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International Protection of Consumer Data

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HKUST CEP Working Paper No. 2020-04

November 30, 2020

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JEL codes: F23, D18, L15

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

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We thank Jin-Hyuk Kim, Larry Qiu, Kathryn Spier, and seminar participants at the Hong Kong University of Science and Technology for their helpful comments. We thank Zhong Long for excellent research assistance. Xinyu Hua gratefully acknowledges financial support from the Research Grant Council of Hong Kong under GRF grant number 16501019. Declarations of interest: none.

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]

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 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

[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.

the European countries surveyed are data fundamentalists, who are unwilling to provide personal information, than consumers in the United States.[3] 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.[4]

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).[5]

The complexity of data usage and protection in the international context raises several important questions. What are the incentives of a multinational firm to collect, use, and protect consumer data, and how do they differ from those of a firm that operates in a single country? When countries with different privacy preferences introduce data 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? This paper conducts an economic analysis that aims to answer these questions.

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

[3] 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.

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

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

the data through, for example, data sales, price discrimination, or targeted advertising. The firm sets the data-usage level associated with the product that is common in both countries.[6] A larger data-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 to—data usage. When making purchase decisions, consumers will consider not only their utility from the product and product price, but also the disutility from the firm's data usage.

We start with the benchmark where the firm sells its product only in one country, which is equivalent to a special case of our model where consumer privacy preference is the same across countries. In this case, if data usage is completely transparent, a firm will fully internalize consumers' disutility from data usage that negatively impacts the demand for its product, and the firm will thus choose the usage level at which its marginal benefit to the firm equals its marginal cost to the consumers, same as the choice of a social planner who could set data usage (but not the firm's price). However, this efficient and also profit-maximizing benchmark is unattainable if transparency is not high enough. The firm would then have the moral hazard of overusing the part of the data that is unobservable to consumers. In equilibrium, consumers correctly anticipate the firm's choice and reduce their willingness to pay for the product, which decreases both profit and efficiency. Therefore, when there is only one country, profit and welfare are both (weakly) higher with more transparency, which enables the firm to commit to (weakly) lower data usage. In this case, although more transparency leads to a higher equilibrium price, total output and consumer surplus nevertheless rise due to higher consumer demand.

We next analyze the firm's data usage in the global market where consumers differ across countries in their preference for privacy. When data usage lacks transparency, there is again the distortion due to the firm's inability to commit not to overuse consumer data. But now,

[6] For reasons such as common product design and common software used to process data, it could be too costly or impractical to apply different data systems or data protections for consumers in different countries (this assumption is further discussed in Section 2). We shall allow the firm to set different usage levels across countries when studying its endogenous data localization decisions in Section 5.

in contrast to the single-country case, the equilibrium data usage can be inefficiently excessive or deficient (from the global perspective) even if there is full transparency. This happens because, due to the difference in consumer disutility from data usage in different countries, the effective price paid by consumers for the product (which includes their disutility from the loss of privacy) generally differs across countries. Thus, when the firm changes data usage, it adjusts its product price differently in different countries if demand curvature is not constant, resulting in different impacts on consumer surplus in the two countries. In this case, the firm's profit-maximizing data usage is no longer efficient even if the firm has full commitment capability. Properties of demand curvature thus play an important role in determining equilibrium data usage and global welfare. Moreover, although increasing transparency (weakly) increases firm profits, it can exacerbate the data-usage distortion and the output distortion associated with it, reducing global welfare.

We further consider the possibility that countries can regulate the use or protection of consumer data by unilaterally imposing caps on data-usage levels. Unlike in the single-country case where regulation alleviates the firm's commitment problem and leads to (weakly) higher welfare, regulation can now reduce total welfare, because a country with a stronger preference for privacy does not internalize the negative impact of more restrictive regulation on the output and data usage in the other country. We demonstrate that equilibrium data regulations increase global welfare when data-usage transparency is low but can reduce welfare when transparency is high. We further provide conditions under which international coordination of data regulation may or may not achieve (full) global efficiency. Properties of demand curvature also play an important role in determining the welfare effects of data regulations.

We finally consider the possibility that the firm may invest in data localization, which allows it to choose a data-usage level specific to a country. The firm can benefit from this option, but its private incentive to make the investment can be inefficiently low. While unilateral data regulations strengthen the firm's incentive to invest in localization, it could also cause (inefficiently) excessive investment and reduce welfare in equilibrium.

Overall, our analysis reveals that the use and protection of consumer data may be inefficient in the global market, not only due to possible lack of transparency in data usage that causes distortion in the single-country case, but also due to differences in consumer preference for privacy across countries. Although data regulations generally improve efficiency when there is only a single country, unilateral regulations can reduce welfare in the presence of multiple countries. There can be substantial gains from international coordination in data regulations, though a uniform level of data usage needs 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 substantial literature on history-based (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 behavioral 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.[7] Conitzer, Taylor, and Wagman (2012) suggest that firms have incentives to protect consumer privacy or data even without regulatory interventions. 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), 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. Ichihashi (2020) shows that, if a firm can commit not to use data for price discrimination, consumers have greater incentives to disclose information, which improves matching and raises the firm's profit. Moreover, targeted advertising can increase or decrease product

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

prices and/or competition (Roy, 2000; Iyer, Soberman, and Villas-Boas, 2005; Chen, 2006; Galeotti and Moraga-Gonzalez, 2008; Athey and Gans, 2010; de Cornière, 2013; Shy and Stenbacka, 2015; 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 data usage is fully transparent so that the firm can commit to it ex ante. By examining equilibrium data regulations across countries, we also identify the regulatory externalities that may prevent the efficient protection of consumer data in the global economy and highlight the potential gains from international policy coordination.[8] Moreover, we shed light on the issue of data localization in international trade by showing how data regulations may improve or worsen market efficiency when firms can invest in data localization.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 characterizes the market equilibrium and discusses how the equilibrium data usage and its welfare implications differ from those in the single-country benchmark. Section 4 examines equilibrium data-usage regulations that are unilaterally chosen by each country. Section 5 examines market outcomes and regulatory impacts when the firm can invest in data localization. Section 6 concludes.

2. THE 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 value u, which is the realization of a random variable with probability distribution $G(u)$ and density $g(u) > 0$ on support $[\underline{u}, \bar{u}]$, where $0 \leq \underline{u} < \bar{u} \leq \infty$.

[8] 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.

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 them to a third party or using them to increase profit from its other products. Denote the firm's usage level of each consumer's data as $x \in [0,1]$. 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 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.[9]

Consumers have disutility from their data being used, but their privacy preference may differ across the two countries. Specifically, a consumer who purchases the product in country H or F suffers disutility x or τx, respectively, where $\tau > 1$ or $\tau < 1$ indicates, respectively, that consumers in F have higher or lower disutility (or a stronger or weaker privacy preference) than those in H. Thus, each consumer's gross value in purchasing the product is $u - x$ in H and $u - \tau x$ in F. When $\tau = 1$, our model will be the same as one where the firm sells in a single country with a unit mass of consumers who have the same privacy preference. While our analysis will focus on the situations where $\tau \neq 1$, the special case of $\tau = 1$ will serve as a useful benchmark for us to show how the usage and protection of consumer data may differ significantly in the global economy with heterogeneous privacy preferences across countries.

The firm's use of consumer data may not be fully observed by consumers before purchase, which limits the firm's ability to (publicly) commit to data usage. We assume that the firm's data-usage level is comprised of two components,

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

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. We interpret a higher θ as

[9] While we will focus on the interpretation that a higher x provides more revenue to the firm, our analysis applies equally to the situation where a higher x corresponds to more cost savings for the firm by exerting less effort to protect consumer data.

reflecting more transparency of data usage.[10]

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. 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 (e.g., name, address, age, and consumption frequency), but it may (intentionally or unintentionally) conceal the collection and use of other information, denoted by x_2, which may include for instance search history, income, and purchase patterns.[11] 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 actions that the firm may or may not be able to commit to.

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. We allow the firm to choose x_2 either before or after consumers purchase the product, but, importantly, x_2 cannot be observed by consumers if it is chosen before their product purchases.[12] 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

[10] 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.

[11] 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.

[12] For example, a firm's investment in data protection may be chosen before product sales but not observed by consumers, whereas data collection for after-sales services or the use of data for (history-based) price discrimination happens after sales.

x (or x_2), and consumers' belief is consistent with the firm's strategy.

Notice that under our formulation the firm sets a common data-usage level in the two countries. It could be impractical or too costly for the firm to process consumer data differently in different countries, possibly due to the nature of the product or the common data software used.[13] In practice, many firms indeed choose to set a common data policy across countries. For example, Microsoft announced in 2018 to extend the same data policy to all global consumers. Facebook has been transferring its European users' data to the US to process under a common data system.[14] More generally, our analysis can extend to situations where a firm's strategies to use and protect data are correlated across countries but not identical. Our simplifying assumption of common data usage facilitates the analysis.[15]

3. EQUILIBRIUM DATA USAGE AND WELFARE

In this section, we characterize equilibrium data usage and equilibrium global welfare. We will start with a general characterization of the equilibrium price and data usage for any τ. We will then discuss the benchmark case with $\tau = 1$, showing that with a single country the firm could maximize profit by fully internalizing the consumer disutility from its usage of consumer data, but may nevertheless use data excessively because the lack of data-usage transparency limits its commitment ability. As expected, welfare increases with data-usage transparency in this case. We next turn to our main interest, the case with $\tau \neq 1$. We show that the nature of the equilibrium data usage and the impact of transparency now also depend on demand curvature. Despite the cross-country difference in privacy preferences and the constraint that the firm chooses only a single level of data usage, the firm's full-commitment data usage again coincides with the globally efficient level

[13] Survey evidence, for instance, shows that having disparate data systems is the main hurdle of customer data management (https://www.aberdeen.com/cmo-essentials/are-you-making-the-most-of-customer-data/).

[14] In September 2020, citing concerns of insufficient data protection, a EU privacy regulator suspended data transfers by Facebook to the US about its EU users. If this decision stands, "Facebook would have to re-engineer its service to silo off most data...from European users, or stop serving them entirely" (see https://www.wsj.com/articles/ireland-to-order-facebook-to-stop-sending-user-data-to-u-s-11599671980).

[15] In Section 5, we will relax this assumption and examine the firm's incentives to invest in data localization, which allows the firm to choose separate levels of data usage in different countries.

if demand has constant curvature, and low transparency in data usage remains the main obstacle to efficiency. However, when demand curvature is not constant, equilibrium data usage is generally distorted even without the commitment problem, and, counterintuitively, welfare can *decrease* when market transparency increases.

3.1 Market Equilibrium

In equilibrium, consumers have correct beliefs about the data-usage level x chosen by the firm. Given the 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

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

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 in countries H and F respectively, which include the purchase price and the disutility from losing privacy. Since $1 - G(p_H + x)$ (or $1 - G(p_F + \tau x)$) is the demand of a consumer in H (or in F), part (i) can be alternatively interpreted as the demand in each country being logconcave. Moreover, $m'(u)$ measures the curvature of demand in each country, and its property will determine how a change in x affects the firm's optimal price.[16] The following lemma characterizes the equilibrium prices given x.

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

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

with outputs in H and F being $\lambda q_H^* \equiv \lambda q_H(p_H^*, x)$ and $(1-\lambda) q_F^* \equiv (1-\lambda) q_F(p_F^*, x)$, respectively. Furthermore, $p_H^* = p_F^*$ and $q_H^* = q_F^*$ if $\tau = 1$; $p_H^* > p_F^*$ and $q_H^* > q_F^*$ if $\tau > 1$; and $p_H^* < p_F^*$ and $q_H^* < q_F^*$ 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, given an exogenous increase in the per-consumer revenue from data usage (for a given level x), $r = r(x)$, 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 in data-usage revenue on product prices, and we call each of their absolute values the *rate of revenue substitution:*

$$\rho_r^H \equiv -\frac{\partial p_H^*}{\partial r} = \frac{1}{1 - m'\left(p_H^* + x\right)} > 0, \qquad \rho_r^F \equiv -\frac{\partial p_F^*}{\partial r} = \frac{1}{1 - m'\left(p_F^* + \tau x\right)} > 0. \tag{5}$$

[16] To see this, denoting demand per consumer at effective price p by $D(p) \equiv 1 - G(p)$, we have $m(p) = -\frac{D(p)}{D'(p)}$ and

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

where $\sigma(p)$ is the curvature of the inverse demand function $P(\cdot) \equiv D^{-1}(\cdot)$. Thus demand is convex or concave respectively if $m'(p) \geq -1$ or ≤ -1 (Aguirre et. al., 2010; Chen and Schwartz, 2015).

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 (i.e., if demand curvature is constant, decreasing, or increasing).

Importantly, 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, $m''(u)$. 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 at the equilibrium prices 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: $\rho_r^H < \rho_r^F$.[17]

We further consider the impacts of an increase in data usage on product prices. Increasing x raises the per-consumer revenue from data usage $r(x)$, which (as shown earlier) motivates the firm to reduce prices. Moreover, the increase in data usage x causes a reduction in consumers' willingness to pay, which also leads to lower prices. Consistent with this intuition, from condition (4) and $m'(u) \leq 0$ (Assumption A1), we have

$$\rho_x^H \equiv \frac{dp_H^*}{dx} = -\frac{r'(x) - m'(p_H^* + x)}{1 - m'\left(p_H^* + x\right)} < 0, \tag{6}$$

$$\rho_x^F \equiv \frac{dp_F^*}{dx} = -\frac{r'(x) - \tau m'(p_F^* + \tau x)}{1 - m'\left(p_F^* + \tau x\right)} < 0. \tag{7}$$

The next lemma summarizes how the equilibrium prices change when data revenue or data usage varies.

[17] 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).

Lemma 2 *(Impacts of Data Usage on Prices) (1) An exogenous increase in data revenue decreases* p_H^* *and* p_F^**. Moreover,* $\rho_r^H < \rho_r^F$ *if* $\tau > 1$ *and* $m''(u) > 0$ *or if* $\tau < 1$ *and* $m''(u) < 0$*;* $\rho_r^H = \rho_r^F$ *if* $m''(u) = 0$*; and* $\rho_r^H > \rho_r^F$ *if* $\tau > 1$ *and* $m''(u) < 0$ *or if* $\tau < 1$ *and* $m''(u) > 0$*. (2) An increase in data usage* x *decreases* p_H^* *and* p_F^**.*

An increase in x raises the firm's data-usage revenue, which motivates the firm to increase output; but it also raises consumer disutility, which decreases output. In choosing x, the firm considers the trade-off between the revenue and consumer disutility from data usage. The firm's equilibrium profit as a function of x is given by

$$\pi(x) = \lambda q_H^*(x)[p_H^* + r(x)] + (1-\lambda)q_F^*(x)[p_F^* + r(x)]. \tag{8}$$

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

$$\pi'(x) = \lambda q_H^*(x)\left[r'(x) - 1\right] + (1-\lambda)q_F^*(x)\left[r'(x) - \tau\right]. \tag{9}$$

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.

Define the firm's profit-maximizing data-usage level under full commitment (or when there is full transparency) by $\widehat{x} = \arg\max_x \pi(x)$. Then $\widehat{x}$ satisfies

$$\pi'(\widehat{x}) = \lambda q_H^*(\widehat{x})\left[r'(\widehat{x}) - 1\right] + (1-\lambda)q_F^*(\widehat{x})\left[r'(\widehat{x}) - \tau\right] = 0, \tag{10}$$

which implies $r'(\widehat{x}) = 1$ if $\tau = 1$ and $\min\{1, \tau\} < r'(\widehat{x}) < \max\{1, \tau\}$ if $\tau \neq 1$. We can consider $r(x) - x$ and $r(x) - \tau x$ as the "net benefits" of data usage per consumer. Thus, $r'(x) - 1$ (or $r'(x) - \tau$) is the marginal net benefit of data usage in country H (or in country F). Condition (10) implies that, if full commitment is feasible, the firm would set x such that the output-weighted marginal net benefits of data usage are equalized (in absolute value) for the two countries.

While $\widehat{x}$ would maximize the firm's profit under full commitment, the equilibrium data usage may differ from $\widehat{x}$ due to the firm's limited commitment ability under insufficient data-usage transparency. In equilibrium we must have $x_2 = 1$, since consumers cannot observe x_2 and profit increases in x_2. Denoting the equilibrium data usage by x^*. Notice also that more transparency allows the firm to commit to less data usage, which would raise the equilibrium prices from Lemma 2.

Proposition 1 *(Equilibrium Data Usage) (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 $x_2 = 1$. An increase in θ increases p_H^* and p_F^* if $\theta < 1 - \widehat{x}$ but has no effect on the prices if $\theta \geq 1 - \widehat{x}$.*

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 transparency is low ($\theta < 1 - \widehat{x}$), the firm chooses a usage level higher than $\widehat{x}$.[18] Since more transparency lowers data usage but raises the equilibrium prices, it can have an ambiguous impact on output and welfare, as will be shown in the next two subsections.

3.2 Benchmark: Data Usage and Welfare with a Single Country

When $\tau = 1$, our model is equivalent to the setting where the firm sells only in one country with a unit mass of consumers who have the same preference for privacy. In this case, condition (10) implies that the firm's data usage under full commitment satisfies $r'(\widehat{x}) = 1$. Proposition 1 shows that raising θ weakly decreases the equilibrium data usage

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

x^* (or consumer disutility from it) but increases the equilibrium price $p^* = p_H^* = p_F^*$ as defined by condition (4). Recall $p^* + x^*$ as the "effective price" for consumers. Denoting $\rho_x = \frac{dp^*}{dx}$, given $x^* \geq \widehat{x}$ and $m'(u) \leq 0$, the marginal effective price of data usage satisfies

$$\rho_x + 1 = \frac{1 - r'(x^*)}{1 - m'(p^* + x^*)} \geq 0, \tag{11}$$

which holds with strict inequality when $r'(x^*) < 1$ or, equivalently, $\theta < 1 - \widehat{x}$. That is, when data usage becomes more transparent, the increase in consumers' willingness to pay due to lower data usage is larger than the increase in product price. Thus, with a single country, more transparency of data usage (weakly) raises total output, $1 - G(p^* + x^*)$.

Welfare as a function of x, under equilibrium price p^*, is

$$W(x) = \pi(x) + \int_{p^*+x}^{\bar{u}} (u - p^* - x) g(u) du, \tag{12}$$

where the second term on the right-hand side is consumer surplus. We have

$$W'(x) = \pi'(x) - [1 - G(p^* + x)](\rho_x + 1), \tag{13}$$

which, given condition (11), can be re-written as

$$W'(x) = \pi'(x) + [1 - G(p^* + x)] \frac{r'(x) - 1}{1 - m'(p^* + x)}. \tag{14}$$

Let x^o maximize $W(x)$, or $W'(x^o) = 0$.[19] Then, (14) implies $\widehat{x} = x^o$ and the firm's profit-maximizing data usage under full commitment also maximizes consumer surplus (as well as total welfare). If the firm sells only in a single country, it would fully internalize consumer disutility from data usage in choosing x if the usage is sufficiently transparent.

Furthermore, since more transparency lowers data usage and raises total output, both consumer surplus and welfare would increase as data usage becomes more transparent, and full efficiency is obtained if $\theta \geq 1 - \widehat{x}$ (which always holds if $\theta = 1$). We summarize this

[19] Condition (14) implies that $W(x)$ is single-peaked as long as $\pi(x)$ is single-peaked.

discussion in the following:

Lemma 3 *(Welfare in the Single-country Benchmark) In the benchmark of a single country, the profit-maximizing data usage also maximizes total welfare ($\widehat{x} = x^o$) if $\theta \geq 1 - \widehat{x}$; the equilibrium data usage will be socially excessive ($x^* > \widehat{x}$) if $\theta < 1 - \widehat{x}$, in which case total output, profit, and consumer surplus all increase in θ.*

Importantly, with a single country, both the firm and consumers will (weakly) benefit from more transparency. When data usage lacks transparency, the firm inefficiently uses too much consumer data. An increase in transparency enables the firm to commit to a lower data-usage level that is more profitable. Even though this leads to a higher price for the product, the effective price for the consumer—the "quality-adjusted" price if we consider less data usage as improving product quality—is reduced when $r'(x^*) < 1$, resulting in also higher consumer surplus. This is in contrast to the result in several recent studies in which more transparency (or higher commitment ability) increases firm profits at the expense of consumers. For example, in Rhodes and Wilson (2018), a firm has private information about its given product quality, and more transparency about quality increases the firm's pricing power when it has high quality and can thus harm consumers. Ichihashi (2020) also finds that a firm's commitment ability increases profit but harms consumers in a model where consumers can choose not to disclose information, whereas the seller either can commit not to utilizing consumer information or is unable to do so.[20] However, as we show in the next subsection, more transparency can also reduce consumer surplus (and welfare) in our model if the firm sells the product across multiple countries.

3.3 Data Usage and Welfare in the Global Economy

We now return to our model of the global economy where the firm sells the same product in two countries that differ in privacy preference ($\tau \neq 1$). We first examine the impacts of more transparency on equilibrium outputs. Recall that, given x, $p_H^* + x$ and $p_F^* + \tau x$ are the

[20] In our model, data usage is endogenously chosen by the firm, commitment ability is a continuous variable, and although consumers may choose not to purchase the product when expecting a higher x, they are otherwise unable to prevent the exploitation of their data by the firm .

effective prices for consumers in the equilibrium. From conditions (4) and (5), the marginal effective prices of data usage satisfy the following conditions:

$$\rho_x^H + 1 = \frac{r'(x) - m'(p_H^* + x)}{m'\left(p_H^* + x\right) - 1} + 1 = -\rho_r^H \left[r'(x) - 1\right], \tag{15}$$

$$\rho_x^F + \tau = \frac{r'(x) - \tau m'(p_F^* + \tau x)}{m'\left(p_F^* + \tau x\right) - 1} + \tau = -\rho_r^F \left[r'(x) - \tau\right], \tag{16}$$

where recall that $\rho_r^H > 0$ and $\rho_r^F > 0$ are the revenue substitution rates. A lower effective price raises the output in each country. Hence, increasing data usage strictly reduces the outputs in both countries if $r'(x) < \min\{1, \tau\}$ but raises the outputs if $r'(x) > \max\{1, \tau\}$. If $\min\{1, \tau\} < r'(x) < \max\{1, \tau\}$, then increasing data usage raises output in one country but reduces output in the other country. The following lemma states that increasing transparency, which leads to lower data usage, can have non-monotonic impacts on the equilibrium outputs in the two countries.

Lemma 4 *(Outputs and Transparency) As θ increases, starting from a low level: if $\tau > 1$, output (weakly) increases in F but first increases and then decreases in H; if $\tau < 1$, output (weakly) increases in H but first increases and then decreases in F.*

Different from the single-country benchmark where output increases in θ, in the global market, increasing θ can reduce output in one of the two countries. More transparency decreases the equilibrium data usage x^* (hence, less consumer disutility from losing privacy) but raises prices p_H^* and p_F^*. Because of the difference in consumers' disutility from data usage across countries, the higher price can outweigh the consumer benefits from lower data usage in the country where consumers have a weaker preference for privacy, resulting in a higher effective price, or lower output, in that country.

The output effects characterized by Lemma 4 implies that increasing θ raises consumer surplus in one country but can have the opposite effect in the other country. This suggests that equilibrium data usage may not maximize global welfare even with full transparency ($\theta = 1$), and global welfare may decrease in θ. We next investigate such possibilities.

Denote global welfare from the two countries as a function of x again by $W(x)$, and now

$$W(x) = \pi(x) + \lambda \int_{p_H^*+x}^{\bar{u}} (u - p_H^* - x)g(u)du + (1-\lambda) \int_{p_F^*+\tau x}^{\bar{u}} (u - p_F^* - \tau x)g(u)du, \quad (17)$$

where the second term is consumer surplus in H (to be denoted as $V^H(x)$) and the third term is consumer surplus in F (to be denoted as $V^F(x)$). Using (1), we have

$$W'(x) = \pi'(x) - \lambda q_H^*(x)(\rho_x^H + 1) - (1-\lambda) q_F^*(x)(\rho_x^F + \tau), \quad (18)$$

where the change of consumer surplus in each country from a marginal increase in x is equal to output multiplied by the marginal effective price of data usage.

From (15) and (16), we can rewrite (18) as

$$W'(x) = \pi'(x) + \lambda q_H^*(x)\rho_r^H [r'(x) - 1] + (1-\lambda) q_F^*(x)\rho_r^F \left[r'(x) - \tau\right]. \quad (19)$$

Under full transparency, $x^* = \widehat{x}$. Recall that $\widehat{x}$ satisfies $\min\{1,\tau\} < r'(\widehat{x}) < \max\{1,\tau\}$, under which the output-weighted marginal net benefits of data usage are equalized (in absolute value) for the two countries (see condition (10)). So, condition (19) implies that, for a marginal change in x from $\widehat{x}$, consumer surplus increases in one country but decreases in the other country. However, the magnitude of the changes in consumer surplus can differ between the two countries, depending on the revenue substitution rates (ρ_r^H and ρ_r^F).

To illustrate, consider the case with $\tau > 1$ and $m''(u) > 0$. Lemma 2 shows that, in this case, a change of data-usage revenue has a larger impact on product price in F than in H ($\rho_r^H < \rho_r^F$), due to the more convex (or less concave) demand at the equilibrium price in F. Thus, given an increase in x from $\widehat{x}$, a larger percentage of the change in net benefits of data usage will be passed through to consumers in F than in H, implying that the increase in consumer surplus in H is smaller than the decrease in consumer surplus in F. The marginal change in x has a second-order effect on profit because profit is maximized at $\widehat{x}$. Therefore, with $\tau > 1$ and $m''(u) > 0$, global welfare is decreasing in x at $x = \widehat{x}$.

By contrast, when $\tau > 1$ and $m''(u) < 0$, a change of data-usage revenue has a smaller impact on price in F than in H ($\rho_r^H > \rho_r^F$), due to the less convex demand at the equilibrium price in F. Thus, given a marginal increase in x from $\widehat{x}$, the increase in consumer surplus in H is larger than the decrease in consumer surplus in F. Therefore, with $\tau > 1$ and $m''(u) < 0$, global welfare is increasing in x at $x = \widehat{x}$.

When $m''(u) = 0$, the revenue substitution rates are equalized ($\rho_r^H = \rho_r^F$). That is, the same percentage of the change in net benefits of data usage will be passed through to consumers in the two countries. Thus, given a marginal change in x from $\widehat{x}$, the increase in consumer surplus in one country offsets the decrease in consumer surplus in the other country. In this case, global welfare is maximized at $x = \widehat{x}$.

Denote the efficient data usage in the global economy again by $x^o = \arg\max_x W(x)$. Given conditions (9) and (19), x^o satisfies

$$W'(x^o) = \lambda q_H^*(x^o)(1 + \rho_r^H)[r'(x^o) - 1] + (1 - \lambda)\, q_F^*(x^o)(1 + \rho_r^F)\left[r'(x^o) - \tau\right] = 0. \quad (20)$$

The discussions above suggest that x^o can be higher or lower than $\widehat{x}$. The proposition below confirms this and further shows that equilibrium global consumer surplus and welfare can *decrease* in the transparency level θ.[21]

Proposition 2 *(Global Welfare) Suppose $\tau \neq 1$. The full-commitment data usage $\widehat{x}$ and the equilibrium data usage x^* can be either higher or lower than the (globally) efficient x^o.*
(i) When $m''(u) \geq 0$, $\widehat{x} \geq x^o$, where the inequality holds strictly if $m''(u) > 0$, and $x^* \geq x^o$. Overall consumer surplus and global welfare (weakly) increase in θ.
(ii) When $m''(u) < 0$, $\widehat{x} < x^o$, and $x^* \geq x^o$ if $\theta \leq 1 - x^o$ but $x^* < x^o$ if $\theta > 1 - x^o$. Overall consumer surplus and global welfare initially increase but then (weakly) decrease in θ.

Therefore, properties of demand curvature play an important role in determining the nature of equilibrium data usage and the impact of transparency in the global economy. Despite the difference in consumer privacy preferences and the common data usage across

[21] We maintain the assumption that $V^H(x) + V^F(x)$ and $W(x)$ are all single-peaked functions.

countries, the firm's data usage under full commitment coincides with the globally efficient level if demand curvature is constant ($m''(u) = 0$). In this case, distortion in data usage occurs again due to the firm's limited commitment ability under insufficient transparency, similarly as for a single country. However, when demand curvature is not constant ($m''(u) \neq 0$), the firm's data usage generally differs from efficiency even under full commitment, and an increase in transparency can reduce global welfare, in contrast to the result when there is only one country. Since profit (weakly) increases in θ, overall consumer surplus must also fall if global welfare decreases in θ.

Examples 1-3 below illustrate cases where $\widehat{x}$ is equal to, higher than, or lower than x^o, and that global welfare may either increase or decrease in θ. We assume $\lambda = 0.5$, $\tau = 2$, and $r(x) = 1 - (1-x)^2$ for $x \in [0,1]$ in all the examples.

Example 1 *Suppose $G(u)$ is a uniform or exponential distribution. Then $m''(u) = 0$. In particular, let $G(u) = u - 1$ on $[1,2]$. Then $x^o = \widehat{x} \approx 0.266$. Welfare increases in θ for $\theta < 0.734$ and becomes constant for $\theta \geq 0.734$.*

Example 2 *Suppose $G(u)$ is a power function distribution: $G(u) = u^a - 1$ for $1 \leq u \leq 2^{1/a}$ and $a > 1$, or a Weibull distribution: $G(u) = 1 - e^{-u^\beta}$ for $u \in [0, \infty)$ and $\beta > 1$. Then $m''(u) > 0$.*[22] *In particular, let $G(u) = u^2 - 1$ for $1 \leq u \leq \sqrt{2}$. Then $\widehat{x} \approx 0.384$ and $x^o \approx 0.260$. Welfare increases in θ for $\theta < 0.616$ and becomes constant for $\theta \geq 0.616$.*

Example 3 *Suppose $G(u)$ is a power function distribution: $G(u) = u^a - 1$ for $1 \leq u \leq 2^{1/a}$ and $0 < a \leq 0.5$. Then $m''(u) < 0$. Let $G(u) = u^{0.5} - 1$ for $1 \leq u \leq 4$. Then, $\widehat{x} \approx 0.262$ and $x^o \approx 0.510$. Welfare increases in θ for $\theta < 0.490$, decreases in θ for $\theta \in (0.490, 0.738)$, and becomes constant for $\theta \geq 0.738$.*

The finding in Proposition 2 that more transparency of data usage can reduce welfare is intriguing. While increases in transparency are generally welfare-improving in a single country, our result indicates that their welfare impact is more nuanced and may have

[22] Given the power function distribution with $a > 1$, $m'(u) = -\frac{u^a - 2(1-a)}{au^a} \leq 0$ and $m''(u) = \frac{2}{u^{a+1}}(a-1) > 0$; and given the Weibull distribution, $m'(u) = -\frac{(\beta-1)u^{-\beta}}{\beta} \leq 0$ and $m''(u) = (\beta-1)u^{-\beta-1} > 0$.

unintended consequences in the global market. Moreover, Proposition 2 suggests that data-usage distortion is more likely to arise internationally than for a single country. While this may suggest more potential benefits from data regulations in the global market, we shall show in the next section that unilateral regulations need not improve global welfare.

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.

4.1 Regulatory Caps on Data Usage

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.[23] 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). 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 profits from both countries (as the firm is located in H), whereas the regulator in F aims to maximize only consumer surplus in F.

We again start with the benchmark of one country (i.e., setting $\tau = 1$ in our model). In this case, as shown by Lemma 3, the firm's full-commitment data usage $\widehat{x}$ maximizes welfare ($x^o = \widehat{x}$), but the equilibrium data usage can be inefficiently excessive due to low transparency (i.e., small θ). Data-usage regulation then solves the firm's commitment problem and always weakly improves efficiency. We thus have:

[23] 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. Note that regulations with usage caps are different from policies aiming to improve transparency of data usage (i.e. increasing θ), though both can reduce equilibrium data usage.

Lemma 5 *(Regulation in the Single-country Benchmark) When there is only one country, a regulatory cap $\sigma = x^o = \widehat{x}$ achieves full efficiency. The regulation increases welfare if and only if $\theta < 1 - \widehat{x}$.*

Next, we return to the international setting where countries have different preferences for privacy ($\tau \neq 1$). Recall that $V^H(x)$ is consumer surplus in H and $V^F(x)$ is consumer surplus in F. Provided that the constraint $x \leq \sigma_H$ is binding, country H will impose cap σ_H such that

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

Provided that $x \leq \sigma_F$ is binding, country F will impose cap σ_F such that

$$V^{F\prime}(x) = (1-\lambda)q_F^*(x)\rho_r^F\left[r'(x)-\tau\right] = 0, \quad (22)$$

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 to sell in both countries. Thus, the more stringent regulation imposed by one country leads to an inefficiently low data-usage in the other country.

Furthermore, the more stringent regulation also reduces the firm's data-usage revenue $r(x)$, which in turn reduces the firm's incentive to increase outputs. In other words, the more stringent regulation can cause a negative externality on the output in the other country.

We show below that, given these cross-country externalities on data usage and output, unilateral regulations lead to inefficiently low data usage and can reduce global welfare.[24]

[24] The result utilizes our maintained assumption that $\pi(x)$ and $W(x)$ are all single-peaked functions.

Proposition 3 *(Unilateral Regulations) Suppose that* $\tau \neq 1$ *and the firm chooses data usage* x^r *that complies with regulations* (σ_H, σ_F). *Then* $x^r = \sigma_F < \min\{x^o, \widehat{x}, \sigma_H\}$ *with* $r'(\sigma_F) = \tau$ *if* $\tau > 1$, *and* $x^r = \sigma_H < \min\{x^o, \widehat{x}, \sigma_F\}$ *with* $V^{H'}(\sigma_H) + \pi'(\sigma_H) = 0$ *if* $\tau < 1$. *There exists some* μ_θ *such that, compared to without regulation, global welfare is higher under unilateral regulations if* $\theta < \mu_\theta$ *but lower otherwise, where* $0 < \mu_\theta < 1$ *if* $m''(u) \leq \delta$ *for some* $\delta > 0$ *and* $|\tau - 1|$ *is not too large.*

Proposition 3 suggests that the welfare impact of data-usage regulations in the global economy differs significantly from that in the single-country setting. Whereas data regulation under a single country always (weakly) improves welfare, it can reduce welfare in the international context. The country with a stronger preference imposes a lower cap to prevent excessive use of consumer data in it, but causes negative output and data-usage externalities in the other country. The former (positive) effect dominates if data usage has low transparency, while the negative externalities dominate if data usage is sufficiently transparent and demand curvature, $m'(u)$, does not increase too fast.[25] The following numerical example illustrates the welfare impact of unilateral regulations.

Example 4 *Suppose that* $G(u)$ *is the uniform distribution on* $[1, 2]$, $\lambda = 0.5$, $\tau = 2$,*and* $r(x) = 1 - (1 - x)^2$ *for* $x \in [0, 1]$. *As shown in Example 1,* $x^o = \widehat{x} \approx 0.266$. *Then compared to without regulation, global welfare is higher under unilateral regulations if* $\theta < \mu_\theta \approx 0.466$ *but lower if* $\theta > \mu_\theta \approx 0.466$.

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* $\tau \neq 1$. *Global welfare is higher under international coordination on data regulations than under unilateral regulations. A*

[25] The condition that demand curvature does not increase too fast holds for many familiar demand functions, for example, linear demand, constant-elasticity demand, exponential demand, AIDS demand (see related discussions by Chen and Schwartz, 2015).

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 differ in their preferences for privacy, unilateral regulations create negative externalities across countries and international coordination improves global welfare. When demand curvature is (weakly) increasing ($m''(u) \geq 0$) or data usage is not transparent enough, the firm would choose $x^* > x^o$ if left unregulated (see Proposition 2), and in this case the uniform cap achieves the global optimum. However, 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 data usage that is lower than the efficient level ($x^* < x^o$). In this case, a uniform cap on data usage fails to achieve the global optimum.

4.2 Discussion: Imperfect Enforcement and Consumer Opt-Out

In our analysis in Section 4.1, we have assumed that regulations are in the form of data-usage caps and they are perfectly enforced. As we discuss below, the welfare effects of regulations under these assumptions can also hold if enforcement is not perfect or regulatory policies take a different form.

Imperfect Regulatory Enforcement

Consider first imperfect enforcement under usage-cap regulations. Specifically, consider the case with $\tau > 1$, and suppose that regulation enforcement on data-usage caps is perfect in H but imperfect in F, with an expected penalty $L > 0$ if the firm violates the regulation in F. The imperfect enforcement in F may reflect the possibility that the violation of the regulation is undetected or the firm faces financial constraints.

From Proposition 3, 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 chooses $x = \sigma_F$, its profit is $\pi(\sigma_F)$. If the firm violates the regulation in country F , it will choose $x = \min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}$.[26] Therefore, the firm would comply with the regulation in F if and only if

$$L \geq \overline{L} \equiv \pi\left(\min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}\right) - \pi\left(\sigma_F\right). \tag{23}$$

When the penalty is large enough ($L \geq \overline{L}$), 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 Section 4.1. When the penalty is relatively small ($L < \overline{L}$), the firm violates the regulation in F. In this case, if $1-\theta > \sigma_H$, the firm chooses $x = \sigma_H$ under regulation, which increases welfare in both countries compared to the scenario with no regulation.

However, for a given penalty $L < \overline{L}$, the countries may have incentives to impose caps different from σ_H and σ_F. For example, 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 $\widetilde{\sigma}_F < \min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}$, then this unilateral regulation change in F raises 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.

Consumer Opt-Out

In recent years, some countries have enacted the "opt-out" regulatory policy, under which firms are required to allow consumers to opt out of the collection and use of their personal data. Unilateral choices of opt-out policy by the two countries can also generate negative externalities that reduce global welfare in our model. To see this, suppose that data usage is sufficiently transparent: $\theta > 1 - \min\{\sigma_H, \sigma_F\}$. 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.

[26] 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 $x = \min\{\max\{\widehat{x}, 1-\theta\}, \sigma_H\}$.

In equilibrium, the firm would always choose $x_2 = 1$, as shown in Section 3. If the firm chooses $x_1 \leq \frac{\min\{\sigma_H,\sigma_F\}-(1-\theta)}{\theta}$, the equilibrium data usage satisfies

$$x = \theta x_1 + (1-\theta) \leq \min\{\sigma_H, \sigma_F\}. \tag{24}$$

If the firm chooses $x_1 > \frac{\min\{\sigma_H,\sigma_F\}-(1-\theta)}{\theta}$, 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 full-commitment data usage level $\widehat{x}$ satisfies

$$1-\theta < \min\{\sigma_H, \sigma_F\} \leq \widehat{x} \leq \max\{\sigma_H, \sigma_F\}, \tag{25}$$

profit is higher when data usage is $\min\{\sigma_H, \sigma_F\}$ than when it is $1-\theta$. Hence, under the opt-out policy, the firm would choose $x = \min\{\sigma_H, \sigma_F\}$. Then, the welfare impact of the opt-out policies will be the same as in Section 4.1. Therefore, unilateral opt-out policies can cause negative output and data-usage externalities across countries that reduce global welfare.

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, the firm may set up local divisions to collect and process data separately. This section allows for this possibility. Assume that the firm may invest a fixed amount $k > 0$ which enables it to choose data-usage x_H and x_F separately in countries H and F. Obviously, the possibility of data localization arises only if $\tau \neq 1$, which we assume throughout this section. We first examine the firm's incentives to make the "localization" investment in the absence of data regulation, and then analyze the welfare effects of unilateral data-usage regulations imposed by the two countries.[27]

Suppose first that there is no data regulation. If the firm invests k, then its optimal prices

[27] We have also considered an alternative form of regulation that directly requires the firm to invest in localization. Such localization requirements, if feasible, have similar welfare effects as those in this section where data-usage regulations indirectly impact the firm's localization decision.

p_H^l and p_F^l satisfy

$$p_H^l + r(x_H) = m\left(p_H^l + x_H\right); \qquad p_F^l + r(x_F) = m\left(p_F^l + \tau x_F\right), \tag{26}$$

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

$$\pi(x_H, x_F) = \lambda q_H^l(x)[p_H^l + r(x_H)] + (1-\lambda)q_F^l(x)[p_F^l + r(x_F)], \tag{27}$$

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

$$r'(\widehat{x}_H) = 1; \quad r'(\widehat{x}_F) = \tau. \tag{28}$$

That is, with data localization, the firm's profit-maximizing data usage levels are also efficient, because it fully internalizes consumers' disutility from losing privacy in each market. Moreover, from condition (19), $\widehat{x}_H$ and $\widehat{x}_F$ also maximize consumer surplus in H and F, respectively. However, the equilibrium data usage may differ from $(\widehat{x}_H, \widehat{x}_F)$ due to the firm's limited commitment ability.

Denote the equilibrium data-usage levels under localization by (x_H^*, x_F^*) and define $k_1(\tau) \equiv \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x})$. The result below states the (unregulated) firm's localization incentive and data usage.

Lemma 6 *(Localization without Regulation) There exists a unique value $\theta^l \in (0,1)$ such that if and only if $k < k_1(\tau)$ and $\theta > \theta^l$, the firm invests in localization; the equilibrium data-usage levels are $x_H^* = \max\{\widehat{x}_H, 1-\theta\}$ and $x_F^* = \max\{\widehat{x}_F, 1-\theta\}$ in H and F respectively. For $\theta > 1 - \max\{\widehat{x}_H, \widehat{x}_F\}$ and for an intermediate range of k, the firm does not invest in localization even though it is efficient to do so.*

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 the efficient incentive to invest in localization, because it does not internalize the gain of consumer surplus.

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 with perfect enforcement) 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 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 $x_F \leq \sigma_F^l$.

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 $\sigma_H^l = \widehat{x}_H$ and F imposes $\sigma_F^l = \widehat{x}_F$, whether or not the firm will respond with localization. Note that $\widehat{x}_F < \widehat{x}_H$ when $\tau > 1$. Given $\sigma_H^l = \widehat{x}_H$, $\widehat{x}_F$ maximizes consumer surplus in F whether or not the firm invests in localization. Thus, $\sigma_F^l = \widehat{x}_F$ is optimal for F and it has no incentive to deviate at the proposed equilibrium.

Next, 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 $\sigma_H^l = \widehat{x}_H$. If the firm does not invest in localization, the constraint $x_H \leq \sigma_H^l$ 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 $\sigma' < \widehat{x}_F$, because it would lower the 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 $\sigma_H^l = \widehat{x}_H$ and

$\sigma_F^l = \widehat{x}_F$ respectively, while the firm will invest in localization.[28]

Given $\sigma_H^l = \widehat{x}_H$ and $\sigma_F^l = \widehat{x}_F$, 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) $\pi(\widehat{x}_H, \widehat{x}_F)$. Define

$$k_2(\tau) \equiv \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\min\{\widehat{x}_H, \widehat{x}_F\}). \tag{29}$$

Then $k_2(\tau) > k_1(\tau) \equiv \pi(\widehat{x}_H, \widehat{x}_F) - \pi(\widehat{x})$ when $\tau \neq 1$. Thus, data regulations strengthen the firm's incentives to invest in localization, because localization allows the firm to avoid distortions in data usage and output caused by unilateral regulations. However, given the option of data localization, regulation may reduce welfare by causing inefficient investment. Formally:

Proposition 4 *(Localization with 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 $k < k_2(\tau)$. (ii) When $\tau < 1$, if $k < k_2(\tau)$, 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 $k < k_1(\tau)$, regulations (weakly) raise welfare. However, if $m''(u) < 0$ and $|\tau - 1|$ is not too large, regulations can reduce welfare for intermediate ranges of k and θ.*

Therefore, our 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 ($k < k_1(\tau)$) and the demand curvature is weakly increasing ($m''(u) \geq 0$), global welfare is maximized if the firm chooses localization and efficient data usages. But the firm lacks the incentive for localization if $\theta \leq \theta^l$ and may also choose excessive data usage. Data regulations can raise global welfare by preventing excessive data usage (as when localization is not possible), and additionally, by enhancing the firm's localization incentive.

On the other hand, when the cost of localization investment is in an intermediate range and the cross-country difference in privacy preferences is not too large, global welfare is

[28] Notice that, given $\tau < 1$, $\sigma_H^l = \widehat{x}_H$ and $\sigma_F^l = \widehat{x}_F$ 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.

maximized if the firm does not invest in localization but chooses the uniform data usage x^o in the two countries. If the firm is left unregulated and the demand curvature is decreasing, the firm would not invest in localization and global welfare is closer to the optimum when the transparency level θ is in an intermediate range (see Proposition 2). However, regulations can lead to excessive investment in localization, reducing global welfare.

Notice that a regulation that requires global uniformity in data usage is generally not optimal, even when countries can coordinate their regulations. Uniformity in the regulation 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 usage in each country through localization.

6. CONCLUSION

This paper introduces an international dimension to the problem of consumer data protection in an otherwise standard model: data usage from product sales generates additional revenue to a multinational firm but disutility to consumers, and the firm recognizes the endogeneity of consumer demand but may lack sufficient commitment ability to properly balance the trade-off in data usage. The analysis and the results, however, are significantly different in the international context, where countries differ in privacy preference. Contrary to the results when the firm sells only in one country, we find that the multinational firm may choose data usage inefficiently even if it has full commitment capability, and increases in transparency (or the firm's commitment ability) can exacerbate data-usage and output distortions, decreasing both consumer surplus and welfare in the global economy. Moreover, while unilaterally-imposed data regulations can improve efficiency by preventing excessive data usage, they may nevertheless reduce global welfare by creating negative externalities on output and data usage across countries and possibly also causing excessive data localization. We further show that properties of demand curvature play important roles for these results in the international market.

The issue of consumer privacy and data protection has attracted substantial attention from economists and policymakers. Our findings suggest that the issue is more complex and presents greater challenges in the international context. There can be significant gains from international coordination on data regulations, though a uniform standard on data usage is generally not warranted.

Our analysis can be extended in several meaningful ways. For instance, while we have focused on consumer disutility from the firm's data usage, consumers' data can also be used to raise their utility (e.g., through improving product match quality), and a more general analysis can explicitly incorporate this possibility. For analytical tractability and to allow for a variety of applications, the data-revenue function in our model takes a reduced form. Future studies can incorporate specific features into the data-revenue function to enrich the analysis in particular applications. Furthermore, in addition to regulatory policies, the legal system, reputation concerns, and (potential) competition can also impact a multinational firm's incentive to protect consumer data. It would be interesting for future research to consider these other mechanisms to gain additional insights on the issue of data protection in the international market and on optimal policy design.

REFERENCES

[1] Aaronson, Susan A., and Patrick Leblond. 2018. "Another digital divide: the rise of data realms and its implications for the WTO". *Journal of International Law* 21, 245-272.

[2] Acquisti, Alessandro, Curtis Taylor and Liad Wagman, "The Economics of Privacy," *Journal of Economic Literature*, Vol. 54 (2016), pp. 442-492.

[3] Anderson, Simon P. and Andre de Palma, "Competition for Attention in the Information (Overload) Age," *RAND Journal of Economics*, Vol. 43 (2012), pp. 1-25.

[4] Aguirre, Inaki, Simon Cowan and John Vickers, "Monopoly Price Discrimination and Demand Curvature," *American Economic Review*, Vol. 100 (2010), pp.1601-1605.

[5] Armstrong, Mark, John Vickers, and Jidong Zhou, "Consumer Protection and the Incentives

to Become Informed," *Journal of the European Economic Association*, Vol. 7 (2009), pp. 399-410.

[6] Athey, Susan, and Joshua Gans, "The Impact of Targeting Technology on Advertising Markets and Media Competition," *American Economic Review*, Vol. 100 (2010), pp. 608-613.

[7] Bellman, Steven, Eric J. Johnson, Steven J. Kobrin, and Gerald L. Lohse, "International Differences in Information Privacy Concerns: A Global Survey of Consumers," *The Information Society*, Vol. 20 (2004), pp. 313-324.

[8] Calzolari, Giacomo and Alessandro Pavan, "On the Optimality of Privacy in Sequential Contracting," *Journal of Economic Theory*, Vol. 130 (2006), pp. 168-204.

[9] Campbell, James, Avi Goldfarb, and Catherine Tucker, "Privacy Regulation and Market Structure," *Journal of Economics and Management Strategy*, Vol. 24 (2015), pp. 47-73.

[10] Chen, Xiaoyang and Aaditya Mattoo. 2008. "Regionalism in standards: good or bad for trade?" *Canadian Journal of Economics* 41(3), 838-863.

[11] Chen, Yongmin, "Paying Customers to Switch," *Journal of Economics and Management Strategy*, Vol. 6 (1997) pp. 877-897.

[12] Chen, Yongmin, "Marketing Innovation," *Journal of Economics and Management Strategy*, Vol. 15 (2006) pp. 101-123.

[13] Chen, Yongmin, and Marius Schwartz, "Differential Pricing when Costs Differ: A Welfare Analysis," *RAND Journal of Economics*, Vol. 46 (2015), pp. 442-460.

[14] Choi, Jay Pil and Heiko Gerlach, "International Antitrust Enforcement and Multimarket Contact," *International Economic Review*, Vol. 53 (2012), pp. 635-658.

[15] Conitzer, Vincent, Curtis R. Taylor, and Liad Wagman, "Hide and Seek: Costly Consumer Privacy in a Market with Repeat Purchases," *Marketing Science*, Vol. 31 (2012), pp. 277-292.

[16] de Cornière, Alexandre, "Search Advertising," *American Economic Journal: Microeconomics*, Vol. 8 (2013), pp. 156-188.

[17] de Cornière, Alexandre and Romain de Nijs, "Online Advertising and Privacy," *RAND Journal of Economics*, Vol. 47 (2016), pp. 48-72.

[18] Fudenberg, Drew, and Jean Tirole, "Customer Poaching and Brand Switching," *RAND Journal of Economics*, Vol. 31 (2000), pp. 634-657.

[19] Galeotti, Andrea, and Jose Luis Moraga-Gonzalez, "Advertising, Segmentation and Prices," *International Journal of Industrial Organization*, Vol. 26 (2008), pp. 1106-1119.

[20] Grossman, Gene M. and Edwin L.C. Lai. 2004. "International protection of intellectual property." *American Economic Review* 94(5), 1635-1653.

[21] Hirshleifer, Jack, "Privacy: Its Origin, Function, and Future," *Journal of Legal Studies*, Vol. 9 (1980), pp. 649-664.

[22] Ichihashi, Shota, "Online Privacy and Information Disclosure by Consumers," *American Economic Review*, Vol. 110 (2020), pp. 569-595.

[23] Iyer, Ganesh, David Soberman, and J. Miguel Villas-Boas, "The Targeting of Advertising," *Management Science*, Vol. 24 (2005)

[24] Johnson, Justin, "Targeted Advertising and Advertising Avoidance," *RAND Journal of Economics*, Vol. 44 (2013), pp. 128-144.

[25] Keen, Michael and Kai A. Konrad. 2013. "The theory of international tax competition and coordination." In Alan Auerbach, Raj Chetty, Martin Feldstein, and Emmanuel Saez, eds. Handbook of Public Economics: Volume 5, Elsevier, 257-328.

[26] Kim, Byung-Cheol and Jay Pil Choi, "Customer Information Sharing: Strategic Incentives and New Implications," *Journal of Economics and Management Strategy*, Vol. 19 (2010), pp. 403-433.

[27] Kim, Jin-Hyuk, Liad Wagman, and Abraham L. Wickelgren, "The Impact of Access to Consumer Data on the Competitive Effects of Horizontal Mergers and Exclusive Dealing," *Journal of Economics and Management Strategy*, Vol. 28 (2019), pp. 373-391.

[28] Posner, Richard A., "The Economics of Privacy," *American Economic Review*, Vol. 71 (1981), pp. 405-409.

[29] Rhodes, Andrew, and Chris M. Wilson, "False Advertising," *RAND Journal of Economics*, Vol. 49 (2018), pp. 348-369.

[30] Roy, Santanu, "Strategic Segmentation of a Market," *International Journal of Industrial Organization*, Vol. 18 (2000), pp. 1279-1290.

[31] Shy, Oz, and Rune Stenbacka, "Customer Privacy and Competition," *Journal of Economics and Management Strategy*, Vol. 25 (2015), pp. 539-562.

[32] Stigler, George J., "An Introduction to Privacy in Economics and Politics," *Journal of Legal Studies*, Vol. 9 (1980), pp. 623-644.

[33] Taylor, Curtis R., "Consumer Privacy and the Market for Customer Information," *RAND Journal of Economics*, Vol. 35 (2004), pp. 631-650.

[34] Taylor, Curtis R. and Liad Wagman, "Consumer Privacy in Oligopolistic Markets: Winners, Losers, and Welfare," *International Journal of Industrial Organization*, Vol. 34 (2014), pp. 80-84.

[35] The United States International Trade Commission. 2014. "Digital trade in the U.S. and global economies," part 2, Investigation no. 332-540, Washington DC.

[36] Van Zandt, Timothy, "Information Overload in a Network of Targeted Communications," *RAND Journal of Economics*, Vol. 35 (2004), pp. 542-560.

[37] Villas-Boas, J. Miguel, "Price Cycles in Markets with Customer Recognition," *RAND Journal of Economics*, Vol. 35 (2004), pp. 486-501.

APPENDIX

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

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

or equivalently,

$$p_H^* + r(x) = m(p_H^* + x), \; p_F^* + r(x) = m(p_F^* + \tau x).$$

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 $p_F^* > \underline{u} - \tau x$. 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 $p_H^* + r(x) \leq p_F^* + r(x)$, which implies $m(p_H^* + x) \leq m(p_F^* + \tau x)$. Since $m'() \leq 0$ (Assumption A1), we have $p_H^* + x \geq p_F^* + \tau x$, or equivalently, $p_H^* - p_F^* \geq \tau x - x > 0$, which becomes 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 $p_H^* + x \geq p_F^* + \tau x$, which implies $m(p_H^* + x) \leq m(p_F^* + \tau x)$. Then we have $p_H^* + r(x) \leq p_F^* + r(x)$, or equivalently, $p_H^* \leq p_F^*$, which is a contradiction. Hence $q_H^* > q_F^*$.

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

Proof of Lemma 2. Part (2) follows from the text. We show part (1) here. 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. 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. Proposition 1 implies that the equilibrium data usage satisfies $r'(x^*) < \min\{1,\tau\}$ when θ is sufficiently small but $\min\{1,\tau\} < r'(x^*) < \max\{1,\tau\}$ when θ is larger. When θ is small such that $r'(x^*) < \min\{1,\tau\}$, from (15) and (16), the marginal effective prices ($\rho_x^H + 1$ and $\rho_x^F + \tau$) are positive in both countries. In this case, increasing θ decreases x^*, which would reduce the effective prices and raise the outputs in both countries. However, when θ is large such that $\min\{1,\tau\} < r'(x^*) < \max\{1,\tau\}$, then from (15) and (16), the marginal effective price is positive in the country with a stronger preference for privacy but negative in the other country. Thus, increasing θ will raise output in the former country but reduce output in the latter. ■

Proof of Proposition 2. Notice that by assumption, $W(x)$ is single-peaked at x^o. If $m'(u)$ is constant and accordingly $\rho_r^H = \rho_r^F$, then (10) and (20) 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 (10) and (20), $W'(\widehat{x}) < 0$, 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 (10) and (20), $W'(\widehat{x}) < 0$, which implies $x^o < \widehat{x}$; whereas if $m''(u) < 0$, then $W'(\widehat{x}) > 0$, which implies $x^o > \widehat{x}$.

The results of global welfare follow directly from the above analysis and Proposition 1.

Now we show the impact of an increase in θ on overall consumer surplus. Condition (19) implies that the marginal consumer surplus is

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

which is negative when x is so large that $r'(x) \leq \min\{1,\tau\}$. Now consider x such that

$\min\{1,\tau\} < r'(x) < \max\{1,\tau\}$ and $x > \widehat{x}$. Condition (10) implies that, given any $x > \widehat{x}$,

$$\pi'(x) = \lambda q_H^*(x)\left[r'(x) - 1\right] + (1-\lambda) q_F^*(x)\left[r'(x) - \tau\right] < 0.$$

Therefore, for any x satisfying $\min\{1,\tau\} < r'(x) < \max\{1,\tau\}$ and $x > \widehat{x}$, $V^{H'}(x) + V^{F'}(x)$ is negative when $\tau > 1$ and $\rho_r^H \leq \rho_r^F$ or when $\tau < 1$ and $\rho_r^H \geq \rho_r^F$ (which holds when $m''(u) \geq 0$). Thus, when $m''(u) \geq 0$, more transparency lows data usage and therefore increases overall consumer surplus.

Given the assumption that consumer surplus is also single-peaked, when $m''(u) < 0$, then the earlier result on global welfare implies that more transparency first increases and then decreases overall consumer surplus. ■

Proof of Proposition 3. (i) 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 (19), $W'(x) > 0$ at $x = \sigma_F$, and from (10), $\pi'(x) > 0$ at $x = \sigma_F$. Hence $\sigma_F < \min\{x^o, \widehat{x}, \sigma_H\}$. Moreover, if $\tau \to 1$, from (19), $\sigma_F \to x^o$.

(ii)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 (19), $\sigma_F \to x^o$. 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 $x^r < \min\{\sigma_H, \sigma_F\}$.

Now, consider three cases. First, suppose $x^o < \widehat{x}$ (a sufficient condition is $m''(u) > 0$ as shown in Proposition 2). 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 $x^o = \widehat{x}$ (a sufficient condition is $m''(u) = 0$). 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, $\min\{\sigma_H, \sigma_F\} < \widehat{x} = x^o$, 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 $x^o > \widehat{x}$ (a sufficient condition is $m''(u) < 0$). 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, $\min\{\sigma_H, \sigma_F\} < \widehat{x} < x^o$, 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 $x^o \geq \widehat{x}$ (or particularly $m''(u) \leq 0$), the cut-off $\mu_\theta < 1 - \widehat{x} < 1$. When $x^o < \widehat{x}$ (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 Lemma 6. It is easy to show that, under localization, $x_H^* = \max\{\widehat{x}_H, 1 - \theta\}$ and $x_F^* = \max\{\widehat{x}_F, 1 - \theta\}$. Recall that, without data localization, the equilibrium data usage is $x^* = \max\{\widehat{x}, 1 - \theta\}$ (see Proposition 1).

(1) We first characterize the firm's localization decision. When $\theta \leq 1 - \max\{\widehat{x}_H, \widehat{x}_F\}$, the equilibrium data usage is the same whether the firm invests in localization or not. When $\theta \geq 1 - \min\{\widehat{x}_H, \widehat{x}_F\}$, 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. Now, 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

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

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 cases.

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

$$\pi(\widehat{x}_H, 1-\theta) - \pi(1-\theta) = \lambda q_H^l(\widehat{x}_H)[p_H^l + r(\widehat{x}_H)] - \lambda q_H^*(1-\theta)[p_H^* + r(1-\theta)]. \tag{30}$$

The first term in (30) 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

$$\pi(\widehat{x}_H, 1-\theta) - \pi(\widehat{x}) = \lambda q_H^l(\widehat{x}_H)[p_H^l + r(\widehat{x}_H)] + (1-\lambda)q_F^l(1-\theta)[p_F^l + r(1-\theta)] - \pi(\widehat{x}), \tag{31}$$

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. Recall that $W(x)$ is global welfare without localization. Denote global welfare under localization (excluding costs k) as

$$W(x_H, x_F) = \lambda \int_{p_H^l + x_H}^{\bar{u}} [u + r(x_H) - x_H] g(u) du + (1-\lambda) \int_{p_F^l + \tau x_F}^{\bar{u}} [u + r(x_F) - \tau x_F] g(u) du. \tag{32}$$

First, suppose $\theta \leq 1 - \max\{\widehat{x}_H, \widehat{x}_F\}$. Then $x_H^* = x_F^* = x^* = 1-\theta$, 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

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

When $k < \pi(x_H^*, x_F^*) - \pi(x^*)$, the firm invests in localization, which is socially efficient. When $k \in [\pi(x_H^*, x_F^*) - \pi(x^*), W(x_H^*, x_F^*) - W(x^*))$, 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 4. (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 $1 - G(p_F^l(\widehat{x}_F) + \tau\widehat{x}_F) > 1 - G(p_F^*(\widehat{x}_H) + \tau\widehat{x}_H)$. When $\tau < 1$, the profit difference strictly decreases in τ. The equilibrium characterization 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 $\tau > 1$. As shown earlier,

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

and, by the envelop theorem,

$$\begin{aligned} & \frac{d[W(\widehat{x}_H, \widehat{x}_F) - W(x^o)]}{d\tau} \\ = \quad & -2(1-\lambda)\{[1 - G(p_F^l(\widehat{x}_F) + \tau\widehat{x}_F)]\widehat{x}_F - [1 - G(p_F^*(x^o) + \tau x^o)]x^o\} > 0. \end{aligned}$$

Therefore, if λ is sufficiently large, 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 $1 - x^o$, $W(\widehat{x}_H, \widehat{x}_F) - W(x^*; \theta) < k_2(\tau)$.

Now consider the case with $\tau < 1$. When τ is 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 $\widehat{k}(\tau) = \max\{W(\widehat{x}_H, \widehat{x}_F) - W(x^o), k_1(\tau)\}$. Then the earlier analysis suggests 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 $\theta \in (\mu'_{\theta 1}, \mu'_{\theta 2})$. ■