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Yongmin Chen, Xinyu Hua, Keith E. Maskus

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International Protection of Consumer Data

Abstract

We study the international protection of consumer data in a model where data usage benefits firms at the expense of their customers. We show that a multinational firm does not balance this trade-off efficiently if its data usage lacks (full) transparency or if consumers' privacy preference differs across countries. Unilateral data regulation by each country addresses the moral-hazard problem associated with opacity, but may nevertheless reduce global welfare due to cross-country externalities that distort output and data usage. The regulations may also cause excessive investment in data localization, even though localization mitigates the externalities. Our findings highlight the need for international coordination. though not necessarily uniformity. on regulations about data usage and protection.

JEL-Codes: L150, L860, F120.

Keywords: consumer data, data usage, privacy, multinational firm, regulation, data localization, international coordination.

Yongmin Chen
University of Colorado / Boulder / USA
yongmin.chen@colorado.edu

Xinyu Hua
Hong Kong University of Science and Technology / Hong Kong
xyhua@ust.hk

Keith E. Maskus
University of Colorado / Boulder / USA
keith.maskus@colorado.edu

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1. INTRODUCTION

A central concern in the digital economy is how to protect consumer data. Digital technologies and the Internet have enabled firms to collect, transmit, and use consumer data for a variety of purposes, ranging from targeted advertising and price discrimination to the design of tailor-made products, bringing new revenue streams to firms. A recent survey estimated that the value of the global data market reached $26 billion in 2019 with an annual growth rate of more than 20%.[1] However, consumers may suffer from the collection and usage of their data by firms, possibly from loss of privacy, unwanted advertising, higher prices due to price discrimination, and security fraud. It was estimated that displayed advertising alone accounted for 18%-79% of data costs for mobile plan users in the United States in 2016.[2] According to government reports, companies use big data for differential pricing that can harm consumers and potentially could require regulation.[3] Moreover, a survey in 2016 showed that 15.4 million U.S. consumers suffered from identity theft and fraud with a total loss of about $16 billion during that year.[4]

Because consumers' demand for a firm's product depends on how the firm treats their personal information, the firm may take actions to (partially) respond to consumers' concerns about data protection by, for example, investing in data safety and obtaining consumers' consent for data collection and usage. The economics and legal literature, discussed below, has investigated the various ways in which firms may utilize consumer data, their incentives and ability to protect data, and data protection regulation. However, there has been little formal analysis of the usage and protection of data when firms sell products in multiple

[1] https://www.onaudience.com/files/OnAudience.com_Global_Data_Market_Size_2017-2019.pdf. The estimation only included the direct value of consumer data transactions. The indirect value from using consumer data was much higher. For example, the value of digital display advertising in 2019 was about $120 billion.

[2] https://www.techdirt.com/articles/20160317/09274333934/why-are-people-using-ad-blockers-ads-can-eat-up-to-79-mobile-data-allotments.shtml.

[3] https://obamawhitehouse.archives.gov/sites/default/files/whitehouse_files/docs/Big_Data_Report_Nonembargo_v2.pdf.

[4] Javelin Strategy & Research: www.javelinstrategy.com.

countries. This is so even though multinational firms play crucial roles in many consumer markets, there are substantial international differences in privacy concerns, and countries vary significantly in data protection regulations. According to a survey in 2018, about 60% of consumers in the United States and Spain are data pragmatists, who would evaluate whether the service is worth the information requested, but such users comprise only 40% in Germany and the Netherlands. At the same time, a larger percentage of consumers in the European countries surveyed are data fundamentalists, who are unwilling to provide personal information, than consumers in the United States.[5] Regulators in various countries have taken different stands in imposing rules on data usage and data protection. In 2018, the European Union enacted the General Data Protection Regulation (GDPR), which imposes significant burdens on firms to notify consumers about data collection and usage and to take effort in data protection. At the other extreme, about 42% of countries still do not have legislation or regulation on data usage and protection.[6]

Moreover, different regulatory requirements in data use have become a front-line issue in international trade, revolving around limitations on the ability of service providers to transmit consumer data across borders. For example, the European Union requires foreign firms to demonstrate that their treatment of data is essentially equivalent to EU standards to qualify for "safe harbor" status and receive such transmission rights. A major concern is the increasing tendency of countries to require data localization directly or indirectly by imposing stringent data regulations (Aaronson and Leblond, 2018; the United States International Trade Commission, 2014).[7]

The complexity of data usage and protection in the international context raises several important analytical questions. What are the incentives of a multinational firm to collect, use, and protect consumer data? When countries with varying preferences introduce data

[5] http://www.globaldma.com/wp-content/uploads/2018/05/Global-data-privacy-report-FINAL.pdf. As argued by Bellman et. al. (2004), such international differences in privacy concerns may be related to different online experiences, cultural differences, and variations of regulation or other protections.

[6] https://www.consumersinternational.org/media/155133/gdpr-briefing.pdf

[7] The recently negotiated US-Mexico-Canada Free Trade Agreement precludes the use of localization requirements.

regulations, what will be the equilibrium non-cooperative standards and how would such regulations affect global welfare? What is the scope for coordinated regulatory approaches that might improve welfare? We conduct an economic analysis of these issues in this paper.

We consider a multinational firm selling a digitally-enabled product in two countries. The firm obtains personal data when consumers purchase the product and can profitably utilize the data through, for example, data sales, price discrimination, or targeted advertising. In our base model, the firm chooses a common level of data usage in the two countries. A larger usage level generates higher data revenue but also greater disutility to consumers. We assume that the firm's choice of data usage has two components, one observable to consumers before product purchase and another that is not. This is a convenient way of modeling the transparency of—or the firm's ability to commit publicly to—data usage. The firm also sets (possibly different) prices in the two countries, whereas consumers will consider, in addition to price, their utility from the product and disutility from the firm's data usage when making purchasing decisions.

If the firm's chosen data-usage level were fully observable to consumers before purchase, and if additionally consumers in the two countries had the same preference for privacy, the firm would fully internalize consumer disutility in selecting its desired data usage, which would coincide with the global optimum. However, the equilibrium choice of data usage often departs from the efficient level (from the global perspective) for two reasons. First, when consumers cannot fully observe how and to what extent their data will be used, the firm suffers from the moral-hazard problem of expanding data use beyond the efficient level.[8] Second, when consumers in one country have larger disutility from data usage than those in the other country, the firm is unable to balance properly the revenue from data usage and consumer disutility, even if it could commit to any level of usage common to both countries. The firm's use of data can then be inefficiently excessive or deficient, depending on the property of demand curvature. Moreover, increasing the transparency of the firm's data usage can have a non-monotonic impact on global welfare, possibly first increasing and

[8] In equilibrium, however, consumers correctly anticipate the firm's choice and thus have a lower willingness to pay for the product.

then decreasing.

We further consider the possibility that the two countries can regulate the use or protection of consumer data by unilaterally imposing caps on data-usage levels. We show that such caps enable the firm to commit to lower data usage and can therefore improve global welfare, but the regulations could also exacerbate equilibrium distortions. In particular, a country with a larger consumer disutility for data usage would not internalize the negative impact of a more restrictive regulation on output and data usage in the other country. We demonstrate that equilibrium data regulations increase global welfare when transparency of data usage is low and consumer privacy concerns are not too different across countries, but can reduce welfare otherwise; and we show how the welfare effects of regulations may also depend on demand curvature properties. Furthermore, we provide conditions under which international coordination of data-protection regimes may or may not achieve (full) global efficiency.

A firm can sometimes invest in data localization, which allows it to choose a data usage level specific to a country, avoiding the mingling of data across countries. The firm can benefit from this option, but in equilibrium, it does not internalize the full benefits of data localization and therefore its private incentive to make the investment can be inefficiently low. While unilateral data-usage regulations strengthen the firm's incentives to invest in localization, it is also possible that they cause (inefficiently) excessive investment and reduce welfare in equilibrium.

Overall, our analysis reveals that unilateral data regulations can either raise or reduce global welfare, depending on the transparency level of data usage, the cross-country difference in privacy preference, and the properties of demand for the product. The analysis shows that there can be substantial gains from international coordination in data regulations, though a uniform level of data usage need not be globally optimal.

Our paper contributes to the literature on personal data and consumer privacy (see the review by Acquisti, Taylor, and Wagman, 2016). The debate over whether the regulatory protection of personal information is socially beneficial or harmful traces back to Hirshleifer (1980), Stigler (1980), and Posner (1981). Later theoretical studies on consumer data and privacy include two strands. First, there is a substantial literature on price discrimination based on consumer past purchases (or behavioral price discrimination) and how it relates to consumer privacy. In early contributions (Chen, 1997; Fudenberg and Tirole, 2000; Villas-Boas, 2004), a firm's price discrimination is based on its own information regarding whether a customer previously patronized itself or a rival. Taylor (2004) provides an original analysis of history-based price discrimination where firms can obtain consumer data from other firms. He identifies privacy as a key issue when there is a market for personal information.[9] Conitzer, Taylor, and Wagman (2012) suggest that firms have incentives to protect consumer privacy or data even without the intervention of regulations. The usage of personal data for price discrimination can also motivate mergers (Campbell, Goldfarb, and Tucker, 2015; Kim, Wagman, and Wickelgren, 2019).

A second strand of the literature explores benefits and costs when firms use personal data to improve marketing or matching between products and consumers. Van Zandt (2004), Hann et al., (2008), Armstrong, Vickers, and Zhou (2009), Anderson and de Palma (2012), and Johnson (2013) discuss how privacy costs affect consumer behavior and firm decisions on targeted advertising. Moreover, targeted advertising can increase or decrease product prices, competition among sellers, and/or competition between online and offline media (Roy, 2000; Esteban, Gil, and Hernandez, 2001; Iyer, Soberman, and Villas-Boas, 2005; Chen, 2006; Gaelotti and Moraga-Gonzalez, 2008; Athey and Gans, 2010; Athey, Calvano, and Gans, 2012; de Cornière, 2013; Shy and Stenbacka, 2015). Similarly, data intermediaries can use data to match firms and consumers (Hagiu and Jullien, 2011; Bergemann and Bonatti, 2011; Zhang, 2011; de Cornière and de Nijs, 2016).

We contribute to the above literature in several ways. Unlike the existing literature's focus on a single market, we analyze the firm's data strategy involving multiple markets. We show that a firm's choice of data-usage level can be inefficiently high or low in a particular country, even when its choice is observable to consumers before their purchases. Also, by examining equilibrium data regulations across countries, we identify the regulatory externalities that

[9] For related contributions, see, for example, Calzolari and Pavan (2006); Kim and Choi (2010); Conitzer, Taylor, and Wagman (2012)

may prevent the efficient protection of consumer data in the global economy and highlight the potential gains from international policy coordination.[10] Moreover, we shed light on the issue of data localization in international trade, as noted earlier, by showing how data regulations may improve or worsen market efficiency when firms have the option of data localization.

The rest of the paper is organized as follows. Section 2 presents our baseline model. Section 3 characterizes the market equilibrium and compares the equilibrium data usage chosen by the firm with the efficient level. Section 4 incorporates data regulations into the model and examines equilibrium regulations that are unilaterally chosen by each country. Section 5 considers the possibility that the firm can invest in data localization, and examines the effects of data regulation in this context. Section 6 discusses some additional extensions. Section 7 concludes.

2. THE BASELINE MODEL

There are two countries, Home (H) and Foreign (F). A multinational firm, located in H, sells a (digitally-enabled) product at prices p_H and p_F respectively in the two countries. We normalize the firm's production cost to 0. A consumer in each country demands one unit of the product and derives a value u, which is a random draw from a probability distribution $g(u) > 0$ with cumulative density $G(u)$ on the support $[\underline{u}, \bar{u}]$, where $0 \leq \underline{u} < \bar{u} \leq \infty$. The mass of consumers is λ in country H and $1 - \lambda$ in country F, with $\lambda \in (0, 1)$.

The transaction of the product brings data about consumers to the firm. The firm can use the data as a second source of revenue, possibly selling the data to a third party or using the data to increase profit from its other products; but consumers have disutility from their personal data being used. We assume that the firm's data-usage level from each consumer

[10] The issue of international policy harmonization has been studied in other contexts, such as patent policies (Grossman and Lai, 2004), technical product standards (Chen and Mattoo, 2008), and tax competition to attract multinational firms (Keen and Konrad, 2013). Such models reflect tradeoffs among multiple welfare objectives in inherently distorted markets. Our focus on data use versus privacy costs is novel in this area.

(who purchases the product) is

$$x = \theta x_1 + (1 - \theta)\, x_2,$$

where x_1 can be observed by consumers before purchase but x_2 cannot, with $x_i \in [0, 1]$ for $i = 1, 2$, whereas $\theta \in [0, 1]$ is exogenous and commonly known. A higher θ reflects more transparency of data usage or a higher ability of the firm to publicly commit to the data-usage level.[11]

This formulation of data usage is aligned with a variety of economic settings. First, it captures the idea that, in serving consumers, the firm can collect various types of information about a consumer, ranging from personal identification (e.g., name, age, occupation, address) to the consumer's transaction and consumption data (e.g., search history, purchase habit, consumption frequency, post-sale service needs). The firm can make public that it will collect and use some of the data, denoted by x_1, which could include information that is required for the transaction and post-sale services, but it may (intentionally or unintentionally) conceal the collection and use of other information, denoted by x_2, which may include for instance consumer search and purchase patterns.[12] A higher value of x_1 or x_2 indicates that the firm collects more information about consumers. The formulation can also reflect the extent to which consumer data may be utilized, with x_1 and x_2 representing respectively data usage that the firm may or may not be able to commit to before consumers purchase the product. Furthermore, we may consider x as the inverse of the firm's effort in protecting consumer data, so that a higher x corresponds to less data protection and lower effort cost, with x_1 and x_2 corresponding to protection levels that the firm may or may not be able to commit to.

As discussed above, the firm's revenue will naturally increase in data usage x. Specifically,

[11] We take θ as a given parameter in our model. As it will become clear later, if the firm were able to choose or influence the value of θ, it could benefit from committing to a higher level of θ.

[12] This is related to the idea of "incomplete contracts". The consumer, or even the firm, may not foresee all possible types of consumer information that may be profitably utilized. Hence, no commitment about the use of such information can be made before the product is purchased, even though all parties expect such use to occur.

we assume that the firm's data-usage revenue from each consumer is $r(x)$, where $r(0) = 0 = r'(1)$, $r'(0)$ is sufficiently high, $r'(x) > 0$ for $x < 1$, and $r''(x) < 0$. When Q_H and Q_F consumers in countries H and F, respectively, purchase the product, the firm's total revenue from data usage is $(Q_H+Q_F)r(x)$, where Q_H and Q_F are determined endogenously.

Consumers in the two countries may differ in their preference for privacy, and their disutility increases in the data-usage level x. Specifically, a consumer who purchases the product in country H or F suffers disutility x or τx, respectively, where $\tau > 0$ measures the relative consumer preference for privacy or the difference in consumers' disutility for data usage between the two countries: When $\tau = 1$, consumers in the two countries have the same preference for privacy, whereas $\tau > 1$ or $\tau < 1$ indicates, respectively, that consumers in F have a stronger or weaker preference than those in H. To summarize, each consumer's gross value in purchasing the product is $u - x$ in H and $u - \tau x$ in F.

We assume that it is optimal for the firm to sell in both countries, which would be true if the expected value of u is relatively high. A strategy of the firm specifies its choices of x_1 and x_2, as well as its prices p_H and p_F in countries H and F, respectively. A consumer with value u in country j, seeing x_1 and p_j for $j = H, L$, chooses whether to purchase the product under her belief about x_2. We study the perfect Bayesian equilibrium of the game, in which the firm's strategy is optimal given consumers' purchasing strategy, consumers' purchasing strategies are optimal given the firm's strategy and their belief about x (or x_2), and consumers' belief is consistent with the firm's strategy.

Note that in this baseline model, the firm sells a standard product with a common data-usage level in the two countries. A firm may choose separate levels of data usage in different countries by investing in data localization, and we shall examine the firm's incentives to do so in Section 5.

3. MARKET EQUILIBRIUM

In equilibrium, consumers have correct beliefs about the data-usage level x chosen by the firm. Given their belief about x and the observed prices (p_H, p_F), a consumer in country

H will purchase the product if $u - x - p_H \geq 0$ while a consumer in country F will do so if $u - \tau x - p_F \geq 0$. Thus, the probability for a consumer in H or F to buy the product is, respectively:

$$q_H = q_H(p_H, x) \equiv 1 - G\left(p_H + x\right); \qquad q_F = q_F(p_F, x) \equiv 1 - G\left(p_F + \tau x\right). \tag{1}$$

Accordingly, the total outputs in H and F are respectively λq_H and $(1-\lambda)\, q_F$. For each unit of output, the firm receives two streams of revenue: the price of the product and the data-usage revenue $r(x)$. Hence, the firm's profit as a function of (p_H, p_F) under given x is

$$\tilde{\pi}\left(p_H, p_F\right) = \lambda q_H(p_H, x)\left[p_H + r\left(x\right)\right] + (1-\lambda)\, q_F(p_F, x)\left[p_F + r\left(x\right)\right]. \tag{2}$$

Denote the inverse hazard rate of the consumer-value distribution by

$$m\left(u\right) \equiv \frac{1 - G\left(u\right)}{g\left(u\right)}. \tag{3}$$

Throughout the paper, we shall maintain the assumption

$$\text{(i) } m'\left(u\right) \leq 0 \quad \text{ and } \quad \text{(ii) } m(\underline{u}) - \underline{u} \geq r(x) - \min\left\{x, \tau x\right\} \quad \text{for } x \in [0,1], \tag{A1}$$

where part (i) is the familiar monotonic hazard-rate condition that is satisfied by many well-known distributions, and part (ii) will rule out the corner solution where the equilibrium price is equal to $\underline{u} - x$ in H or $\underline{u} - \tau x$ in F. We define $p_H + x$ and $p_F + \tau x$ as the "effective prices" for consumers respectively in countries H and F, which include the purchase price and the disutility from losing privacy. Since $1 - G\left(p_H + x\right)$ (or $1 - G\left(p_F + \tau x\right)$) is the demand of a consumer in country H (or F), part (i) can be alternatively interpreted as a firm's demand in each country being logconcave. Moreover, denoting demand per consumer at effective price p by $D\left(p\right) \equiv 1 - G\left(p\right)$, we have $m\left(p\right) = -\frac{D(p)}{D'(p)}$ and

$$m'\left(p\right) = -1 + \frac{D\left(p\right) D''\left(p\right)}{\left[D'\left(p\right)\right]^2} = -1 + \left[\frac{1}{-\frac{p}{D(p)}\left[D'\left(p\right)\right]}\right]\left[-\frac{pD''\left(p\right)}{D'\left(p\right)}\right] = -1 + \frac{\alpha\left(p\right)}{\eta\left(p\right)},$$

where $\alpha\left(p\right)$ is the curvature and $\eta\left(p\right)$ the price elasticity of $D\left(p\right)$, whereas $\frac{\alpha}{\eta}$ equals the curvature of the inverse demand function; and demand is convex or concave if, respectively, $m'\left(p\right) + 1 \geq 0$ or ≤ 0 (Chen and Schwartz, 2015). Hence, $m'\left(u\right) + 1$ measures the curvature of demand in each country, and its property will determine how a change in x affects the firm's optimal price, or the firm's trade off between the revenues from product sales and data usage. The following lemma characterizes the equilibrium prices given x.

Lemma 1 *(Equilibrium Prices) Given x, the equilibrium prices in the two countries uniquely satisfy*

$$p_H^* = m\left(p_H^* + x\right) - r(x); \qquad p_F^* = m\left(p_F^* + \tau x\right) - r(x), \tag{4}$$

with equilibrium outputs $\lambda q_H^* = \lambda q_H(p_H^*, x)$ and $(1-\lambda)\, q_F^* = (1-\lambda)\, q_F(p_F^*, x)$. Furthermore: $p_H^* = p_F^*$, $q_H^* = q_F^*$ if $\tau = 1$; $p_H^* > p_F^*$, $q_H^* > q_F^*$ if $\tau > 1$; and $p_H^* < p_F^*$, $q_H^* < q_F^*$ if $\tau < 1$.

Lemma 1 implies that, given data usage x, the firm has a lower price of the product but a *higher* "effective price" (and accordingly, a *lower* expected output per consumer) in the country where consumers have larger disutility from losing privacy. Furthermore, when the per-consumer revenue from data usage, $r(x)$, increases, the firm's optimal prices will decrease. This is because when the revenue from data usage is higher, the firm has incentives to generate a larger output—hence also more consumer data—by reducing prices. From condition (4), we can derive $\frac{\partial p_H^*}{\partial r}$ and $\frac{\partial p_F^*}{\partial r}$, which measure the impacts of an exogenous increase of data-usage revenue (for a given level x) on product prices, and we call their absolute values the *rates of revenue substitution:*

$$\rho_r^H \equiv -\frac{\partial p_H^*}{\partial r} = -\frac{1}{m'\left(p_H^* + x\right) - 1}, \qquad \rho_r^F \equiv -\frac{\partial p_F^*}{\partial r} = -\frac{1}{m'\left(p_F^* + \tau x\right) - 1}. \tag{5}$$

The rate of revenue substitution reflects the firm's tradeoff between revenues from direct product sales and the use of consumer data. Note that the revenue substitution rates are constant, decreasing, or increasing in x, respectively if $m\,(u)$ is linear, concave, or convex (equivalently, if the demand curvature $m'(u) + 1$ is constant, decreasing, or increasing).

An increase in data revenue can have different impacts on product prices in the two countries, depending on the relative preference for privacy, τ, and the change (rate) of demand curvature in each country, $m''(u)$. For illustration, consider the case with $\tau > 1$ and $m''(u) > 0$. Since $\tau > 1$, country F has a stronger preference for privacy and, as shown in Lemma 1, the effective price is higher in F than in H: $p_F^* + \tau x > p_H^* + x$. Given $m''(u) > 0$, the demand curvature at the equilibrium price is thus larger in country F than in country H. When r rises, both p_F^* and p_H^* fall, but for the same price decrease there is more output expansion in F than in H because demand is more convex (or less concave) in F. Therefore, when $\tau > 1$ and $m''(u) > 0$, an increase in r would result in a large decrease in p_F^* than in p_H^*, so that the revenue substitution rate in H is smaller than that in F, $\rho_r^H < \rho_r^F$.[13] The following lemma confirms this intuition and compares the revenue substitution rates in the other cases as well.

Lemma 2 *(Revenue Substitution Rates) An exogenous increase of r has a smaller impact on p_H^* than on p_F^*, $\rho_r^H < \rho_r^F$, if $\tau > 1$ and $m''(u) > 0$ or if $\tau < 1$ and $m''(u) < 0$; whereas it has a larger impact on p_H^* than on p_F^*, $\rho_r^H > \rho_r^F$, if $\tau > 1$ and $m''(u) < 0$ or if $\tau < 1$ and $m''(u) > 0$.*

Next, we examine how the choice of data usage x affects the output and profit in each country. Suppose that the firm could commit to any data-usage level. From condition (4), we can derive the impacts of a marginal increase of x on product prices:

$$\rho_x^H \equiv \frac{dp_H^*}{dx} = \frac{r'(x) - m'(p_H^* + x)}{m'\left(p_H^* + x\right) - 1}, \tag{6}$$

$$\rho_x^F \equiv \frac{dp_F^*}{dx} = \frac{r'(x) - \tau m'(p_F^* + \tau x)}{m'\left(p_F^* + \tau x\right) - 1}. \tag{7}$$

Using condition (5), we can rewrite (6) and (7) as

$$\rho_x^H + 1 = -\rho_r^H \left[r'(x) - 1\right], \quad \text{and} \quad \rho_x^F + \tau = -\rho_r^F \left[r'(x) - \tau\right]. \tag{8}$$

Recall that $p_H^* + x$ and $p_F^* + \tau x$ are the effective prices for consumers in the two countries. So, $\rho_x^H + 1$ and $\rho_x^F + \tau$ are marginal effective prices of data usage in H and F, respectively. We can also consider $r(x) - x$ and $r(x) - \tau x$ as the "net benefits" of data usage per consumer,

[13] If we consider the reduction of data-usage revenue as the firm's opportunity cost when the firm raises product price, then the revenue substitution rate is analogous to the cost pass-through rate in the literature on monopoly and differential pricing, where demand curvature and how it changes play crucial roles in the welfare analysis (e.g. Aguirre et. al., 2010; Chen and Schwartz, 2015).

which include the firm's data-usage revenue and each consumer's disutility from losing privacy. Thus, $r'(x)-1$ and $r'(x)-\tau$ represent the marginal net benefit of data usage, in H and F respectively. Condition (8) says that the marginal effective price of data usage in each country equals, in absolute value, the revenue substitution rate multiplied by the marginal net benefit of data usage in the country. Because $r'(x)$ can be higher than $\max\{1,\tau\}$ for small x and lower than $\min\{1,\tau\}$ for high x, ρ_x^H+1 and ρ_x^F+1 can be either positive or negative.

Note that the equilibrium output in each country, $\lambda[1-G(p_H^*+x)]$ in H and $(1-\lambda)[1-G(p_F^*+\tau x)]$ in F, decreases in the effective price. Then condition (8) implies that a marginal increase of data usage x increases (or decreases) the output in country H when $r'(x)>1$ (or when $r'(x)<1$). Similarly, a marginal increase of data usage x increases (or decreases) the output in country F when $r'(x)>\tau$ (or when $r'(x)<\tau$). Intuitively, an increase of data usage increases consumer disutility, which reduces the output; but the increase of data usage also raises the firm's data-usage revenue, which motivates the firm to increase the output by reducing product prices. The next result summarizes the non-monotonic impacts of data usage on outputs.

Lemma 3 *(Output Changes) The equilibrium output in each country first increases and then decreases in x, with the maximal output in country H and in country F achieved respectively when $r'(x)=1$ and when $r'(x)=\tau$.*

In choosing x, the firm needs to consider the trade-offs between the data-usage revenue and consumer disutility from losing privacy, as well as the non-monotonic impacts on the outputs. The firm's equilibrium profit as a function of x is given by

$$\pi(x)=\lambda q_H^*(x)[p_H^*+r(x)]+(1-\lambda)q_F^*(x)[p_F^*+r(x)]. \tag{9}$$

Utilizing the envelop theorem and condition (4), we have

$$\pi'(x)=\lambda q_H^*(x)\left[r'(x)-1\right]+(1-\lambda)q_F^*(x)\left[r'(x)-\tau\right]. \tag{10}$$

Hence, increasing data usage strictly raises firm profits if $r'(x)>\max\{1,\tau\}$ and strictly reduces firm profits if $r'(x)<\min\{1,\tau\}$. Intuitively, when $r'(x)<\min\{1,\tau\}$, the marginal revenue of data usage is lower than the marginal disutility of privacy loss in both countries, and the opposite is true when $r'(x) > \max\{1, \tau\}$. When $\min\{1, \tau\} < r'(x) < \max\{1, \tau\}$, the marginal revenue of data usage is higher than the marginal disutility in one country but lower in the other country, in which case the firm's optimal data-usage must balance these two conflicting effects. We shall maintain the assumption that $\pi(x)$ is single-peaked, which is ensured if $r(x)$ is sufficiently concave.

Suppose that the firm could commit to any data-usage level. Define the (unconstrained) profit-maximizing level as $\widehat{x} = \arg\max_x \pi(x)$. Then $\widehat{x}$ satisfies

$$\pi'(\widehat{x}) = \lambda q_H^*(\widehat{x}) \left[r'(\widehat{x}) - 1\right] + (1-\lambda) q_F^*(\widehat{x}) \left[r'(\widehat{x}) - \tau\right] = 0, \tag{11}$$

which implies $r'(\widehat{x}) = 1$ if $\tau = 1$ and $\min\{1, \tau\} < r'(\widehat{x}) < \max\{1, \tau\}$ if $\tau \neq 1$. Recall that $r'(x) - 1$ (or $r'(x) - \tau$) is the marginal net benefit of data usage in country H (or in country F). Thus, for profit maximization, the firm desires to set x such that the output-weighted marginal net benefits of data usage are equalized (in absolute value) for the two countries.

While $\widehat{x}$ maximizes the firm's profit, the equilibrium data usage may differ from $\widehat{x}$ due to the firm's inability to commit to x_2. Denoting the equilibrium data usage by x^*, we have:

Proposition 1 *(Equilibrium Data Usage) The equilibrium data usage x^* weakly decreases in the transparency level θ: (i) if $\theta < 1 - \widehat{x}$, then $x^* = 1 - \theta > \widehat{x}$, with $x_1 = 0$ and $x_2 = 1$; (ii) if $\theta \geq 1 - \widehat{x}$, then $x^* = \widehat{x}$, with $x_1 = \frac{\widehat{x} - (1-\theta)}{\theta}$ and $x_2 = 1$.*

In equilibrium we must have $x_2 = 1$, as consumers cannot observe x_2 and it is optimal for the firm to choose the highest possible x_2 to increase data-usage revenue. If data usage is sufficiently transparent ($\theta \geq 1 - \widehat{x}$), the firm can commit to the (unconstrained) profit-maximizing usage level, $x^* = \widehat{x}$, whereas if data usage is not sufficiently transparent ($\theta < 1 - \widehat{x}$), the firm chooses a usage level higher than $\widehat{x}$.[14]

Global Welfare Benchmark

[14] Thus, if the firm were able to commit to any transparency level, it would have the incentives to choose $\theta \geq 1 - \widehat{x}$.

We next consider the data-usage level that would maximize global welfare and examine how welfare may change with transparency.[15] We assume that the firm can still choose its profit-maximizing prices in the two countries. Global welfare from the two countries as a function of x is

$$W(x) = \lambda \int_{p_H^*+x}^{\bar{u}} [u + r(x) - x] g(u) du + (1-\lambda) \int_{p_F^*+\tau x}^{\bar{u}} [u + r(x) - \tau x] g(u) du. \tag{12}$$

Then:

$$\begin{aligned} W'(x) \;\; &= \;\; \lambda \left\{ -\left(p_H^* + r\left(x\right)\right) g(p_H^* + x) \left(\rho_x^H + 1\right) + \left[r'(x) - 1\right]\left[1 - G\left(p_H^* + x\right)\right] \right\} + (1-\lambda) \cdot \\ &\quad \left\{ -[p_F^* + r(x)] g(p_F^* + \tau x) \left[\rho_x^F + \tau\right] + \left(r'\left(x\right) - \tau\right)\left[1 - G\left(p_F^* + \tau x\right)\right] \right\}. \end{aligned} \tag{13}$$

Using (1), (4) and (5), we can rewrite (13) as

$$W'(x) = \lambda q_H^*(x)(1 + \rho_r^H)[r'(x) - 1] + (1-\lambda)\, q_F^*(x)(1 + \rho_r^F) \left[r'\left(x\right) - \tau\right], \tag{14}$$

where we recall $\rho_r^H = -\frac{1}{m'\left(p_H^*+x\right)-1} > 0$ and $\rho_r^F = -\frac{1}{m'\left(p_F^*+\tau x\right)-1} > 0$ as the revenue substitution rates. Hence, increasing data usage strictly raises global welfare if the marginal net benefit of data usage is positive in both countries (i.e., $r'(x) - \max\{1, \tau\} > 0$), and it strictly reduces global welfare if the marginal net benefit of data usage is negative in both countries (i.e., $r'(x) < \min\{1, \tau\}$).

Denote the globally efficient data usage by $x^o = \arg\max_x W\left(x\right)$. Then x^o satisfies

$$W'(x^o) = \lambda q_H^*(x^o)(1 + \rho_r^H)[r'(x^o) - 1] + (1-\lambda)\, q_F^*(x^o)(1 + \rho_r^F) \left[r'\left(x^o\right) - \tau\right] = 0, \tag{15}$$

which implies $r'(x^o) = 1$ if $\tau = 1$ and $\min\{1, \tau\} < r'(x^o) < \max\{1, \tau\}$ if $\tau \neq 1$. Comparing (11) and (15), the result below shows that x^o can be higher or lower than its (unconstrained) profit-maximizing counterpart $\widehat{x}$.

Lemma 4 *(Efficient versus Profit-maximizing Data Usage) The profit-maximizing data usage is efficient ($\widehat{x} = x^o$) if $\tau = 1$ or if $m''\left(u\right) = 0$, inefficiently high ($\widehat{x} > x^o$) if $\tau \neq 1$ and $m''\left(u\right) > 0$, and inefficiently low ($\widehat{x} < x^o$) if $\tau \neq 1$ and $m''\left(u\right) < 0$.*

[15] Notice that this welfare benchmark assumes that the firm must choose the common data-usage level in both countries. When the firm can invest in data localization, global welfare may be maximized if the firm chooses different levels of data usage in different countries.

If there were a single country, or equivalently if $\tau = 1$, the firm's profit-maximizing data usage would coincide with the efficient level. However, if the two countries have different privacy preferences and the demand curvature is not a constant ($m''(u) \neq 0$), the firm's privately-optimal data usage can diverge from the efficient level. To see the intuition, rewrite (14) as

$$W'(x) = \pi'(x) + \lambda q_H^*(x)\rho_r^H[r'(x) - 1] + (1-\lambda)\, q_F^*(x)\rho_r^F\left[r'(x) - \tau\right], \tag{16}$$

where $\lambda q_H^*(x)\rho_r^H[r'(x) - 1]$ is the impact of a marginal increase of data usage on consumer surplus in country H and $(1-\lambda)\, q_F^*(x)\rho_r^F[r'(x) - \tau]$ is the corresponding impact in country F. The changes in consumer surplus depend on the revenue substitution rates (ρ_r^H and ρ_r^F) and the output-weighted marginal net benefits of data usage in H and in F.

Consider the scenario where $\tau > 1$ and $m''(u) > 0$. Lemma 2 shows that, in this case, the revenue substitution rate in country H is lower than that in country F ($\rho_r^H < \rho_r^F$), due to the more convex demand at the equilibrium price in country F. Since $\tau > 1$, the privately-desired data usage $\widehat{x}$ satisfies $1 < r'(\widehat{x}) < \tau$. As indicated by condition (11), for a small increase in x from $\widehat{x}$, the output-weighted marginal net benefit of x in H equals the absolute value of the output-weighted marginal net benefit of x in F. Thus, condition (16) implies that the increase of consumer surplus in H is smaller than the decrease of consumer surplus in F. Intuitively, the marginal change of data usage would cause a larger impact on consumer surplus in the country with a larger price change. The small increase of data usage also changes firm profit, which however is a second-order effect. Therefore, the increase of data usage reduces global welfare. Similar intuition can be obtained when $\tau < 1$ and $m''(u) > 0$. To summarize, the firm's optimal data usage exceeds the globally efficient level when $\tau \neq 1$ and the demand curvature is increasing (i.e., $m(u)$ is convex).

By contrast, the firm's optimal data usage is below the global optimum when $\tau \neq 1$ and the demand curvature is decreasing (i.e. $m(u)$ is concave). For illustration, suppose that $\tau > 1$ and $m''(u) < 0$. As shown in Lemma 2, the revenue substitution rate in country H is larger than that in country F ($\rho_r^H > \rho_r^F$), due to the more convex demand at the equilibrium price in country H. Accordingly, for a small increase of data usage from $\widehat{x}$, the increase of consumer surplus in H is larger than the decrease of consumer surplus in F. Thus, the increase of data usage raises global welfare.

Following Proposition 1 and Lemma 4, the next result compares the equilibrium (x^*) and efficient (x^o) data-usage levels, and investigates the impact of transparency on equilibrium global welfare:

Proposition 2 *(Global Welfare and Transparency)*
(i) Suppose $\tau = 1$ or $m''(u) = 0$. Then $x^* > x^o$ if $\theta < 1 - \widehat{x}$ and $x^* = x^o$ if $\theta \geq 1 - \widehat{x}$. Global welfare increases in θ if $\theta < 1 - \widehat{x}$ and is equal to $W(x^o)$ if $\theta \geq 1 - \widehat{x}$.
(ii) Suppose $\tau \neq 1$ and $m''(u) > 0$ (i.e. increasing demand curvature). Then $x^* > x^o$ for all θ. Global welfare increases in θ if $\theta < 1 - \widehat{x}$ and is equal to $W(\widehat{x})$ if $\theta \geq 1 - \widehat{x}$.
(iii) Suppose $\tau \neq 1$ and $m''(u) < 0$ (i.e. decreasing demand curvature). Then $x^* > x^o$ if $\theta < 1 - x^o$, $x^* = x^o$ if $\theta = 1 - x^o$, and $x^* < x^o$ if $\theta > 1 - x^o$. Global welfare increases in θ if $\theta < 1 - x^o$, decreases in θ if $\theta \in (1 - x^o, 1 - \widehat{x})$, and is equal to $W(\widehat{x})$ if $\theta \geq 1 - \widehat{x}$.

When data usage is not transparent enough (i.e. θ is small), the equilibrium data-usage level is greater than the global optimum even if the firm's most desired x coincides with the efficient level ($\widehat{x} = x^o$), due to the firm's moral hazard. More transparency mitigates the moral hazard problem and enables the firm to commit to a lower data-usage level. The welfare impact, however, depends on the cross-country difference in privacy preference, τ, and how the demand curvature, $m'(u)$, changes. As shown in Lemma 4, the firm's privately-desired data usage, $\widehat{x}$, is higher than the globally efficient level when $\tau \neq 1$ and demand curvature $m'(u) + 1$ is increasing (or $m(u)$ is convex). Even if the firm can commit to any data-usage level, or there is no problem of transparency, the firm still over-uses consumer data compared to what is (globally) efficient. In this case, more transparency (i.e. a larger θ) weakly increases global welfare but cannot achieve the global optimum.

Interestingly, it is also possible that welfare is non-monotonic in the transparency parameter θ, first increasing and then decreasing. As shown in Lemma 4, $\widehat{x} < x^o$ when $\tau \neq 1$ and demand curvature $m'(u) + 1$ is decreasing (or $m(u)$ is concave). In this case, more transparency can exacerbate the distortion in data usage and reduce global welfare, because it allows the firm to commit to a data-usage level that is inefficiently low.

Proposition 2 highlights how moral hazard and asymmetric preferences across countries may lead to distortions in data usage. Furthermore, global welfare weakly increases in the transparency level of data usage when the countries have the same preference for privacy and/or when demand curvature is weakly increasing ($m''(u) \geq 0$), but can otherwise have an inverted U-shaped relationship with θ.

Examples 1 and 2 below illustrate cases where global welfare weakly increases in the transparency of data usage, while Example 3 illustrates cases where global welfare can have an inverted U-shaped relationship with the transparency of data usage.

Example 1 *Suppose $G(u)$ is a uniform or exponential distribution ($m''(u) = 0$ and $m'(u) \leq 0$). Global welfare weakly increases in θ. In particular, let $\lambda = 0.5$ (i.e. the two markets have the same size), $\tau = 1.5$, $G(u) = u - 1$ on $[1, 2]$, and $r(x) = 1 - (1 - x)^2$ for $x \in [0, 1]$. Then $x^o = \widehat{x} \approx 0.39$. Welfare increases in θ for $\theta < 0.61$ and becomes constant for $\theta \geq 0.61$.*

Example 2 *Suppose $G(u)$ is a power function distribution: $G(u) = u^a$ for $0 \leq u \leq 1$ and $a > 1$, with*

$$m'(u) = -\frac{a - 1 + u^a}{au^a} \leq 0 \text{ and } m''(u) = \frac{1}{u^{a+1}}(a - 1) > 0;$$

or a Weibull distribution: $G(u) = 1 - e^{-u^\beta}$ for $u \in [0, \infty)$ and $\beta > 1$, with

$$m'(u) = -\frac{(\beta - 1)u^{-\beta}}{\beta} \leq 0 \text{ and } m''(u) = (\beta - 1)u^{-\beta-1} > 0.$$

Global welfare weakly increases in θ if $\tau \neq 1$. In particular, let $\lambda = 0.5$, $\tau = 1.5$, $G(u) = u^2$ for $0 \leq u \leq 1$, and $r(x) = 1-(1-x)^2$ for $x \in [0, 1]$. Then we have $\widehat{x} \approx 0.380$ and $x^o \approx 0.379$. Welfare increases in θ for $\theta < 0.620$ and becomes constant for $\theta \geq 0.620$.

Example 3 *Suppose $G(u)$ is a power function distribution: $G(u) = u^a - 1$ for $1 \leq u \leq 2^{1/a}$ and $0 < a \leq 0.5$, with*

$$m'(u) = -\frac{u^a - 2(1 - a)}{au^a} \leq 0 \text{ and } m''(u) = \frac{2}{u^{a+1}}(a - 1) < 0.$$

Global welfare has an inverted U-shaped relationship with θ if $\tau \neq 1$. In particular, let $\lambda = 0.5$, $\tau = 1.5$, $G(u) = u^{0.5} - 1$ for $1 \leq u \leq 4$, and $r(x) = 1 - (1 - x)^2$ for $x \in [0, 1]$.

Then we have $\widehat{x} = 0.2$ *and* $x^o \approx 0.39$. *Welfare increases in* θ *for* $\theta < 0.61$, *decreases in* θ *for* $\theta \in (0.61, 0.8)$, *and becomes constant for* $\theta \geq 0.8$.

The finding in Proposition 2 that more transparency of data usage can reduce welfare is intriguing. Many countries have regulations aimed at improving transparency by requiring firms to disclose data usage or data protection. While increases in transparency are often considered as welfare-improving, our result indicates that their welfare impact is more nuanced and may have unintended consequences.

4. REGULATIONS ON DATA USAGE

In recent years, countries have been enacting regulations on the use and protection of data. Compared to consumers, regulators are in a better position to monitor and verify data usages. In this section, we turn to the question of how regulations may impact data usage and global welfare. We assume that regulators in countries H and F independently and simultaneously set caps on data usage, σ_H and σ_F, so that the firm is required to choose $x \leq \sigma_H$ and $x \leq \sigma_F$ in the respective countries.[16] Although the firm is unable to announce its choice of x to consumers before they purchase the product, a regulator can find out the firm's choice of x ex post and can therefore implement the regulation (possibly with a high penalty for violations).

Consumer surplus in H or in F is, respectively,

$$V^H(x) = \lambda \int_{p_H^*+x}^{\bar{u}} (u - p_H^* - x) g(u) du, \tag{17}$$

$$V^F(x) = (1-\lambda) \int_{p_F^*+\tau x}^{\bar{u}} (u - p_F^* - \tau x) g(u) du. \tag{18}$$

We assume that the regulatory objective of each country is to maximize its total surplus. That is, the regulator in H aims to maximize the sum of consumer surplus in H and firm

[16] Notice that even if the firm transmits consumer data in F back to H, it still needs to follow regulations set by F when using the data. Notice also that regulations with usage caps are different from policies aiming to improve transparency of data usage (i.e. increasing θ). As shown in Section 3, when $\theta = 1$, the firm chooses the profit-maximizing usage $\widehat{x}$. In contrast, under the usage caps, the firm has to choose $x \leq \min\{\sigma_H, \sigma_F\}$.

profits in both countries (as the firm is located in H), whereas the regulator in F aims to maximize only consumer surplus in F. Notice that

$$V^{H'}(x) = \lambda q_H^*(x)\rho_r^H \left[r'(x) - 1\right], \tag{19}$$

$$V^{F'}(x) = (1-\lambda)q_F^*(x)\rho_r^F \left[r'(x) - \tau\right], \tag{20}$$

where we recall $q_H^*(x) = 1 - G(p_H^* + x)$ and $q_F^*(x) = 1 - G(p_F^* + \tau x)$. Therefore, provided that the constraint $x \leq \sigma_H$ is binding, country H will impose the cap σ_H such that

$$V^{H'}(\sigma_H) + \pi'(\sigma_H) = \lambda q_H^*(\sigma_H)\left[r'(\sigma_H) - 1\right](1+\rho_r^H) + (1-\lambda)q_F^*(\sigma_H)\left[r'(\sigma_H) - \tau\right] = 0, \tag{21}$$

which implies $\min\{1,\tau\} \leq r'(\sigma_H) \leq \max\{1,\tau\}$. Provided that $x \leq \sigma_F$ is binding, country F will impose the cap σ_F such that

$$V^{F'}(\sigma_F) = 0, \tag{22}$$

which implies $r'(\sigma_F) = \tau$.

When consumers in country F have a stronger preference for privacy ($\tau > 1$), conditions (21) and (22) imply that F imposes a more stringent regulation than H, that is, $\sigma_F < \sigma_H$. Similarly, when consumers in country H have a stronger preference for privacy ($\tau < 1$), H imposes a more stringent restriction on data usage with $\sigma_F > \sigma_H$. The firm will need to comply with the lower of the two caps in order to sell in both countries. We show below that, as long as $\tau \neq 1$, the firm has to follow the lower cap which, however, is below the efficient data-usage x^o that maximizes global welfare.[17]

Lemma 5 *(Regulations on Data Usage) (i) When $\tau = 1$, both countries impose a cap equal to the efficient data-usage level, $\sigma_H = \sigma_F = x^o = \widehat{x}$. (ii) When $\tau > 1$, country F imposes a lower cap on data usage with $r'(\sigma_F) = \tau$ and $\sigma_F < \min\{x^o, \widehat{x}, \sigma_H\}$. (iii) When $\tau < 1$, country H imposes a lower cap with $\tau < r'(\sigma_H) < 1$ and $\sigma_H < \min\{x^o, \widehat{x}, \sigma_F\}$.*

Thus, unilateral regulations on data usage may cause externalities across countries that possibly exacerbate market distortions. When consumers in the two countries have different

[17] The result utilizes our maintained assumption that $\pi(x)$, $V^j(x)$ for $j = H, F$, and $W(x)$ are all single-peaked functions.

preferences for privacy, the country with a stronger preference imposes a restriction on data usage which is inefficiently low for the other country. Since the firm is constrained by the more stringent restriction, this data-usage externality reduces the welfare in the other country.

Furthermore, as shown in Lemma 3, the output in each country first increases and then decreases in data usage, with the maximal output in H achieved when $r'(x) = 1$ and the maximal output in F achieved when $r'(x) = \tau$. The more stringent restriction imposed by one country reduces the firm's data-usage revenue $r(x)$, which in turn reduces the firm's incentives to increase outputs. In other words, the more stringent regulation causes a negative externality on the output in the other country.

The next result describes the equilibrium welfare effects of unilateral regulations.

Proposition 3 *(Welfare and Unilateral Regulations) Suppose that the firm chooses data usage x^r that complies with the regulations (σ_H, σ_F).*
(i) When $\tau = 1$, $x^r = x^o = \widehat{x}$; unilateral regulations improve global welfare if $\theta < 1 - \widehat{x}$ and do not affect welfare if $\theta \geq 1 - \widehat{x}$.
(ii) When $\tau \neq 1$, $x^r = \sigma_F$ with $r'(\sigma_F) = \tau$ if $\tau > 1$, and $x^r = \sigma_H$ with $V^{H'}(\sigma_H) + \pi'(\sigma_H) = 0$ if $\tau < 1$. Moreover, there exists some μ_θ such that the regulations increase welfare if $\theta < \mu_\theta$ but decrease welfare otherwise, where $\mu_\theta > 0$ if $|\tau - 1|$ is sufficiently small, and $\mu_\theta < 1$ if $m''(u) \leq \delta$ for some $\delta > 0$.

Proposition 3 provides conditions for unilateral data regulations to improve or reduce global welfare. When consumers in the two countries have sufficiently similar preferences for privacy, data regulation enables the firm to overcome its moral hazard problem and to choose the more efficient data-usage level. But when the two countries differ substantially in privacy preferences, the country with a stronger preference imposes a lower cap on data usage, which does not internalize the negative output and data-usage effects in the other country. Thus, data regulations may either increase or decrease global welfare, depending on the preference difference $|\tau - 1|$ in the two countries and the transparency parameter θ, as illustrated in the example below.

Example 4 *Suppose that $G(u)$ is the uniform distribution on $[1,2]$, $\lambda = 0.5$, $\tau = 1.5$, and $r(x) = 1 - (1-x)^2$ for $x \in [0,1]$. As shown in Example 1, $x^o = \widehat{x} \approx 0.39$. Then unilateral regulations on data usage increase global welfare if $\theta < \mu_\theta \approx 0.48$ but decrease global welfare if $\theta > \mu_\theta \approx 0.48$.*

If the countries can coordinate their regulations, then it would be optimal for them to enforce the efficient data usage x^o. Intriguingly, however, setting a uniform cap on data usage may not achieve the global optimum, even if the cap is set jointly by the two countries.

Corollary 1 *(International Coordination) Suppose that the countries could coordinate in data-usage regulations.*
(i) When $\tau = 1$, international coordination does not affect global welfare.
(ii) When $\tau \neq 1$, international coordination increases global welfare. A uniform cap $\sigma = x^o$ achieves the global optimum if $m''(u) \geq 0$ or if $m''(u) < 0$ and $\theta \leq 1 - x^o$, but fails to do so if $m''(u) < 0$ and $\theta > 1 - x^o$.

When consumers in the two countries have the same preference for privacy ($\tau = 1$), unilateral regulations achieve the global optimum (see Proposition 3) and international coordination has no effect on global welfare. When consumers in the two countries differ in their preferences for privacy, unilateral regulations can create negative externalities across countries. In this case, international coordination always improves global welfare. When demand curvature is (weakly) increasing ($m''(u) \geq 0$) or data usage is not very transparent, the firm would choose $x^* > x^o$, and in this case the uniform cap achieves the global optimum. However, as shown in Proposition 2, when demand curvature is decreasing ($m''(u) < 0$) and data usage is highly transparent ($\theta > 1 - x^o$), the firm will find it optimal (and can commit) to choose a data-usage level that is lower than the efficient level ($x^* < x^o$). In this case, a uniform cap on data usage cannot lead to the efficient level x^o.

5. DATA LOCALIZATION

It is possible that a firm can choose a different level of data usage in a different country by making certain investments, for example, setting up local servers to store and process data. This section allows for this possibility. In subsection 5.1, we examine the firm's incentives to make the "localization" investment, in the absence of data regulation. In subsection 5.2, we further analyze the welfare effects of data-usage regulations unilaterally imposed by the two countries that may change the firm's incentives to invest in localization.[18]

5.1 Localization without Data Regulation

Suppose that there is no data regulation, and the firm may invest a fixed amount $k > 0$ which enables it to choose data-usage levels x_H and x_F separately in countries H and F.

If the firm invests k, then similar to the analysis in Section 3, the firm's optimal prices p_H^l and p_F^l satisfy

$$p_H^l + r(x_H) = m\left(p_H^l + x_H\right); \qquad p_F^l + r(x_F) = m\left(p_F^l + \tau x_F\right), \tag{23}$$

where the superscript l denotes for localization. The firm's profit (excluding investment costs k) as a function of (x_H, x_F) is

$$\pi(x_H, x_F) = \lambda q_H^l(x)[p_H^l + r(x_H)] + (1-\lambda) q_F^l(x)[p_F^l + r(x_F)], \tag{24}$$

where $q_H^l(x) \equiv 1 - G\left(p_H^l + x_H\right)$ and $q_F^l(x) \equiv 1 - G\left(p_F^l + \tau x_F\right)$. One can show that the profit-maximizing data-usage levels, denoted as $(\widehat{x}_H, \widehat{x}_F)$, satisfy

$$r'\left(\widehat{x}_H\right) = 1; \qquad r'\left(\widehat{x}_F\right) = \tau. \tag{25}$$

That is, with data localization, the firm desires to choose usage levels that are also efficient for each market, because it fully internalizes consumers' disutility from losing privacy.

[18] We have also considered an alternative form of regulation that directly requires the firm to invest in localization. The welfare effects of such localization requirements, if feasible, are similar to the results in subsection 5.2 where data-usage regulations indirectly impact the firm's incentive to invest in localization.

Moreover, from conditions (19) and (20), these privately-desired usage levels also maximize consumer surplus in each country.

Recall that, without data localization, the firm's most desired data-usage, $\widehat{x}$, satisfies $\min\{1,\tau\} < r'(\widehat{x}) < \max\{1,\tau\}$ when $\tau \neq 1$. We thus have the following comparison

$$\min\{\widehat{x}_H, \widehat{x}_F\} < \widehat{x} < \max\{\widehat{x}_H, \widehat{x}_F\} \text{ if } \tau \neq 1; \qquad \widehat{x} = \widehat{x}_H = \widehat{x}_F = x^o \text{ if } \tau = 1. \tag{26}$$

Hence, the firm may invest in data localization only if consumers in the two countries differ in their preferences for privacy ($\tau \neq 1$).

While $(\widehat{x}_H, \widehat{x}_F)$ maximize the firm's profit under localization, the equilibrium levels may differ from $(\widehat{x}_H, \widehat{x}_F)$ due to the firm's limited commitment ability on data usage. Denoting the equilibrium levels under localization by (x_H^*, x_F^*), we have:

Lemma 6 *(Equilibrium Data Usage Under Localization) Suppose $\tau \neq 1$ and the firm invests in data localization. The firm's equilibrium data-usage levels weakly decrease in the transparency level θ: (i) if $\theta \leq 1 - \max\{\widehat{x}_H, \widehat{x}_F\}$, then $x_H^* = x_F^* = 1 - \theta$; (ii) if $1 - \max\{\widehat{x}_H, \widehat{x}_F\} < \theta < 1 - \min\{\widehat{x}_H, \widehat{x}_F\}$, then $x_H^* = \widehat{x}_H$ and $x_F^* = 1 - \theta$ if $\tau > 1$ while $x_H^* = 1 - \theta$ and $x_F^* = \widehat{x}_F$ if $\tau < 1$; (iii) if $\theta \geq 1 - \min\{\widehat{x}_H, \widehat{x}_F\}$, then $x_H^* = \widehat{x}_H$ and $x_F^* = \widehat{x}_F$.*

Given Lemma 6 and Proposition 1, when the transparency of data usage is low ($\theta \leq 1 - \max\{\widehat{x}_H, \widehat{x}_F\}$), the equilibrium data usage is the same whether the firm invests in localization or not. When data usage is highly transparent ($\theta \geq 1 - \min\{\widehat{x}_H, \widehat{x}_F\}$), the profit difference between localization and no localization, $\pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x})$, does not depend on the transparency parameter θ. We further show in the appendix that, for $\tau \neq 1$ and the intermediate range $\theta \in (1 - \max\{\widehat{x}_H, \widehat{x}_F\}, 1 - \min\{\widehat{x}_H, \widehat{x}_F\})$, the profit difference between localization and no localization, $\pi(x_H^*, x_F^*; \theta) - \pi(x^*; \theta)$, strictly increases in θ.

The relationship between the profit difference caused by localization and the transparency parameter θ can be understood intuitively as follows. Data localization is costly but allows the firm to choose different usage levels in the two countries, which raises firm profit. When data usage is not very transparent (i.e. under severe moral hazard problems), the equilibrium choices of data usage with and without localization both tend to be high. In this case, localization does not change the usage levels by much and therefore the profit difference is small. In contrast, when data usage becomes more transparent, the firm has more "flexibility" in committing to usage levels. In this case, localization facilitates larger changes of usage levels and, accordingly, causes a greater change in profit. In other words, the benefit of data localization to the firm is greater when data usage is more transparent.[19]

Define $k_1 = k_1(\tau) \equiv \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x})$. Then the earlier analysis implies that, given any $k < k_1(\tau)$, there exists a unique value θ^l such that

$$\pi(x_H^*, x_F^*; \theta^l) - \pi(x^*; \theta^l) = k. \tag{27}$$

The unregulated firm invests in localization if and only if $k < k_1(\tau)$ and $\theta > \theta^l$.

Since the firm fully absorbs the costs of localization investment, a voluntary localization decision not only raises firm profit but also enhances global welfare. However, the firm may not have sufficient incentives to invest in localization compared to what efficiency requires, as the firm does not internalize the gain of consumer surplus. Recall that $W(x)$ is global welfare without localization. Denote global welfare under localization (excluding costs k) as

$$W(x_H, x_F) = \lambda \int_{p_H^l + x_H}^{\bar{u}} [u + r(x_H) - x_H] g(u) du + (1 - \lambda) \int_{p_F^l + \tau x_F}^{\bar{u}} [u + r(x_F) - \tau x_F] g(u) du. \tag{28}$$

Suppose that $\tau > 1$. If $\theta \leq 1 - \widehat{x}_H$, then Proposition 1 and Lemma 6 imply that the equilibrium data-usage levels remain the same no matter whether the firm invests in localization or not ($x_H^* = x_F^* = x^*$), in which case the firm's decision of not investing in localization is efficient.

If $\theta > 1 - \widehat{x}_H$, then localization changes the equilibrium data-usage levels such that $x_H^* = \widehat{x}_H > x^*$ and $\widehat{x}_F \leq x_F^* \leq x^*$. Recall that $\widehat{x}_H$ and $\widehat{x}_F$ maximize both welfare and consumer surplus respectively in country H and F. Therefore, the welfare gain from

[19] As shown in Lemma 3, $(\widehat{x}_H, \widehat{x}_F)$ maximize the outputs in the two countries. Under localization, more transparency causes the firm's data-usage levels to be closer to $(\widehat{x}_H, \widehat{x}_F)$ and therefore raises the outputs in both countries.

localization is strictly larger than the profit increase (excluding costs k):

$$W\left(x_H^*, x_F^*\right) - W\left(x^*\right) > \pi\left(x_H^*, x_F^*\right) - \pi\left(x^*\right) > 0. \tag{29}$$

The same results can be obtained when $\tau < 1$. Thus, if the investment cost k is smaller than the welfare gain but larger than the profit increase, the localization incentive by the firm is inefficiently low. The following proposition summarizes the (unregulated) firm's localization incentives.

Proposition 4 *(Localization without Regulation) Suppose $\tau \neq 1$. When $k \geq k_1(\tau)$, the firm does not invest in data localization; when $k < k_1(\tau)$, there exists a unique $\theta^l \in (1 - \max\{\widehat{x}_H, \widehat{x}_F\},\ 1 - \min\{\widehat{x}_H, \widehat{x}_F\})$, which increases in k, such that the firm invests in localization and chooses data-usage levels $x_H^* = \max\{\widehat{x}_H, 1-\theta\}$ and $x_F^* = \max\{\widehat{x}_F, 1-\theta\}$ if and only if $\theta > \theta^l$. The option of localization weakly increases firm profit and global welfare, but for $\theta > 1 - \max\{\widehat{x}_H, \widehat{x}_F\}$ and an intermediate range of k, the firm does not invest in localization even though it is efficient to do so.*

5.2 Localization with Data Regulation

Now suppose that regulators in both countries independently and simultaneously impose data-usage caps (σ_H^l in H and σ_F^l in F) and, after observing the regulations, the firm chooses whether to invest in localization (as well as makes corresponding price and data-usage decisions). The regulator in each country sets a usage cap, correctly anticipating the cap set in the other country and potential responses from the firm in equilibrium. There can be two possible types of equilibria: one in which the firm does not invest in localization and another in which the firm does. If the firm does not invest in localization, it has to follow the lower of the two caps in the two countries: $x \leq \min\{\sigma_H^l, \sigma_F^l\}$. If the firm invests in localization, however, it can choose different usage levels in the two countries such that $x_H \leq \sigma_H^l$ and $x_F \leq \sigma_F^l$.

As we have shown, if consumers in the two countries have the same preference for privacy ($\tau = 1$), the data-usage level x^o maximizes both firm profit and welfare in each country. In this case, the countries will impose caps $\sigma^l_H = \sigma^l_F = x^o$, and the firm does not invest in localization. We shall thus focus on the cases where $\tau > 1$ or $\tau < 1$ below.

Suppose first that $\tau > 1$; that is, consumers in country F have a stronger preference for privacy. In this case, there always exists an equilibrium in which H imposes $\sigma^l_H = \widehat{x}_H$ and F imposes $\sigma^l_F = \widehat{x}_F$, whether or not the firm will respond with localization. We show that neither country has the incentive to deviate from its cap at the proposed equilibrium. Recall that $\widehat{x}_F < \widehat{x}_H$ when $\tau > 1$. Given $\sigma^l_H = \widehat{x}_H$, $\widehat{x}_F$ maximizes the surplus in F whether or not the firm invests in localization. Thus, $\sigma^l_F = \widehat{x}_F$ is optimal for F and it has no incentive to deviate.

Now consider the incentive of H. If the firm invests in localization and chooses $\widehat{x}_H$ in H and $\widehat{x}_F$ in F, the welfare for H (sum of the consumer surplus in H and the firm's profit in two countries) will be maximized. Therefore, anticipating localization, H has no incentive to deviate from the cap $\sigma^l_H = \widehat{x}_H$. If the firm does not invest in localization, the constraint $x_H \leq \sigma^l_H$ is not binding and the firm would choose data usage $\widehat{x}_F < \widehat{x}_H$ in both countries. Still, H cannot benefit from any deviation to set a binding cap below $\widehat{x}_F$, because any binding cap by H, say $\sigma' < \widehat{x}_F$, would result in data-usage level σ' in H, lowering welfare for H.

Suppose next that $\tau < 1$, that is, consumers in H have a stronger preference for privacy. Unlike the case with $\tau > 1$, here the optimal cap in H depends on whether the firm will choose localization. We focus on the equilibrium where the regulators impose $\sigma^l_H = \widehat{x}_H$ and $\sigma^l_F = \widehat{x}_F$ respectively, while the firm will invest in localization, where $\widehat{x}_F > \widehat{x}_H$ with $\tau < 1$.[20]

Given $\sigma^l_H = \widehat{x}_H$ and $\sigma^l_F = \widehat{x}_F$, if the firm does not invest in localization, the equilibrium data usage is $\min\{\widehat{x}_H, \widehat{x}_F\}$ and profit is $\pi(\min\{\widehat{x}_H, \widehat{x}_F\})$; if the firm invests in localization, the data-usage levels are $\widehat{x}_H$ in H and $\widehat{x}_F$ in F, resulting in profit (excluding costs k)

[20] Notice that, given $\tau < 1$, $\sigma^l_H = \widehat{x}_H$ and $\sigma^l_F = \widehat{x}_F$ cannot be supported in any equilibrium where the firm does not invest in localization, as H can then deviate to a cap slightly larger than $\widehat{x}_H$, which would not change the firm's localization decision but raise welfare for H.

$\pi(\widehat{x}_H, \widehat{x}_F)$. Define

$$k_2(\tau) \equiv \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\min\{\widehat{x}_H, \widehat{x}_F\}). \tag{30}$$

Then, given $\sigma_H^l = \widehat{x}_H$ and $\sigma_F^l = \widehat{x}_F$, the firm invests in localization if and only if $k < k_2(\tau)$. In the appendix, we show that $k_2(\tau)$ increases in τ when $\tau > 1$ and decreases in τ when $\tau < 1$. Intuitively, without localization, when the cross-country difference in privacy preference ($|\tau - 1|$) is larger, there would be a larger difference between the firm's privately-desired data-usage and the lower of the caps imposed in the two countries. Accordingly, the profit difference caused by localization becomes greater.

Note that $k_2(\tau) > k_1(\tau) \equiv \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x}) > 0$ when $\tau \neq 1$. As shown in Section 5.1, if there is no regulation, the firm invests in localization if and only if $k < k_1(\tau)$ and $\theta > \theta^l$. In contrast, under regulations $\sigma_H^l = \widehat{x}_H$ and $\sigma_F^l = \widehat{x}_F$, the firm invests in localization if and only if $k < k_2(\tau)$. That is, data regulations strengthen the firm's incentives to invest in localization, because localization allows the firm to follow the different data-usage caps in the two countries instead of complying with the lower of the two caps.

When localization is feasible, will data regulations enhance or reduce global welfare? If the firm does not invest in localization with or without regulation, then the welfare impact of regulations is the same as in Proposition 3. If the firm will always choose localization, then regulations weakly increase global welfare by possibly increasing the firm's commitment ability. However, if the firm will choose localization under and only under regulation, then regulation may reduce welfare by causing inefficient localization investment. Formally:

Proposition 5 *(Localization with Data Regulation) (i) When $\tau > 1$, there exists an equilibrium with $\sigma_H^l = \widehat{x}_H$ and $\sigma_F^l = \widehat{x}_F$ under which the firm chooses localization if and only if $k < k_2(\tau)$, where $k_2(\tau)$ increases in τ. (ii) When $\tau < 1$, if $k < k_2(\tau)$, where $k_2(\tau)$ decreases in τ, there exists an equilibrium with $\sigma_H^l = \widehat{x}_H$ and $\sigma_F^l = \widehat{x}_F$ under which the firm chooses localization. In both (i) and (ii), if $m''(u) \geq 0$ and $k < k_1(\tau) < k_2(\tau)$, then regulations (weakly) increase global welfare. However, if $m''(u) < 0$ and $k \in [k_1(\tau), k_2(\tau))$, there is a set of parameter values under which regulations reduce welfare.*

Therefore, our main result that data regulations can either increase or decrease global welfare remains valid when data localization is feasible. When localization investment is not too costly ($k < k_1(\tau) < k_2(\tau)$) and the demand curvature is weakly increasing ($m''(u) \geq 0$), global welfare is maximized if the firm chooses both localization and efficient data usages. But the firm lacks the incentive for localization if $\theta \leq \theta^l$ and may also be unable to commit to the efficient data-usage levels. Data regulations can raise global welfare by solving the firm's commitment problem (as when localization is not possible), and additionally, regulations can increase welfare by enhancing the firm's localization incentive.

On the other hand, when localization investment is more costly and the demand curvature is decreasing, global welfare is maximized if the firm chooses the uniform data-usage level x^o in the two countries, without localization. Global welfare in this case varies non-monotonically with θ and is closer to the global optimum when θ is in an intermediate range (see Proposition 3). However, regulations can lead to excessive investment in localization, reducing global welfare.[21]

Importantly, a uniform data-usage regulation is generally not optimal, even when countries can coordinate their regulations. Uniformity in the regulation of data usage for each country does not allow for the flexibility desirable under preference diversity across countries, and it cannot realize the potential gains when the firm can choose the efficient data usages through localization or when coordinated regulations can impose optimally differentiated data-usage caps in different countries.

6. DISCUSSION

To convey our ideas in the most transparent way, we have considered a highly stylized model. The main insights of our analysis will continue to hold in more general settings. Below, we discuss two possible extensions.

[21] We choose to spare the readers from the complicated expressions that explicitly characterize the set of parameter values under which regulations reduce welfare in Proposition 5.

6.1 Imperfect Enforcement of Regulation

Our baseline model assumes that regulations are perfectly enforced and the firm always complies with both caps on data usage. The insights regarding cross-country externalities remain robust even when regulation enforcement is imperfect. For illustration, suppose that there is no data localization and consider the scenario with $\tau > 1$. Suppose further that regulators in H and F can independently and simultaneously set caps on data usage and regulation enforcement is perfect in H but imperfect in F, with an expected penalty $D > 0$ if the firm violates the regulation in F. This limited liability reflects the possibility that the violation of regulation is undetected or the firm faces financial constraints.

As shown in Lemma 5, when enforcement is perfect, the optimal caps satisfy $r'(\sigma_F) = \tau$ and $V^{H'}(\sigma_H) + \pi'(\sigma_H) = 0$. When $\tau > 1$, we have $\sigma_F < \min\{x^o, \widehat{x}, \sigma_H\}$ and $\sigma_H > \widehat{x}$. Suppose that the countries maintain the same caps σ_H and σ_F under imperfect enforcement. If the firm follows the regulations and choose $x = \sigma_F$, its profit is $\pi(\sigma_F)$. If the firm violates the regulation in country F , it will choose $x = \min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}$.[22] Therefore, the firm would comply with the regulation in F if and only if

$$D \geq \overline{D} \equiv \pi\left(\min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}\right) - \pi\left(\sigma_F\right). \tag{31}$$

When the penalty is large, $D \geq \overline{D}$, the firm complies with the more stringent regulation σ_F, which causes negative output and data-usage externalities in country H, the same as in the baseline model. When the penalty is small, $D < \overline{D}$, the firm violates the regulation in F. In this case, if $1 - \theta > \sigma_H$, the firm chooses $x = \sigma_H$, which mitigates the moral hazard problem and increases welfare in both countries compared to the scenario with no regulation.

Moreover, for a given penalty D, the countries may have incentives to impose caps different from σ_H and σ_F. For example, if $D < \overline{D}$, country F may impose a less-restrictive cap $\widetilde{\sigma}_F > \sigma_F$ to ensure that the firm will comply with the cap in F. If

[22] As shown in Proposition 1, the unregulated firm chooses $x = \max\{\widehat{x}, 1-\theta\}$. If the firm violates the regulation in F but has to comply with the regulation in H, then its optimal choice of data usage is $x = \min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}$.

$\widetilde{\sigma}_F < \min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}$, then this unilateral regulation change in F increases consumer surplus in F but may reduce global welfare. Similarly, country H may impose a less-restrictive cap $\widetilde{\sigma}_H > \sigma_H$, motivating the firm to violate the regulation in country F. Such strategic behavior can further reduce global welfare, suggesting one more reason for international coordination on regulations.

6.2 Consumer Opt-Out

In recent years, some countries have enacted the "opt-out" policy, which allows consumers to opt out of the collection and use of their personal data by firms. We can incorporate the opt-out policy in our model. Suppose that there is no data localization and data usage transparency is not too low: $\theta > 1 - \min\{\sigma_H, \sigma_F\}$. Recall that consumers only observe x_1 but not x_2. Suppose that H allows consumers to opt out of observable data collection when $x_1 > \frac{\sigma_H - (1-\theta)}{\theta}$ and F allows consumers to opt out of observable data collection when $x_1 > \frac{\sigma_F - (1-\theta)}{\theta}$. Since consumers have a strict preference for privacy, they would indeed opt out when these conditions are met.

In equilibrium, the firm always chooses $x_2 = 1$, as shown in Section 4. If the firm chooses $x_1 \leq \frac{\min\{\sigma_H, \sigma_F\} - (1-\theta)}{\theta}$, then the equilibrium data-usage level satisfies

$$x = \theta x_1 + (1-\theta) \leq \min\{\sigma_H, \sigma_F\}. \tag{32}$$

If the firm chooses $x_1 > \frac{\min\{\sigma_H, \sigma_F\} - (1-\theta)}{\theta}$, then consumers will opt out, in which case x_1 drops to 0 and the data-usage level becomes $x = x_2 = 1 - \theta$. Since the firm's privately-desired data-usage $\widehat{x}$ satisfies

$$1 - \theta < \min\{\sigma_H, \sigma_F\} \leq \widehat{x} \leq \max\{\sigma_H, \sigma_F\}, \tag{33}$$

profit is higher when data usage is $\min\{\sigma_H, \sigma_F\}$ than when it is $1-\theta$. Therefore, under the opt-out policy, the firm would choose $x = \min\{\sigma_H, \sigma_F\}$. Then the welfare impact of the regulations will be the same as in Section 4. Unilateral opt-out policies can cause negative output and data-usage externalities across countries.

7. CONCLUSION

This paper has conducted an economic analysis of the use and protection of consumer data in an international context. We find that a multinational firm may inefficiently exploit consumer data due to moral hazard or international differences in consumer preference for privacy. Unilateral data regulations imposed by individual countries can impact global welfare positively by solving the moral hazard problem but negatively due to output reductions or data-usage distortions from cross-country externalities. Properties of demand curvature play important roles in determining the net welfare effect. We also show that data regulations can improve welfare when they encourage—but do not cause excessive—investment in data localization. There is significant scope of welfare gains from international coordination in regulations to protect consumer data, though a uniform standard on data usage is generally not warranted.

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APPENDIX

The appendix contains proofs for Lemma 1, Lemma 2, Proposition 1, Lemma 4, Lemma 5, Proposition 3, Proposition 4, and Proposition 5.

Proof of Lemma 1. Equilibrium prices p_H^* and p_F^*, when they are interior, satisfy the first-order conditions

$$\begin{aligned}\frac{\partial \tilde{\pi}(p_H, p_F)}{\partial p_H} &= [1 - G(p_H^* + x)] - [p_H^* + r(x)]\, g(p_H^* + x) = 0, \\ \frac{\partial \tilde{\pi}(p_H, p_F)}{\partial p_F} &= [1 - G(p_F^* + \tau x)] - [p_F^* + r(x)]\, g(p_F^* + \tau x) = 0,\end{aligned}$$

or equivalently,

$$\begin{aligned}p_H^* + r(x) &= m(p_H^* + x), \\ p_F^* + r(x) &= m(p_F^* + \tau x).\end{aligned}$$

If condition (ii) in Assumption A1 holds, $m(p_H + x) \geq p_H + r(x)$ when $p_H = \underline{u} - x$, and condition (i) then ensures a unique interior solution of $p_H^* > \underline{u} - x$. Similarly, Assumption A1 ensures the unique existence of $p_F^* > \underline{u} - \tau x$.

Next, if $\tau = 1$, obviously $p_H^* = p_F^*$ and $q_H^* = q_F^*$.

If $\tau > 1$, suppose to the contrary that $p_H^* \leq p_F^*$. Then

$$\begin{aligned}p_H^* + r(x) &\leq p_F^* + r(x) \\ &\Longrightarrow m(p_H^* + x) \leq m(p_F^* + \tau x) \\ &\Longrightarrow p_H^* + x \geq p_F^* + \tau x \\ &\Longrightarrow p_H^* - p_F^* \geq \tau x - x > 0,\end{aligned}$$

a contradiction. Hence $p_H^* > p_F^*$. Moreover, suppose to the contrary that $q_H^* = 1 - G(p_H^* + x) \leq 1 - G(p_F^* + \tau x) = q_F^*$. Then

$$\begin{aligned}p_H^* + x &\geq p_F^* + \tau x \\ &\Longrightarrow m(p_H^* + x) \leq m(p_F^* + \tau x) \\ &\Longrightarrow p_H^* + r(x) \leq p_F^* + r(x) \\ &\Longrightarrow p_H^* \leq p_F^*,\end{aligned}$$

a contradiction. Hence $q_H^* > q_F^*$.

The proof for the case of $\tau < 1$ is similar and omitted. ■

Proof of Lemma 2. As shown in Lemma 1, if $\tau > 1$, then $p_H^* + x < p_F^* + \tau x$ and $q_H^* > q_F^*$. In this case, $\rho_r^H > \rho_r^F$ if $m''(u) < 0$ while $\rho_r^H < \rho_r^F$ if $m''(u) > 0$.

Similarly, if $\tau < 1$, then $p_H^* + x > p_F^* + \tau x$ and $q_H^* < q_F^*$. In this case, $\rho_r^H > \rho_r^F$ if $m''(u) > 0$ while $\rho_r^H < \rho_r^F$ if $m''(u) < 0$. ■

Proof of Proposition 1. Since consumers cannot observe x_2 before purchase, in the equilibrium $x_2 = 1$ and consumers hold the correct belief. If $\theta < 1 - \widehat{x}$, since $\pi(x)$ is decreasing for $x > \widehat{x}$, it is also decreasing in x_1. Hence $x_1 = 0$ and $x^* = \theta x_1 + (1-\theta) = 1-\theta$. On the other hand, if $\theta \geq 1 - \widehat{x}$, then $x^* = \theta x_1 + (1-\theta) = \widehat{x}$ maximizes $\pi(x)$, which implies $x_1 = \frac{\widehat{x} - (1-\theta)}{\theta}$. ■

Proof of Lemma 4. Notice that by assumption, $W(x)$ is single-peaked at x^o. If $\tau = 1$, then $p_H^* = p_F^*$ and $\rho_r^H = \rho_r^F$, and it follows from (11) and (15) that $x^o = \widehat{x}$. If $m'(u)$ is constant and accordingly $\rho_r^H = \rho_r^F$, then (11) and (15) become the same, which implies $x^o = \widehat{x}$.

If $\tau > 1$, then $p_H^* + x < p_F^* + \tau x$ and $q_H^* > q_F^*$. Note that $1 < r'(\widehat{x}) < \tau \;\; if \;\; \tau > 1$. If additionally $m''(u) > 0$ so that $\rho_r^H < \rho_r^F$ at $r(\widehat{x})$, then from (11) and (15), $W'(\widehat{x}) < 0$, which implies $x^o < \widehat{x}$; whereas if $m''(u) < 0$ so that $\rho_r^H > \rho_r^F$ at $r(\widehat{x})$, then $W'(\widehat{x}) > 0$, which implies $x^o > \widehat{x}$.

If $\tau < 1$, then $p_H^* + x > p_F^* + \tau x$ and $q_H^* < q_F^*$. Note that $1 > r'(\widehat{x}) > \tau \; if \;\; \tau < 1$. If additionally $m''(u) > 0$ so that $\rho_r^H > \rho_r^F$ at $r(\widehat{x})$, then, from (11) and (15), $W'(\widehat{x}) < 0$, which implies $x^o < \widehat{x}$; whereas if $m''(u) < 0$, then $W'(\widehat{x}) > 0$, which implies $x^o > \widehat{x}$. ■

Proof of Lemma 5. (i) When $\tau = 1$, $p_H^* = p_F^*$, and $r'(\sigma_H) = 1$ solves (21). Therefore, $\sigma_H = \sigma_F = x^o = \widehat{x}$.

(ii) When $\tau > 1$, $r'(\sigma_F) = \tau > 1$. Since $\rho_r^H > 0$, $[r'(x) - 1](1 + \rho_r^H) > 0$ at $x = \sigma_F$. Therefore, from (21), $V^{H'}(x) + \pi'(x) > 0$ at $x = \sigma_F$. Thus $\sigma_H > \sigma_F$. Also, from (14), $W'(x) > 0$ at $x = \sigma_F$, and from (11), $\pi'(x) > 0$ at $x = \sigma_F$. Hence $\sigma_F < \min\{x^o, \widehat{x}, \sigma_H\}$.

Moreover, if $\tau \to 1$, from (14), $\sigma_F \to x^o$.

(iii)When $\tau < 1$, $r'(\sigma_F) = \tau < 1$. Since $[r'(x) - 1](1+\rho_r^H) < 0$ at $x = \sigma_F$, $V^{H'}(x) + \pi'(x) < 0$ at $x = \sigma_F$, and hence $\sigma_H < \sigma_F$ because $V^{H'}(\sigma_H) + \pi'(\sigma_H) = 0$. Since $V^{H'}(x) + \pi'(x) > 0$ when $r'(x) = 1$, we have $r'(\sigma_H) < 1$. Moreover, $W'(\sigma_H) > 0$ and $\pi'(\sigma_H) > 0$. Hence $x^o > \sigma_H$ because $W'(x^o) = 0$ and $\widehat{x} > \sigma_H$ because $\pi'(\widehat{x}) = 0$. Moreover, if $\tau \to 1$, from (14), $\sigma_F \to x^o$. ■

Proof of Proposition 3. To comply with regulations, $x^r = \min\{\sigma_H, \sigma_F\}$. Notice that $\pi'(x) > 0$ for any $x < \min\{\sigma_H, \sigma_F\}$. So the firm would not choose $x^r < \min\{\sigma_H, \sigma_F\}$.

(i) When $\tau = 1$, from Lemma 5, $x^r = x^o = \widehat{x}$. If $\theta < 1 - \widehat{x}$, $x^* = 1 - \theta > x^o$, and hence regulations improve welfare. If $\theta \geq 1 - \widehat{x}$, then $x^* = x^r = x^o$, and hence welfare is the same with or without regulation.

(ii) When $\tau > 1$, from Lemma 5, $x^r = \sigma_F < \min\{x^o, \widehat{x}, \sigma_H\}$, with $r'(\sigma_F) = \tau$. When $\tau < 1$, from Lemma 5, $x^r = \sigma_H < \min\{x^o, \widehat{x}, \sigma_F\}$, with $V^{H'}(\sigma_H) + \pi'(\sigma_H) = 0$. Now, consider three cases.

First, suppose $\tau \neq 1$ and $x^o < \widehat{x}$ (a sufficient condition is $m''(u) > 0$ as shown by Lemma 4). Then similar to Proposition 2, if there is no regulation, $x^* > x^o$, with $W(x^*)$ increasing in θ for $\theta < 1 - \widehat{x}$ and $W(x^*) = W(\widehat{x})$ for $\theta \geq 1 - \widehat{x}$. In contrast, with regulations, welfare $W(x^r)$ is independent of θ. Therefore, there exists μ_θ such that $W(x^r) > W(x^*)$ if and only if $\theta < \mu_\theta$. Note that the range of $\theta < \mu_\theta$ or the range of $\theta > \mu_\theta$ may degenerate to be empty.

Second, suppose $\tau \neq 1$ and $x^o = \widehat{x}$ (a sufficient condition is $m''(u) = 0$ as shown by Lemma 4). Then similar to Proposition 2, if there is no regulation, $x^* > x^o$ if $\theta < 1 - \widehat{x}$ and $x^* = x^o$ if $\theta \geq 1 - \widehat{x}$, with $W(x^*)$ increasing in θ for $\theta < 1 - \widehat{x}$ and $W(x^*) = W(x^o)$ for $\theta \geq 1 - \widehat{x}$. If there is regulation, from Lemma 5, $\min\{\sigma_H, \sigma_F\} < \widehat{x} = x^o$, which implies $W(x^r) < W(x^*) = W(\widehat{x}) = W(x^o)$ when $\theta \geq 1 - \widehat{x}$. Therefore, there exists $\mu_\theta \in [0, 1 - \widehat{x})$ such that $W(x^r) < W(x^*)$ if and only if $\theta > \mu_\theta$.

Third, suppose $\tau \neq 1$ and $x^o > \widehat{x}$ (a sufficient condition is $m''(u) < 0$ as shown by Lemma 4). Then similar to Proposition 2, if there is no regulation, $x^* > x^o$ if $\theta < 1 - x^o$, $x^* = x^o$ if

$\theta = 1 - x^o$, $x^* < x^o$ if $\theta \in (1 - x^o, 1 - \widehat{x})$, and $x^* = \widehat{x}$ if $\theta \geq 1 - \widehat{x}$, with $W(x^*)$ increasing in θ for $\theta < 1 - x^o$ and decreasing in θ for $\theta \in (1 - x^o, 1 - \widehat{x})$. That is, without regulation, $W(x^*)$ has an inverted U-shaped relationship with θ. If there is regulation, from Lemma 5 , $\min\{\sigma_H, \sigma_F\} < \widehat{x} < x^o$, which implies $W(x^r) < W(x^*) = W(\widehat{x})$ when $\theta \geq 1 - \widehat{x}$. Therefore, there exists $\mu_\theta \in [0, 1 - \widehat{x})$ such that $W(x^r) < W(x^*)$ if and only if $\theta > \mu_\theta$.

To summarize, when $\tau \neq 1$ and $x^o \geq \widehat{x}$ (or particularly $m''(u) \leq 0$), the cut-off $\mu_\theta < 1 - \widehat{x} < 1$. When $\tau \neq 1$ and $x^o < \widehat{x}$ (or particularly $m''(u) > 0$), in general μ_θ may be less than or equal to 1. However, if $m''(u)$ is sufficiently small relative to $|\tau - 1|$ and $\theta \geq 1 - \widehat{x}$, then $\widehat{x}$ is sufficiently close to x^o while x^r is much larger than x^o, and hence $W(x^r) < W(x^*) = W(\widehat{x})$,which implies $\mu_\theta < 1 - \widehat{x} < 1$.

It remains to identify conditions under which $\mu_\theta > 0$. Note that, without regulation $W(x^*) \to W(1)$ as $\theta \to 0$, while with regulation $W(x^r) \to W(x^o)$ as $\tau \to 1$ for any θ. Because $W(x^o) - W(1)$ is bounded away from zero and $W(x^r) - W(x^o) \to 0$ as $\tau \to 1$, there exists $\mu_\tau > 0$ such that if $|\tau - 1| \leq \mu_\tau$, then $W(x^r) > W(1)$ (that is, $\mu_\theta > 0$). ■

Proof of Proposition 4.

(1) We first characterize the firm's localization decisions. Suppose that $\tau > 1$ and $\theta \in (1 - \max\{\widehat{x}_H, \widehat{x}_F\}, 1 - \min\{\widehat{x}_H, \widehat{x}_F\})$. In this case, $\widehat{x}_H > \widehat{x}_F$. With localization, firm profit (excluding costs k) is

$$\pi(\widehat{x}_H, 1-\theta) = \lambda q_H^l(\widehat{x}_H)[p_H^l + r(\widehat{x}_H)] + (1-\lambda)q_F^l(1-\theta)[p_F^l + r(1-\theta)].$$

According to Proposition 1, without localization, firm profit is

$$\begin{aligned}\pi(\max\{\widehat{x}, 1-\theta\}) &= \lambda q_H^*(\max\{\widehat{x}, 1-\theta\})[p_H^* + r(\max\{\widehat{x}, 1-\theta\})] \\ &\quad +(1-\lambda)q_F^*(\max\{\widehat{x}, 1-\theta\})[p_F^* + r(\max\{\widehat{x}, 1-\theta\})].\end{aligned}$$

Since $\max\{\widehat{x}, 1-\theta\} \geq 1-\theta > \widehat{x}_F$, firm profit in country F is higher under localization. By definition, firm profit in country H is maximized by $\widehat{x}_H$. Therefore, total profit (excluding costs k) is higher under data localization. Now consider two case.

First, suppose $\theta < 1 - \widehat{x}$. The profit difference (excluding costs k) becomes

$$\pi(\widehat{x}_H, 1-\theta) - \pi(1-\theta) = \lambda q_H^l(\widehat{x}_H)[p_H^l + r(\widehat{x}_H)] - \lambda q_H^*(1-\theta)[p_H^* + r(1-\theta)]. \qquad (34)$$

The first term in (34) is independent of θ. The second term, $\lambda q_H^*(1-\theta)[p_H^* + r(1-\theta)]$, is the firm's profit in country H when $x = 1-\theta$. Since $\widehat{x}_H$ maximizes firm profit in H and $x = 1-\theta < \widehat{x}_H$, firm profit in country H increases in x or, equivalently, decreases in θ. Accordingly, the profit difference $\pi(\widehat{x}_H, 1-\theta) - \pi(1-\theta)$ increases in θ.

Second, suppose $\theta \geq 1-\widehat{x}$. The profit difference (excluding costs k) becomes

$$\pi(\widehat{x}_H, 1-\theta) - \pi(\widehat{x}) = \lambda q_H^l(\widehat{x}_H)[p_H^l + r(\widehat{x}_H)] + (1-\lambda) q_F^l(1-\theta)[p_F^l + r(1-\theta)] - \pi(\widehat{x}), \quad (35)$$

where only the second term (the firm's profit in country F under localization) depends on θ. Since $\widehat{x}_F$ maximizes firm profit in F and $x = 1-\theta > \widehat{x}_F$, the second term decreases in x or, equivalently, increases in θ. Accordingly, the profit difference $\pi(\widehat{x}_H, 1-\theta) - \pi(\widehat{x})$ increases in θ.

To summarize, when $\tau > 1$ and $\theta \in (1-\widehat{x}_H, 1-\widehat{x}_F)$, the profit difference between localization and no localization strictly increases in θ. The same result can be obtained when $\tau < 1$ and $\theta \in (1-\widehat{x}_F, 1-\widehat{x}_H)$. Thus, given any $k < k_1(\tau) = \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x})$, there exists a unique θ^l such that $\pi(x_H^*, x_F^*; \theta) - \pi(x^*; \theta) > k$ if and only if $\theta > \theta^l$. The earlier analysis also implies θ^l increases in k.

(2) Now we examine whether the firm's decision about localization is socially efficient or not. Consider three ranges of θ.

First, suppose $\theta \leq 1 - \max\{\widehat{x}_H, \widehat{x}_F\}$. As shown in the text, $x_H^* = x_F^* = x^* = 1-\theta$, so that the firm would never invest in localization and this decision is socially efficient.

Second, suppose $\theta \geq 1 - \min\{\widehat{x}_H, \widehat{x}_F\}$. Since $\min\{\widehat{x}_H, \widehat{x}_F\} < \widehat{x}$, $\theta > 1-\widehat{x}$. Then $x_H^* = \widehat{x}_H$ and $x_F^* = \widehat{x}_F$ with localization, and $x^* = \widehat{x}$ without localization. The firm invests in localization if and only if $k < k_1(\tau)$. Note that

$$W(\widehat{x}_H, \widehat{x}_F) - W(\widehat{x}) > \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x}) = k_1(\tau).$$

When $k < k_1(\tau)$, the firm invests in localization, which is socially efficient. When $k \in [k_1(\tau), W(\widehat{x}_H, \widehat{x}_F) - W(\widehat{x}))$, the firm does not invest in localization while localization raises global welfare. When $k > W(\widehat{x}_H, \widehat{x}_F) - W(\widehat{x})$, the firm does not invest in localization and this decision is efficient.

Finally, suppose $1-\max\{\widehat{x}_H, \widehat{x}_F\} < \theta < 1-\min\{\widehat{x}_H, \widehat{x}_F\}$. The firm invests in localization if and only if $k < k_1(\tau)$ and $\theta > \theta^l$, where $\theta^l \in (1-\max\{\widehat{x}_H, \widehat{x}_F\}, 1-\min\{\widehat{x}_H, \widehat{x}_F\})$. Notice that $\theta^l \to 1-\max\{\widehat{x}_H, \widehat{x}_F\}$ if $k \to 0$ and $\theta^l \to 1-\min\{\widehat{x}_H, \widehat{x}_F\}$ if $k \to k_1(\tau)$. Given any $\theta \in (1-\max\{\widehat{x}_H, \widehat{x}_F\}, 1-\min\{\widehat{x}_H, \widehat{x}_F\})$, we have

$$W\left(x_H^*, x_F^*\right) - W\left(x^*\right) > \pi\left(x_H^*, x_F^*\right) - \pi\left(x^*\right).$$

When $k < \pi\left(x_H^*, x_F^*\right) - \pi\left(x^*\right)$, the firm invests in localization, which is socially efficient. When $k \in [\pi\left(x_H^*, x_F^*\right) - \pi\left(x^*\right), W\left(x_H^*, x_F^*\right) - W\left(x^*\right))$, the firm does not invest in localization while localization raises global welfare. When $k > W\left(x_H^*, x_F^*\right) - W\left(x^*\right)$, the firm does not invest in localization and this decision is efficient. ■

Proof of Proposition 5. (i) Suppose $\tau > 1$. Then $\min\{\widehat{x}_H, \widehat{x}_F\} = \widehat{x}_F$ and $k_2(\tau) = \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x}_F)$. Note

$$k_2'(\tau) = \frac{d\pi(\widehat{x}_H, \widehat{x}_F)}{d\tau} - \frac{d\pi(\widehat{x}_F)}{d\tau} = -\lambda[1 - G(p_H^*(\widehat{x}_F) + \widehat{x}_F)]\frac{d\widehat{x}_F}{d\tau} > 0,$$

given $\frac{d\widehat{x}_F}{d\tau} = \frac{1}{r''(\widehat{x}_F)} < 0$. That is, when $\tau > 1$, the profit difference $k_2(\tau) = \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x}_F)$ strictly increases in τ and is arbitrarily close to 0 when $\tau \to 1$. The equilibrium characterization follows from the text.

(ii) Suppose $\tau < 1$. Then $\min\{\widehat{x}_H, \widehat{x}_F\} = \widehat{x}_H$ and $k_2(\tau) = \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x}_H)$. Note that

$$k_2'(\tau) = -(1-\lambda)[1 - G(p_F^l(\widehat{x}_F) + \tau\widehat{x}_F)]\widehat{x}_F - (1-\lambda)[1 - G(p_F^*(\widehat{x}_H) + \tau\widehat{x}_H)]\widehat{x}_H < 0,$$

given $\widehat{x}_F > \widehat{x}_H$ and $1 - G(p_F^l(\widehat{x}_F) + \tau\widehat{x}_F) > 1 - G(p_F^*(\widehat{x}_H) + \tau\widehat{x}_H)$ from Lemma 3. When $\tau < 1$, the profit difference strictly decreases in τ. The equilibrium characterization then follows from the text.

Now we consider the welfare impact of data-usage regulations.

First, suppose $\tau \neq 1$ and $k < k_1(\tau) < k_2(\tau)$. When there is no regulation, the firm invests in localization if and only if $\theta > \theta^l$; when there are data regulations, the firm always invests in localization. Therefore, when $\theta > \theta^l$, the welfare difference between having regulations and not having regulations is

$$[W(\widehat{x}_H, \widehat{x}_F) - k] - [W(x_H^*, x_F^*; \theta) - k] \geq 0.$$

When $\theta \leq \theta^l$, the welfare difference is $[W(\widehat{x}_H, \widehat{x}_F) - k] - W(x^*; \theta)$. Proposition 3 implies that, if $m''(u) \geq 0$ and there is no localization, global welfare $W(x^*; \theta)$ increases in θ for $\theta \leq \theta^l$. By the definition of θ^l, we have

$$W(x_H^*, x_F^*; \theta^l) - W(x^*; \theta^l) > \pi(x_H^*, x_F^*; \theta^l) - \pi(x^*; \theta^l) = k.$$

Then by continuity, for any $\theta \leq \theta^l$, we have

$$[W(\widehat{x}_H, \widehat{x}_F) - k] - W(x^*; \theta) > 0.$$

To summarize, given $\tau \neq 1$ and $k < k_1(\tau) < k_2(\tau)$, if $m''(u) \geq 0$, regulations (weakly) increase welfare for any $\theta \in [0, 1]$.

Next, suppose $m''(u) < 0$ and $k \in [k_1(\tau), k_2(\tau))$. Proposition 3 implies that, if there is no regulation and the firm does not invest in localization, global welfare $W(x^*; \theta)$ has an inverted U-shaped relationship with θ and achieves the optimum $W(x^o)$ when $\theta = 1 - x^o$. Consider the special case with $\theta = 1 - x^o$. If $k \in [k_1(\tau), k_2(\tau))$, when there is no regulation, the firm does not invest in localization and global welfare is $W(x^o)$; when there are regulations, the firm invests in localization and global welfare is $W(\widehat{x}_H, \widehat{x}_F) - k$. Then regulations reduce global welfare if

$$W(\widehat{x}_H, \widehat{x}_F) - W(x^o) < k < k_2(\tau).$$

Consider the case with $\tau > 1$. We have

$$k_2'(\tau) = -\lambda[1 - G(p_H^*(\widehat{x}_F) + \widehat{x}_F)]\frac{d\widehat{x}_F}{d\tau} > 0,$$

and, by the envelop theorem,

$$\begin{aligned} & \frac{d[W(\widehat{x}_H, \widehat{x}_F) - W(x^o)]}{d\tau} \\ = \quad & -2(1-\lambda)\{[1 - G(p_F^l(\widehat{x}_F) + \tau\widehat{x}_F)]\widehat{x}_F - [1 - G(p_F^*(x^o) + \tau x^o)]x^o\}. \end{aligned}$$

Therefore, if λ is greater than but arbitrarily close to 1, we have $k_2'(\tau) > \frac{d[W(\widehat{x}_H, \widehat{x}_F) - W(x^o)]}{d\tau}$. Moreover, when $\tau = 1$, $\widehat{x}_H = \widehat{x}_F = x^o$ so that $W(\widehat{x}_H, \widehat{x}_F) - W(x^o) = k_2(\tau)$. Then by continuity, when λ is sufficiently large, there exists $\widetilde{\tau} > 1$ such that for any $\tau \in (1, \widetilde{\tau})$, we have

$$W(\widehat{x}_H, \widehat{x}_F) - W(x^o) < k_2(\tau),$$

which further implies that, for θ arbitrarily close to $1 - x^o$,

$$W(\widehat{x}_H, \widehat{x}_F) - W(x^*; \theta) < k_2(\tau).$$

Similarly, when τ is less than but arbitrarily close to 1, $\widehat{x}_H$ is arbitrarily close to x^o, so that

$$\begin{aligned} k_2'(\tau) &= -(1-\lambda)\{[1 - G(p_F^l(\widehat{x}_F) + \tau\widehat{x}_F)]\widehat{x}_F - [1 - G(p_F^*(\widehat{x}_H) + \tau\widehat{x}_H)]\widehat{x}_H\} \\ &> \frac{d[W(\widehat{x}_H, \widehat{x}_F) - W(x^o)]}{d\tau}. \end{aligned}$$

Therefore, there exists $\widehat{\tau} < 1$ such that for any $\tau \in (\widehat{\tau}, 1)$, we have

$$W(\widehat{x}_H, \widehat{x}_F) - W(x^o) < k_2(\tau),$$

which further implies that, for θ arbitrarily close to $1 - x^o$,

$$W(\widehat{x}_H, \widehat{x}_F) - W(x^*; \theta) < k_2(\tau).$$

Define $\widehat{k}(\tau) = \max\{W(\widehat{x}_H, \widehat{x}_F) - W(x^o), k_1(\tau)\}$. To summarize, we have two sets of parameter values under which regulations reduce global welfare: (1) when $m''(u) < 0$ and λ is sufficiently large, there exist $\widetilde{\tau} > 1$ and (for any $\tau \in (1, \widetilde{\tau})$) $\mu_{\theta 1}$ and $\mu_{\theta 2}$, with $\mu_{\theta 1} < \mu_{\theta 2}$, such that regulations reduce welfare if $k \in (\widehat{k}(\tau), k_2(\tau))$ and $\theta \in (\mu_{\theta 1}, \mu_{\theta 2})$; (2) when $m''(u) < 0$, there exists $\widehat{\tau} < 1$ and (for any $\tau \in (\widehat{\tau}, 1)$) $\mu'_{\theta 1}$ and $\mu'_{\theta 2}$, with $\mu'_{\theta 1} < \mu'_{\theta 2}$, such that regulations reduce welfare if $k \in (\widehat{k}(\tau), k_2(\tau))$ and $\theta \in (\mu'_{\theta 1}, \mu'_{\theta 2})$. ■