, i.e. $\alpha^\star = \text{argmax}_\alpha \Pi_S$.

LEMMA 4 **(Provider Output)**. *(a) If provider's profit is concave in its output (second-order condition is satisfied,* $d^2\Pi_S(.^{*,\star})/d\alpha^2 < 0$*) and* $\alpha^\star = \text{argmax}_\alpha \Pi_S \geq \underline{\alpha}$*, the provider sets an optimal level of output which maximizes its profit.*
(b) Otherwise, the provider has no incentive to increase α*, and would therefore set it to the minimum value* $\alpha = \underline{\alpha}$*.*

Lemma 4 provides the general conditions for provider output being higher than the minimum required output. These conditions, however, cannot be further simplified. Nevertheless, we can consider some interesting insights. We can confirm that in the case where demand decreases with provider output ($dD_i^*(\alpha,p)/d\alpha < 0$, that is if $D_i^{(\alpha)}(.) < K$ from Lemma 2), the provider has no incentive to increase α. This is because both its demand (which is the sum of demands firms, $D_1^* + D_2^*$) and service tier investments it receives (c_i^*) decrease with provider output (α). Moreover, there is a cost to increasing output. In this case, the provider sets output to the minimum required output ($\underline{\alpha}$). The low provider output may be either beneficial or detrimental to the firms, depending on the demand externality (discussed in Lemma 3).

On the other hand, if demand increases with provider output ($dD_i^*(\alpha,p)/d\alpha > 0$, that is if $D_i^{(\alpha)}(.) > K$ from Lemma 2), then the provider may have an incentive to increase α, and this depends on the relative change in service tiers (c_i^*) and demands (D_i^*) from firms, and provider's cost of output (θ) with respect to output (α). If conditions in *(a)* are met, the provider sets its output above the minimum required output ($\alpha \geq \underline{\alpha}$). Here, the additional revenue that the provider receives due to increased demand for its service is larger than the reduced revenue due to reduced service tier and increased cost of output. The higher provider output may be either beneficial or detrimental to the firms, depending on their demand externality.

PROPOSITION 1 **(Provider Output and Firm Profit)**. *There are conditions under which the provider sets its output to $\alpha^\star > \underline{\alpha}$, and this increase in provider output harms the downstream firms' profits if their externalities are positive and large (strong demand complementarities).*

The conditions for the first part of Proposition 1 (provider sets an output higher than the minimum required) come from Lemma 4, and for the second part (whether the increased output hurts firms' profits) come from Lemma 3. This proposition outlines that in certain conditions, it is detrimental to the industry to have a provider that sets its output higher than the minimum required output. This demonstrates the possibility of a scenario where provider and firms' incentives are misaligned: the provider sets a high output, which hurts downstream firms' profit.

4. Discussion and Conclusion

Providers in different industries, and especially in the domain of ICT, strive to continually improve their service offerings. Firms, facing a menu of offered services, choose the service tier that maximizes their profit. We study the impact of provider output on the downstream firms' chosen service tier, as well as on firm demand and profit. We show that whereas in the case that firms' demands are independent, increased provider output is beneficial, this is not necessarily the case if firms have demand externalities. Specifically, if firms experience large positive externalities (e.g. they offer complementary products), increased output may drive firms to a sub-optimal equilibrium and yield lower profit. We demonstrate the possibility of a scenario where provider and firms' incentives are misaligned, where the provider sets a high output and this hurts downstream firms' profit.

We reveal an interesting and counter-intuitive phenomenon on the relationship of providers and firms in terms of output and service tier. Contrary to the common wisdom that suggests higher output is always better, we find that there are situations in which it is rational for firms to have a provider with lower output. Additionally, our findings have implications for policymakers, who may be able to control this misalignment using regulation on provider selection in industries where strong complementarities exist.

In the context of cybersecurity, this work may explain why firms are slow to adopt secure services. Although a provider may be able to improve their security output or service offerings, the firm may not be able to incorporate the additional features in their own product. We also show that as the provider output increases, firms may end up at an equilibrium where the overall security level that customers receive is lower. This has important implications for policy makers to ensure adequate security of products.

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Appendix A: Proofs

Lemma 1

Taking the derivative of first order conditions in (6) with respect to provider output (α) and using the chain rule we have:

$$\frac{d[\frac{d\Pi_i(.^*)}{dc_i(.)}]}{d\alpha} = \frac{d^2\Pi_i(.^*)}{dc_i^2}\frac{dc_i^*}{d\alpha} + \frac{d^2\Pi_i(.^*)}{dc_i dc_j}\frac{dc_j^*}{d\alpha} + \frac{d^2\Pi_i(.^*)}{dc_i d\alpha} = [[p - c_i^*(.)]D_i^{(c_i,c_i)}(.^*) - 2D_i^{(c_i)}(.^*)]\frac{dc_i^*}{d\alpha}$$
$$+ [[p - c_i^*(.)]D_i^{(c_i,c_j)}(.^*) - D_i^{(c_j)}(.^*)]\frac{dc_j^*}{d\alpha} + [p - c_i^*(.)]D_i^{(c_i,\alpha)}(.^*) - D_i^{(\alpha)}(.^*) = 0,\ \forall i,j = 1,2\ ,\ i \neq j. \quad (10)$$

Using the system of equations in (10), we can derive the impact of provider output on firm investments as follows:

$$\frac{dc_i^*}{d\alpha} = \frac{[[p-c_j^*]D_j^{(c_j,\alpha)} - D_j^{(\alpha)}][[p-c_i^*]D_i^{(c_i,c_j)} - D_i^{(c_j)}] + [[p-c_i^*]D_i^{(c_i,\alpha)} - D_i^{(\alpha)}][[p-c_j^*]D_j^{(c_j,c_j)} - 2D_j^{(c_j)}]}{[[p-c_i^*]D_i^{(c_i,c_j)} - D_i^{(c_j)}][[p-c_j^*]D_j^{(c_j,c_i)} - D_j^{(c_i)}] - [[p-c_i^*]D_i^{(c_i,c_i)} - 2D_i^{(c_i)}][[p-c_j^*]D_j^{(c_j,c_j)} - 2D_j^{(c_j)}]} \quad \forall i,j=1,2\ ,\ i\neq j. \quad (11)$$

Due to symmetric firm demands (Assumption 8) and substituting the service tier from (8), this can be derived as:

$$\frac{dc_i^*}{d\alpha} = \frac{[p-c_i^*(.)]D_i^{(c_i,\alpha)}(.^*) - D_i^{(\alpha)}(.^*)}{2D_i^{(c_i)}(.^*) + D_i^{(c_j)}(.^*) - [p-c_i^*(.)][D_i^{(c_i,c_i)}(.^*) + D_i^{(c_i,c_j)}(.^*)]} \quad \forall i,j = 1,2 \quad , \quad i \neq j. \quad (12)$$

We know from Assumptions 4 and 5 that $D_i^{(\alpha)} > 0$ and $D_i^{(c_i,\alpha)} < 0$, and from Assumption 7 that $D_i^{(c_i)} > |e_j|$. Further, we know that $D_i^{(c_i,c_i)} < 0$ and $D_i^{(c_i,c_j)} < 0$ from Assumptions 3 and 6, respectively. Therefore, $dc_i^*/d\alpha < 0$. Q.E.D.

Lemma 2

We know from the first order conditions (6) that $D_i^*(.) \equiv D_i(.^*) = [p-c_i^*(.)]D_i^{(c_i)}(.^*)$. Taking the derivative of this with respect to provider output we have:

$$\begin{aligned}\frac{d}{d\alpha}D_i^*(.) = \frac{d}{d\alpha}D_i(.^*) &= [p-c_i^*(.)][D_i^{(c_i,c_i)}(.^*)\frac{dc_i^*}{d\alpha} + D_i^{(c_i,c_j)}(.^*)\frac{dc_j^*}{d\alpha} + D_i^{(c_i,\alpha)}(.^*)] - D_i^{(c_i)}(.^*)\frac{dc_i^*}{d\alpha} \\ &= \frac{dc_i^*}{d\alpha}[[p-c_i^*(.)]D_i^{(c_i,c_i)}(.^*) - D_i^{(c_i)}(.^*)] + [p-c_i^*(.)][D_i^{(c_i,c_j)}(.^*)\frac{dc_j^*}{d\alpha} + D_i^{(c_i,\alpha)}(.^*)]. \quad (13)\end{aligned}$$

We can then substitute for $dc_j^*/d\alpha = dc_i^*/d\alpha$ (due to symmetry) in (12) to get:

$$\frac{d}{d\alpha}D_i^*(\alpha,p) = \frac{D_i^{(\alpha)}(.^*)[D_i^{(c_i)}(.^*) - [p-c_i^*(.)][D_i^{(c_i,c_i)}(.^*) + D_i^{(c_i,c_j)}(.^*)]] + D_i^{(c_i,\alpha)}(.^*)[p-c_i^*(.)][D_i^{(c_i)}(.^*) + D_i^{(c_j)}(.^*)]}{2D_i^{(c_i)}(.^*) + D_i^{(c_j)}(.^*) - [p-c_i^*(.)][D_i^{(c_i,c_i)}(.^*) + D_i^{(c_i,c_j)}(.^*)]} \quad \forall i,j=1,2\ ,\ i\neq j. \quad (14)$$

This is positive when $D_i^{(\alpha)}(.^*) > K > 0$. Q.E.D.

Lemma 3

We define $\Pi^*(.) \equiv \Pi(.^*)$. Taking the derivative of the optimal profit (4) with respect to provider output we have:

$$\frac{d}{d\alpha}\Pi_i^*(.) = \frac{d}{d\alpha}\Pi_i(.^*) = \Pi_i^{(c_i)}(.^*)\frac{dc_i^*}{d\alpha} + \Pi_i^{(c_j)}(.^*)\frac{dc_j^*}{d\alpha} + \Pi_i^{(\alpha)}(.^*) = [p - c_i^*(.)][D_i^{(c_j)}(.^*)\frac{dc_j^*}{d\alpha} + D_i^{(\alpha)}(.^*)],$$

$$\forall i, j = 1, 2\ ,\ i \neq j. \quad (15)$$

We know from Assumptions 4 and 9 that $D_i^{(\alpha)}(.^*) > 0$ and $p - c_i^*(.) \geq 0$, respectively. Further, from Lemma 1, we know that $dc_j^*/d\alpha < 0$. Therefore, $d\Pi_i^*(.)/d\alpha < 0$ only if $e_i \geq -D_i^{(\alpha)}(.^*)/[dc_j^*/d\alpha]$. Q.E.D.

Lemma 4

This lemma lays out the conditions for having an optimal provider output ($\alpha^\star$) that maximizes provider's profit. These conditions cannot be further simplified.

Proposition 1

These results are directly derived from Lemmas 3 and 4.