On the welfare analysis of external reference pricing and reimbursement policy*

Análisis de bienestar de precios referenciales externos y política de reembolso

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Abstract

The co-existence of external referencing pricing (ERP) and reimbursement policy is common in many countries. Thus, this research examines whether or not the imposition of ERP is socially desirable in the presence of reimbursement policy. For direct sales channel, we find that the home social welfare is worse-off with ERP if the home copayment rate is too high. Our main results are robust under indirect sales channel. Moreover, the home social welfare under the pharmacy-purchasing-price (PPP) ERP is larger than that under the ex-factory-price (EFP) ERP if the home copayment rate is high enough. Finally, the profit of brand-name firm under indirect sales channel is higher than that under direct sales channel if the home copayment rate is too high.

Key words: *Copayment rate, direct and indirect sales channeles, external reference pricing, reimbursement policy.*

JEL Classification: *F10, I11, I18, D42.*

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Resumen

Precios referenciales externos (ERP) y políticas de reembolso coexisten en muchos países. Este documento evalúa si ERP son socialmente deseables en presencia de políticas de reembolso. Para el canal de venta directa, encontramos que el bienestar social del hogar está peor con ERP si la tasa de copago de la vivienda es demasiado alta. Nuestros principales resultados son robustos bajo el canal de ventas indirectas. Además, el bienestar social bajo el precio de compra de farmacia (PPP) es mayor que el del ERP de precio de fábrica (EFP) si la tasa de copago es lo suficientemente alta. Finalmente, el beneficio de la empresa de marca en el canal de ventas indirectas es mayor que el del canal de ventas directas si la tasa de copago es demasiado alta.

Palabras clave: *Tasa de copago, canales de venta directa e indirecta, precios de referencia externos, política de reembolso.*

Clasificación JEL: *F10, I11, I18, D42.*

1. Introduction

External reference pricing (ERP) is the most common tool implemented by many countries to achieve the goal of pharmaceutical cost containment, where drug prices in one or several countries are used as referencing prices to determine drug prices in a given country. Overall, 24 of 30 OECD countries and 20 of 27 EU countries apply ERP to pricing drugs (Dedet, 2016; Vogler *et al.*, 2020). The practice of ERP is also popular in other regions such as the Middle East and South Asia, East Asia, Africa, and South America (Verghese *et al.*, 2019; Vogler *et al.*, 2020). If firms sell directly, ERP is subject to foreign prices. However, if firms serve globally throughout agents, ERP is subject to either wholesale prices or foreign prices, that is so-called ex-factory-price (EFP) or pharmacy-purchasing-price (PPP) ERP, respectively.

From 2018, ERP has received much attention as President Trump's administration proposed to adopt ERP. Supporting this plan, Kang *et al.* (2019) and Mulcahy *et al.* (2021) show that ERP could reduce the U.S. drug expenditure and improve the social welfare. Theoretically, Geng and Saggi (2017, 2020) and Iravani *et al.* (2020) show that a country is always socially desirable with ERP if a producer exports. Similarly, Marinoso *et al.* (2011) indicate that a country is better-off with ERP if its fixed copayment is high. Empirically, Hakonsen *et al.* (2009) indicate that ERP is the most successful method to reduce drug prices in nine EU countries. Salter (2015) and Holtorf *et al.* (2019) find that ERP might enhance the welfare of home countries. Considering the EU region, Vogler *et al.* (2014) suggest that ERP is effective to raise patients' access to drugs and to reduce healthcare expenditure. Disagreeing with arguments, Kanavos *et al.* (2020) criticize that the efficiency of ERP is not clear, especially in the long run, and it may bring some unintended consequences to consumers and public payers. In sum, there is a strong confirmation about the success of ERP, but there still has a debate. In this paper, we investigate whether ERP is a welfare-improving policy, and under what circumstances ERP may not be a socially beneficial policy.

In practice, the co-existence of ERP and reimbursement policy is common in many countries (see Table 1). The reimbursement policy covers some certain expenses to receive healthcare services or medical bills. Motive to implement the reimbursement policy is two-folds: Encouraging pharmaceutical firms to research and develop potential drugs/medicines, and helping consumers to access more drugs (Bruen *et al.*, 2016). In Slovakia, authorities apply ERP to determine reimbursement policy and to manage national expenditure for pharmaceuticals (Albreht *et al.*, 2009). In Italy, ERP is used as a basis to negotiate drug prices and to discuss reimbursement process. Similarly, in Spain and France, ERP is a crucial tool to negotiate prices between authorities and drug manufacturers (Ruggeri and Nolte, 2013; Kanavos *et al.*, 2017). Stargardt and Schreyogg (2007) suggest that countries can use ERP to determine reimbursement prices. Practically, the reimbursement policy can be a fixed copayment, a copayment rate, or a combination (Kanavos *et al.*, 2017; Leopold *et al.*, 2012; Vogler *et al.*, 2018). In this paper, we consider the reimbursement policy as a copayment rate only. Copayment rates are usually set by law, thus they take time to amend (Marinoso *et al.*, 2011). Moreover, copayment rates often vary on drugs. Therefore, we take the copayment rate as given, and our analysis can carry out any possibility of copayment rate.

It is a fact that ERP is not the only instrument to deter the market power of brand-name firms. Introducing generic drugs can achieve the same results. The penetration of generic drugs in market is allowed after patents are expired, that will make brand-name firms behave more aggressively. As a result, generic drugs can improve social welfare (Brekke *et al.*, 2011; Dirnagl and Cocoli, 2016; Geng and Saggi, 2020). Give the above discussions, we therefore incorporate the reimbursement policy and generic producer to figure out how they affect the implementation of ERP.

In pharmaceutical industry, producers commonly distribute drugs throughout either direct or indirect sales channels (Kanavos *et al.*, 2011; Iravani *et al.*, 2020). Under direct sales channel, manufacturers serve foreign markets directly; while under indirect sales channel, they serve globally through foreign agents. In this paper, we examine both distribution channels.

We build a simple two-country model: home country and foreign country. There is a brand-name producer located in the home and potentially serves both countries. In each country, there is a local generic producer. Since the generic drug is off-patent, it can be produced ubiquitously. Practically, generic drugs usually face the difficulties associated to compulsory licenses and documenting processes for exporting. Thus, we assume two generic firms serve locally only.

TABLE 1
PRACTICE OF ERP AND REIMBURSEMENT IN SELECTED COUNTIRES

Country	ERP				Reimbursement Type	Link
	Scope	Types	Basket size	Revision		
Austria	All medicines	Average	24	6 months	Fixed copayment	Yes
Belgium	National positive list	Average	26	Launch only	Copayment rate	No
Bulgaria	National positive list	Lowest	10	6 months	Copayment rate	Yes
Czech	National positive list	Average	17	Annually	Copayment rate	Yes
Estonia	National positive list	Ceiling	3	Annually	Fixed copayment + Copayment rate	Yes
France	National positive list	Flooring	4	4-5 years	Fixed copayment + Copayment rate	Yes
Greece	National positive list	Average	22	2 years	Fixed copayment + Copayment rate	Yes
Latvia	National positive list	Lowest	27	2 years	Fixed copayment + Copayment rate	Yes
Portugal	National positive list	Lowest	3	Annually	Copayment rate	Yes
Romania	All medicines	Lowest	12	Annually	Copayment rate	Yes
Slovakia	National positive list	Average	27	6 months	Copayment rate	Yes
Slovenia	National positive list	Lowest	3	6 months	Copayment rate	No
Spain	National positive list	Lowest	16	2 years	Copayment rate	Yes
Jordan	All medicines	Average	16	2 years	Copayment rate	Yes/ Critical
Lebanon	All medicines	Ceiling	14	5 years	Copayment rate	Yes/ Critical

Source: Complication from Leopold *et al.* (2012), Kanavos *et al.* (2017), and Vogler *et al.* (2018).

We consider two scenarios that either or not the home government indexes the brand-name drug in an ERP system.

Our findings show that under direct sales channel, the home social welfare can be worse-off with ERP. With ERP, an increase in the home copayment rate creates both negative effects and positive effects on the home social welfare; while without ERP, it is independent of the social welfare. Thus, if the home copayment rate is high enough, the home social welfare is worse-off with ERP. Our main insights are robust under indirect sales channel. Comparatively, the home social welfare (brand-name profit) is better-off with PPP ERP (indirect sales channel) if the home copayment rate is relatively high.

Our model is close to Geng and Saggi (2017, 2020) and Iravani *et al.* (2020), but it is different in several key factors. First, Geng and Saggi (2017, 2020) and

Iravani *et al.* (2020) ignore the role of reimbursement policy. Second, Geng and Saggi (2017, 2020) consider only direct sales channel, while both direct and indirect sales channels are incorporated in our model.

Our model is also related to Marinoso *et al.* (2011), but they consider a fixed copayment, while we investigate a copayment rate. A fixed copayment is inflexible and it does not affect the market price. However, a copayment rate will affect the market price, then indirectly affects ERP. In addition, they focus on consumer surplus only since a drug producer is located in a third country; while we consider the home social welfare including the profits of producers.

The remainder of the paper is structured as follows. Section 2 describes the basic model. Section 3 investigates direct sales channel. Section 4 analyzes indirect sales channel. Section 5 concludes the paper.

2. Basic model

We consider a pharmaceutical industry consisting of a brand-name drug and a generic drug in a two-country model: home (H) and foreign (F). A brand-name drug producer is located in country H, and potentially serves both markets. The brand-name drug is on-patent and protected in both countries. Each country has one local generic producer that produces generic drug and serves locally. For simplicity, the marginal production costs of two drugs are normalized to zero.[1]

An individual consumer's utility when she consumes the brand-name drug and generic drug is $u=\theta-p+\gamma p$ and $\tilde{u}=\alpha\theta-\tilde{p}+\gamma\tilde{p}$, respectively. If a consumer does not buy products, utility is zero. We note that the variables with no superscript "*" denote variables in country H, while those with superscript "*" denotes variables in country F. θ represents the consumer's taste of quality. Two countries are considered as both having a unity continuum of consumers, but the different tastes of quality that are uniformly distributed in interval $\left[0,\overline{\theta}\right]$ in country H and interval [0,1] in country F. α is the effectiveness of generic drug, $0<\alpha<1$, implying that the brand-name drug is perceived higher quality. For simplicity, we assume that the quality levels of generic drugs in both countries are equal, i.e., $\alpha^*=\alpha$. p and $\tilde{p}$ are the brand-name and generic prices, respectively. $\gamma\in[0,1)$ is a copayment rate that is paid by authorities, i.e., national health agencies. If $\gamma=0$, consumers pay full prices. We restrict $\gamma<1$ for two reasons: Ensuring meaningful analysis and avoiding a scenario of wasteful source by oversupplying of drugs. Two countries differ in two main features: Consumers' taste of drug quality, i.e., $\overline{\theta}\geq\overline{\theta}^*=1$ and copayment rates, i.e., γ and γ^*.

In country H, a marginal consumer θ_b between buying the brand-name drug or generic drug is $\theta_b=\dfrac{(1-\gamma)(p-\tilde{p})}{1-\alpha}$. A marginal consumer θ_g between

1 See Marinoso *et al.* (2011), Geng and Saggi (2017, 2020), and Iravani *et al.* (2020).

buying and not buying the generic drug is $\theta_g = \frac{(1-\gamma)\tilde{p}}{\alpha}$. Thus, demands for the brand-name and generic drugs are $q = \frac{1}{\bar{\theta}}(\bar{\theta} - \theta_b)$ and $\tilde{q} = \frac{1}{\bar{\theta}}(\theta_b - \theta_g)$, respectively. Similarly, in country F, demands for the brand-name and generic drugs are obtained as $q^* = 1 - \theta_b^*$ and $\tilde{q}^* = \theta_b^* - \theta_g^*$, where $\theta_b^* = \frac{(1-\gamma^*)(p^* - \tilde{p}^*)}{1-\alpha}$ and $\theta_g^* = \frac{(1-\gamma^*)\tilde{p}^*}{\alpha}$, respectively.

The game structure is as follows. In the first stage, government H imposes ERP where the home brand-name price is regulated to be equal to its foreign price. In the second stage, the brand-name firm decides to serve either country H only or both countries H and F. If he abandons country F, he competes in price with the generic firm in country H only but does not serve the brand-name drug in country F. If he decides to export, he simultaneously competes in price with the generic firms in both markets. With ERP, if the brand-name firm chooses to serve country H only, that is π_H, serving as his exporting reservation profit. Hereafter, we assume the brand-name firm has an incentive to serve both markets under ERP. To ensure an incentive for government H to impose ERP and the brand-name firm to export under ERP, we have the following assumption:

Assumption 1: $\frac{1-\gamma}{1-\gamma^*} \le \bar{\theta} \le \frac{3(1-\gamma)}{1-\gamma^*}$.

3. Direct sales channel

3.1. Without ERP

Under this scenario, the brand-name producer freely serves and competes with the local generic producer in each country. Given that, in the final stage, the brand-name and generic firms maximize the following equation:

$$(1) \qquad \begin{cases} \max\limits_{p,p^*} \Pi = \frac{1}{\bar{\theta}}\left[\bar{\theta} - \frac{(1-\gamma)(p-\tilde{p})}{1-\alpha}\right]p + \left[1 - \frac{(1-\gamma^*)(p^* - \tilde{p}^*)}{1-\alpha}\right]p^* \\ \max\limits_{\tilde{p}} \tilde{\pi} = \frac{1}{\bar{\theta}}\left[\frac{(1-\gamma)(p-\tilde{p})}{1-\alpha} - \frac{(1-\gamma)\tilde{p}}{\alpha}\right]\tilde{p} \\ \max\limits_{\tilde{p}^*} \tilde{\pi}^* = \left[\frac{(1-\gamma^*)(p^* - \tilde{p}^*)}{1-\alpha} - \frac{(1-\gamma^*)\tilde{p}^*}{\alpha}\right]\tilde{p}^* \end{cases}$$

It is straightforward to derive the best response functions from the equation (1) as:

$$p(\tilde{p})=\frac{1}{2}\left[\tilde{p}+\frac{(1-\alpha)\bar{\theta}}{1-\gamma}\right],\ p^{*}\left(\tilde{p}^{*}\right)=\frac{1}{2}\left(\tilde{p}^{*}+\frac{1-\alpha}{1-\gamma^{*}}\right),\ \tilde{p}(p)=\frac{p}{2},\ \tilde{p}^{*}\left(p^{*}\right)=\frac{p^{*}}{2}.$$

The brand-name and generic prices are strategic complements as a change in the brand-name price reinforces a change in the generic price and vice versa.

By solving the maximizing problems in the equation (1), we achieve the equilibrium prices as:

$$p^{N}=\frac{2\bar{\theta}(1-\alpha)}{(1-\gamma)(4-\alpha)},\quad p^{*N}=\frac{2(1-\alpha)}{\left(1-\gamma^{*}\right)(4-\alpha)},\quad \tilde{p}^{N}=\frac{\alpha(1-\alpha)\bar{\theta}}{(1-\gamma)(4-\alpha)},$$
$$\tilde{p}^{*N}=\frac{\alpha(1-\alpha)}{\left(1-\gamma^{*}\right)(4-\alpha)}.$$

The superscript "*N*" denotes the equilibrium outcomes. Using these prices, we can derive the profits as Π^{N} and $\tilde{\pi}^{N}$.

The home social welfare is defined by the sum of consumer surplus, profits of brand-name and generic firms, and subtraction of expenditure as:

(2) $$sw^{N}=cs^{N}+\Pi^{N}+\tilde{\pi}^{N}-E^{N},$$

where $E^{N}=\gamma\left(p^{N}q^{N}+\tilde{p}^{N}\tilde{q}^{N}\right)$, $cs^{N}=\frac{1}{\bar{\theta}}\int_{\hat{\theta}_{b}}^{\bar{\theta}}\left[z-(1-\gamma)p^{N}\right]dz+\frac{1}{\bar{\theta}}\int_{\hat{\theta}_{g}}^{\hat{\theta}_{b}}\left[\alpha z-(1-\gamma)\tilde{p}^{N}\right]dz.$ All results are reported in Appendix 1.

We perform the effects of the home copayment rate on the equilibrium outcomes in the following lemma.

Lemma 1. *Under direct sales channel without ERP, we have:*

(i) The profits of brand-name and generic firms, and expenditure in country H increase in the home copayment rate;
(ii) The consumer surplus and social welfare in country H are independent of the home copayment rate.
Proof: See Appendix 1.

Lemma 1 is standard and in line with the findings by Birg (2015). A higher copayment rate gives rise to consumers' willingness-to-pay, which allows firms to charge higher prices that leads to higher profits. Next, it is found that $\frac{\partial p^{N}}{\partial\gamma}>0$ and $\frac{\partial\tilde{p}^{N}}{\partial\gamma}>0,$ indicating that the public expenditure increases with the home copayment rate. Without ERP, two countries H and F are segmented, and two drugs are vertically differentiated. Both firms in each country can adjust the prices to capture all reimbursed payments. Thus, any change in the copayment rate does not influence the effective prices, i.e., $\frac{\partial(1-\gamma)p^N}{\partial\gamma}=0$, $\frac{\partial(1-\gamma)\tilde{p}^N}{\partial\gamma}=0$. This implies that all public expenditure would be completely transferred into profits. Therefore, the consumer surplus and social welfare in country H are independent of the home copayment rate.

3.2. With ERP

With ERP, if the brand-name firm exports, the home price is regulated to be equal to its foreign price, i.e., $p=p^*$. Given that, in the final stage, solving the equation (1) and *s.t.* $p=p^*$ yields the equilibrium prices as:

$$p^E=p^{*E}=\frac{4(1-\alpha)\bar{\theta}}{(4-\alpha)\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]},\quad \tilde{p}^E=\tilde{p}^{*E}=\frac{2\alpha(1-\alpha)\bar{\theta}}{(4-\alpha)\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]}.$$

The superscript "E" denotes the equilibrium outcomes. By routine calculations, we have the profits as Π^E and $\tilde{\pi}^E$. Similarly, we attain the home social welfare, i.e., sw^E. All results are reported in Appendix 2.

The following lemma represents the effects of the home copayment rate on the equilibrium outcomes in country H.

Lemma 2. *Under direct sales channel with ERP, the following hold:*

(i) The home brand-name profit, total expenditure, and consumer surplus increase in the home copayment rate; while the home generic and foreign brand-name firms' profits decrease in the home copayment rate;
(ii) The home social welfare is a concave function of the home copayment rate.
Proof: See Appendix 2.

It is straightforward to show that ERP generates some negative spillover effects on the foreign brand-name price. This is because when the home price is directly linked by its foreign price, the brand-name firm will set a higher foreign price to reduce its profit loss in country H. An increase in the home copayment rate leads to an increase in the home consumers' willingness-to-pay, leading to an increase in the home brand-name price. In other words, an increase in the home copayment rate makes the home (foreign) brand-name price move closer to (far away from) its free-trade price that increases (decreases) the home (foreign) brand-name profit.

For the home generic profit, we first notice that the copayment rate positively affects the home generic price. However, the copayment rate with ERP negatively affects the home generic demand. This is because the effect of copayment rate with ERP on the brand-name marginal consumer is significantly stronger than that on the generic marginal consumer, [2] suggesting that an increase in the copayment rate reduces the home generic demand. Since the demand effect is stronger than the price effect, the home generic profit is decreasing in the copayment rate.

The effects of the home copayment rate on the consumer surplus and expenditure in country H are intuitive. An increase in the home copayment rate lowers the effective prices, but raises the market prices, which directly increases the consumer surplus and expenditure.

For the home social welfare, we first note that Part (i) of Lemma 2 indicates that an increase in the home copayment rate generates the opposite effects on the components of home social welfare. In addition, when the home copayment rate is small (high), the beneficial effect of ERP on the home social welfare dominates (is dominated by) the negative effect of copayment rate. Therefore, the home social welfare is a concave function of the home copayment rate.

3.3. With vs. Without ERP

We first notice that under a case of no home reimbursement policy (i.e., $\gamma = 0$), irrespective of the foreign copayment rate, if the brand-name firm exports, ERP is always socially desirable, i.e., $sw^E\big|_{\gamma=0} > sw^N\big|_{\gamma=0}$. This is because there exists the effect of ERP only, which always benefits the home social welfare. This result is in line with the findings by Geng and Saggi (2017, 2020) and Iravani *et al.* (2020) whereby without reimbursement policy, ERP is always socially desirable for the home country.

We now discuss a case of with the reimbursement policy to see how it affects the home social welfare. Comparing sw^N and sw^E, we arrive at the following proposition.

Proposition 1. *With direct sales channel, the home social welfare with ERP is lower than that without ERP if* $\gamma > \overline{\gamma}$; *otherwise, it is higher.*
Proof: See Appendix 3.

The finding indicates that incorporating the generic producer and the reimbursement policy may make the home social welfare worse-off with ERP. With ERP, the home generic price is relatively high, but the home generic demand significantly reduces, which results in a higher generic expenditure and a lower generic profit. Precisely, the contribution of generic producer to the home social

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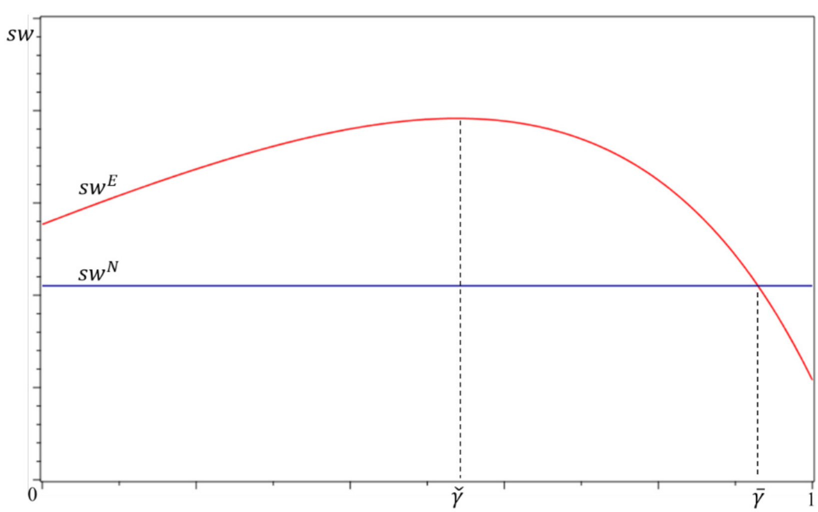
2 $\dfrac{\partial\theta_b^E}{\partial\gamma} = -\dfrac{2(2-\alpha)\left(1-\gamma^*\right)\overline{\theta}^2}{(4-\alpha)\left[(1-\gamma)+\left(1-\gamma^*\right)\overline{\theta}\right]^2} < 0$, $\dfrac{\partial\theta_g^E}{\partial\gamma} = -\dfrac{2(1-\alpha)\left(1-\gamma^*\right)\overline{\theta}^2}{(4-\alpha)\left[(1-\gamma)+\left(1-\gamma^*\right)\overline{\theta}\right]^2} < 0$, and $\left|\dfrac{\partial\theta_b^E}{\partial\gamma}\right| - \left|\dfrac{\partial\theta_g^E}{\partial\gamma}\right| = \dfrac{2\left(1-\gamma^*\right)\overline{\theta}^2}{(4-\alpha)\left[(1-\gamma)+\left(1-\gamma^*\right)\overline{\theta}\right]^2} > 0.$

welfare is considerably lower with ERP compared with one without ERP. In addition, Lemma 2 shows that the home copayment rate with ERP creates both negative and positive effects on the home social welfare. If the home copayment rate is high enough, the negative effects dominate the positive effects, suggesting that the home social welfare with ERP is decreasing in the home copayment rate. Note that the home copayment rate is independent of home social welfare without ERP from Lemma 1. Therefore, the home social welfare is worse-off with ERP when the home copayment rate is high enough, i.e., $\gamma > \bar{\gamma}$ (see Figure 1).

Marinoso *et al.* (2011) show that ERP is better-off for a country with a high copayment. Since the copayment in their setting is a fixed fee, an exporting firm located in a third country would set a relatively higher price with a higher copayment. Therefore, an importing country with a higher copayment is more likely to impose ERP to reduce prices. Our model, however, suggests that the ERP-enhancing social welfare with a relatively high copayment is not robust under an exporting country. The result by Geng and Saggi (2017, 2020) and Iravani *et al.* (2020), that ERP is socially desirable, is naturally sensitive with the presence of reimbursement policy. This is because they ignore the roles of expenditure and generic profit. Precisely, our findings provide a crucial recommendation for policy-makers on executing ERP in pharmaceutical-producing countries, especially in the United State, which has proposed to adopt ERP. Our findings are supporting for empirical literature by Fontrier *et al.* (2019), Gill *et al.* (2019), and Kanavos *et al.* (2020) that the social welfare can be worse-off with ERP. Thus, policy-makers are not necessary to pursue the implementation of ERP.

FIGURE 1
SOCIAL WELFARE COMPARISON UNDER DIRECT SALES CHANNEL



4. Indirect Sales Channel

In this section, we consider indirect sales channel where the brand-name firm sells the drug in country F by signing a linear contract with a foreign agent. The linear contracts are popular in pharmaceutical industry (Grennan, 2013; Gaudin, 2019). Under such a case, there are two possible types of ERP: Ex-factory price-based or list-price-based (EFP) ERP and pharmacy-purchasing-price-based (PPP) ERP (Iravani *et al.*, 2020; Ollendorf *et al.*, 2021). With EFP ERP, the home brand-name price is determined equally to its wholesale price. Many countries are applying EFP ERP such as Spain, Greece, and Belgium. EFP ERP is popular since the price is determined before country-specific markups are realized, therefore it moderates comparisons between countries (Ollendorf *et al.*, 2021). With PPP ERP, the home brand-name price is indexed equally to its foreign price. Some countries are using this approach such as Finland, the Netherlands, Austria, Cyprus, and Ireland.

Demands for the brand-name and generic drugs in each market are the same as those in section 2. The game is structured as follows. In the first stage, government H implements either no ERP or EFP (PPP) ERP. In the second stage, the brand-name producer determines a linear contract, i.e., w, to a foreign agent. In the last stage, the brand-name firm and local generic firms simultaneously determine the prices. The following assumption holds to ensure the imposition of ERP and the exporting decision of brand-name firm:

Assumption 2: $\dfrac{(3-\alpha)(1-\gamma)}{(2-\alpha)\left(1-\gamma^{*}\right)} \le \bar{\theta} \le \dfrac{(4-\alpha)^{2}(1-\gamma)}{(2-\alpha)^{2}\left(1-\gamma^{*}\right)}$.

To save space, we report all results for Section 4 in Appendix 4.

4.1. Without ERP

Without ERP, the brand-name firm freely competes with the local generic firm in each market. Given that, in the final stage, they maximize the following equation:

$$(3)\qquad \begin{cases} \max\limits_{p} \Pi = \dfrac{1}{\bar{\theta}}\left[\bar{\theta} - \dfrac{(1-\gamma)(p-\tilde{p})}{1-\alpha}\right]p + wq^{*} \\ \max\limits_{p^{*}} \pi^{*} = \left[1 - \dfrac{\left(1-\gamma^{*}\right)\left(p^{*}-\tilde{p}^{*}\right)}{1-\alpha}\right]\left(p^{*}-w\right) \\ \max\limits_{\tilde{p}} \tilde{\pi} = \dfrac{1}{\bar{\theta}}\left[\dfrac{(1-\gamma)(p-\tilde{p})}{1-\alpha} - \dfrac{(1-\gamma)\tilde{p}}{\alpha}\right]\tilde{p} \\ \max\limits_{\tilde{p}^{*}} \tilde{\pi}^{*} = \left[\dfrac{\left(1-\gamma^{*}\right)\left(p^{*}-\tilde{p}^{*}\right)}{1-\alpha} - \dfrac{\left(1-\gamma^{*}\right)\tilde{p}^{*}}{\alpha}\right]\tilde{p}^{*} \end{cases}$$

By solving the maximizing problems in the equation (3), we derive the final-stage prices as:

$$p=\frac{2(1-\alpha)\bar{\theta}}{(4-\alpha)(1-\gamma)},\;\; \tilde{p}=\frac{\alpha(1-\alpha)\bar{\theta}}{(4-\alpha)(1-\gamma)},\;\; p^{*}(w)=\frac{2\left[(1-\alpha)+\left(1-\gamma^{*}\right)w\right]}{(4-\alpha)\left(1-\gamma^{*}\right)},$$

$$\tilde{p}^{*}(w)=\frac{\alpha\left[(1-\alpha)+\left(1-\gamma^{*}\right)w\right]}{(4-\alpha)\left(1-\gamma^{*}\right)}.$$

In the second stage, the brand-name firm maximizes:

$$\max_{w}\Pi=\frac{1}{\bar{\theta}}\left[\bar{\theta}-\frac{(1-\gamma)(p-\tilde{p}(w))}{1-\alpha}\right]p+wq^{*}(w). \tag{4}$$

Solving (4) yields the wholesale price, $w^{n}=\frac{1-\alpha}{(2-\alpha)\left(1-\gamma^{*}\right)}$. The variables with superscript "n" represent the equilibria. By using w^n, we can derive the equilibrium prices as:

$$p=\frac{2(1-\alpha)\bar{\theta}}{(4-\alpha)(1-\gamma)},\;\; \tilde{p}=\frac{\alpha(1-\alpha)\bar{\theta}}{(4-\alpha)(1-\gamma)},\;\; p^{*n}=\frac{2(1-\alpha)(3-\alpha)}{(2-\alpha)(4-\alpha)\left(1-\gamma^{*}\right)},$$

$$\tilde{p}^{*n}=\frac{\alpha(1-\alpha)(3-\alpha)}{(2-\alpha)(4-\alpha)\left(1-\gamma^{*}\right)}.$$

It is found $p^{n}\geq p^{*n}$ by Assumption 2, implying that government H has an incentive to impose ERP.[3] By substituting these prices into the profit functions, we obtain the equilibrium profits, Π^{n} and $\tilde{\pi}^{n}$.

Then, the home social welfare is realized as sw^n. Similarly, it is found that without ERP, the consumer surplus and social welfare are independent of home copayment rate under indirect sales channel.

4.2. With EFP ERP

Under this context, the home brand-name price is equal to the wholesale price. Given that, in the last stage, we solve the equation (3) and *s.t.* $p = w$, then the final-stage prices are realized as:

[3] EFP ERP requires $p^{n}\geq w^{n}$. However, $p^{n}\geq p^{*n}$ and $p^{*n}\geq w^{n}$; thus, $p^{n}\geq w^{n}$ holds.

$$p = w,\quad \tilde{p}(w) = \frac{\alpha w}{2},\quad p^*(w) = \frac{2\left[(1-\alpha)+\left(1-\gamma^*\right)w\right]}{(4-\alpha)\left(1-\gamma^*\right)},$$
$$\tilde{p}^*(w) = \frac{\alpha\left[(1-\alpha)+\left(1-\gamma^*\right)w\right]}{(4-\alpha)\left(1-\gamma^*\right)}.$$

In the second stage, the brand-name firm maximizes:

(5) $$\max_w \Pi = \frac{1}{\overline{\theta}}\left[\overline{\theta} - \frac{(1-\gamma)(w-\tilde{p}(w))}{1-\alpha}\right]w + wq^*(w).$$

Solving (5) yields the wholesale price, i.e., $w^d = \frac{(1-\alpha)(6-\alpha)\overline{\theta}}{(2-\alpha)\left[(1-\gamma)(4-\alpha)+\left(1-\gamma^*\right)\overline{\theta}\right]}$. The variables with superscript "*d*" denote the equilibrium outcomes. Given that, we can achieve the optimal prices as:

$$p^d = \frac{(1-\alpha)(6-\alpha)\overline{\theta}}{(2-\alpha)\left[(1-\gamma)(4-\alpha)+\left(1-\gamma^*\right)\overline{\theta}\right]},\ \tilde{p}^d = \frac{\alpha(1-\alpha)(6-\alpha)\overline{\theta}}{2(2-\alpha)\left[(1-\gamma)(4-\alpha)+\left(1-\gamma^*\right)\overline{\theta}\right]},$$
$$p^{*d} = \frac{2\left(8-\alpha^3+7\alpha^2-14\alpha\right)(1-\gamma)+\left(3\alpha^2-13\alpha+10\right)\left(1-\gamma^*\right)\overline{\theta}}{(4-\alpha)\left(1-\gamma^*\right)(2-\alpha)\left[(1-\gamma)(4-\alpha)+\left(1-\gamma^*\right)\overline{\theta}\right]},$$
$$\tilde{p}^{*d} = \frac{\alpha\left(8-\alpha^3+7\alpha^2-14\alpha\right)(1-\gamma)+\left(3\alpha^2-13\alpha+10\right)\left(1-\gamma^*\right)\overline{\theta}}{(4-\alpha)\left(1-\gamma^*\right)(2-\alpha)\left[(1-\gamma)(4-\alpha)+\left(1-\gamma^*\right)\overline{\theta}\right]}.$$

By routine calculations, we can derive the profits, Π^d and $\tilde{\pi}^d$.[4] Then, we obtain the home social welfare as sw^d.

4.3. With PPP ERP

Under this case, if the brand-name firm exports, its home price is regulated to be equal to its foreign price. Given that, in the final stage, by solving the equation (3) and *s.t.* $p = p^*$, we obtain the final-stage prices as:

$$p(w) = p^*(w) = \frac{2\left[(1-\alpha)+\left(1-\gamma^*\right)w\right]}{(4-\alpha)\left(1-\gamma^*\right)},\ \tilde{p}(w) = \tilde{p}^*(w) = \frac{\alpha\left[(1-\alpha)+\left(1-\gamma^*\right)w\right]}{(4-\alpha)\left(1-\gamma^*\right)}$$

4 $\Pi^d > \pi_H$ by Assumption 2.

In the second stage, the brand-name firm solves:

$$\max_{w} \Pi = \frac{1}{\overline{\theta}}\left[\overline{\theta} - \frac{(1-\gamma)\left(p^{*}(w) - \tilde{p}(w)\right)}{1-\alpha}\right] w + wq^{*}(w). \quad (6)$$

By solving (6), we obtain the wholesale price, i.e., $w^{r} = \frac{2(1-\alpha)\left[(4-\alpha)\left(1-\gamma^{*}\right)\overline{\theta} - (2-\alpha)(1-\gamma)\right]}{\left(1-\gamma^{*}\right)\left[\left(\alpha^{2}-6\alpha+8\right)\left(1-\gamma^{*}\right)\overline{\theta} + 2(2-\alpha)(1-\gamma)\right]}$. The variables with superscript "*r*" represent the equilibria. Similarly, we can derive the equilibrium prices as:

$$p^{r} = p^{*r} = \frac{2(1-\alpha)(4-\alpha)\overline{\theta}}{(2-\alpha)\left[2(1-\gamma) + (4-\alpha)\left(1-\gamma^{*}\right)\overline{\theta}\right]},$$

$$\tilde{p}^{r} = \tilde{p}^{*r} = \frac{\alpha(1-\alpha)(4-\alpha)\overline{\theta}}{(2-\alpha)\left[2(1-\gamma) + (4-\alpha)\left(1-\gamma^{*}\right)\overline{\theta}\right]}.$$

By using these prices, we can obtain the profits, i.e., Π^{r} and $\tilde{\pi}^{r}$.[5] Finally, we can achieve the home social welfare as sw^{r}.

Firm's choice: Direct vs. Indirect sales channel

Now, a question that arises is: Over which type of sales channel, either direct or indirect, results in a higher brand-name profit? By comparing Π^{E} with Π^{d} and Π^{r}, we build the following proposition.

Proposition 2. *The brand-name profit under direct sales channel is lower than that under indirect sales channel if the home copayment rate is high enough, i.e.,* $\Pi^{E} < \Pi^{d}\left(\Pi^{r}\right)$ *if* $\gamma > \gamma^{D}\left(\gamma^{R}\right)$.
Proof: See Appendix 5.

Some may think that indirect sales channel would result in a lower profit for the brand-name firm since some rent from country F comes to the foreign agent. However, indirect sales channel creates double-marginalization problem, which relatively raises the foreign brand-name price. Intuitively, the increasing magnitude of home brand-name price by an increase in the home copayment rate under indirect sales channel is stronger than that under direct sales channel.

5 $\Pi^{r} > \pi_{H}$ by Assumption 2.

Keep in mind that country H is more lucrative than country F. Therefore, if the home copayment rate is high enough, the gain in country H dominates the loss in country F, which leads to a higher brand-name profit under indirect sales channel.

Our findings give theoretical evidence that the copayment rate is one of the crucial factors to determine the firm's behavior in choosing the distribution channel of drugs. To some extent the results practically explain why indirect distributions are common in pharmaceutical industry. Our results provide a framework for empirical works to test either direct sales channel or indirect sales channel with ERP is more profitable for exporting firms.

Indirect sales channel: EFP ERP vs. PPP ERP

As mentioned previously, it is popularly common in pharmaceutical industry that producers often distribute drugs internationally through indirect sales channels. Suppose the exporting brand-name firm signs a linear contract with a foreign agent. A question arises: If government H imposes ERP, which type of ERP, either EFP ERP or PPP ERP, results in a larger home social welfare? To explore this issue, we compare sw^d and sw^r. We summarize the result in the following proposition.

Proposition 3. *Given indirect sales channel, the home social welfare is better-off with PPP ERP if the home copayment is high enough, i.e.,* $\gamma > \gamma^s$.
Proof: See Appendix 6.

It is no doubt that the brand-name price with EFP ERP is lower than that with PPP ERP, i.e., $p^d < p^r$.[6] For the home social welfare, this price effect is in favor of EFP ERP. However, it is found that the change in the brand-name price caused by an increase in the home copayment rate is much more intensified under EFP ERP versus under PPP ERP. This indicates that when the home copayment rate is higher, the negative effect of the home copayment rate on the home social welfare is stronger with EFP ERP than PPP ERP. Thus, when the home copayment rate is higher enough, the negative copayment rate effect is able to overweigh the positive price effect, which results in a higher home social welfare under PPP ERP. Again, our findings show that the presence of generic producer and copayment rate plays a significant role in the ERP-choosing decision of the home government. Our results are complementary to Iravani *et al.* (2020) that the home social welfare might be higher with PPP ERP. However, they conclude this result depends on the drug valuation of consumers, while the home copayment rate is crucial in our paper.

6 $p^d - p^r = -\frac{(1-\alpha)\left[2(5-\alpha)(1-\gamma)-(2-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]\bar{\theta}}{\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]} < 0$ by Assumption 2.

4.4. With vs. Without ERP

Comparing sw^n with sw^d and sw^r under indirect sales channel, we arrive at the following proposition.

Proposition 4. *Under indirect sales channel, there exists a critical value of the home copayment rate, i.e.,* $\gamma > \gamma^d \, (\gamma > \gamma^r)$, *the home social welfare is worse-off with EFP (PPP) ERP.*

Proof: See Appendix 7.

The findings confirm the key result obtained in Proposition 1, whereby ERP under the presence of home generic producer and reimbursement policy is worse-off if the home copayment rate is too high. Intuitions are similar to those in Proposition 1. However, the possibility of home social welfare being better-off without ERP is more likely to occur under indirect sales channel rather than direct sales channel, i.e., $\bar{\gamma} > \gamma^r \; (\bar{\gamma} > \gamma^d)$. [7] This is because the existence of double-marginalization problem under indirect sales channel aggressively pushes up the foreign brand-name price, which directly (indirectly) gives rise on the home brand-name price due to inter-linking by ERP. This implies that both EFP ERP and PPP ERP create a higher home expenditure, a lower home generic profit and a lower foreign brand-name revenue compared with those under direct sales channel with ERP. Therefore, given a copayment rate, the home social welfare benefit of ERP is more likely to occur under direct sales channel rather than under indirect sales channel.

5. Conclusion

External reference pricing is a common policy in many countries. From 2018, ERP has received much attention as the U.S has proposed to adopt ERP, because many argue that ERP is socially desirable. However, some strongly criticize the efficiency of ERP. Therefore, our paper incorporates the copayment rate and generic producer to investigate whether ERP is efficient. Both direct and indirect sales channel are discussed in the paper.

We build a two-country model, whereby there are two local generic producers and a brand-name producer. The generic producers serve locally, while the brand-name producer potentially serves both markets. Our findings show that under direct sales channel the home social welfare is worse-off with ERP if the home copayment rate is too high. Our main insights are robust under indirect

7 It is complicated to perform a specific ranking of γ, we have simulated numerical examples to show $\bar{\gamma} > \gamma^r > \gamma^d$. The results are upon request. We thank a referee for this comment.

sales channel.[8] Our results indicate that the implementation of ERP is not necessary to be socially desirable. Thus, policymakers who are either implementing or planning to use ERP (the United State for example) should pay more attention to the roles of national healthcare policy in general, and the copayment rate in specific. Higher supports from the reimbursement actually generate disadvantages on the social welfare if ERP is incorporated.

Furthermore, if the exporting firm chooses indirect sales channel, the home social welfare with PPP ERP is larger than that with EFP ERP if the home copayment rate is high enough. In addition, the brand-name profit is higher under indirect sales channel than that under direct sales channel if the home copayment rate is too high. These findings provide theoretical frameworks for further empirical works to investigate whether the home governments (the exporting firms) is better-off with PPP ERP (indirect sales channel).

In practice, an imposition of ERP is more complicated than our settings. The current model ignores the international trade of generic drugs and restricts to the case of a brand-name firm locating in country H. Therefore, there may be some room to relax these assumptions to figure out firm's strategy and the ERP implementation. Some may also incorporate an endogenous copayment rate. We leave these potential topics for future research.

[8] Our results hold when the reference pricing is given on the reimbursement. The results are upon request. We thank a referee for this comment.

Appendix

Appendix 1. Results for section 3.1 and Proof of Lemma 1

The results without ERP are as:

$$\pi^N = \frac{4(1-\alpha)\bar{\theta}}{(1-\gamma)(4-\alpha)^2},\ \pi^{*N} = \frac{4(1-\alpha)}{\left(1-\gamma^*\right)(4-\alpha)^2},\ \tilde{\pi}^N = \frac{\alpha(1-\alpha)\bar{\theta}}{(1-\gamma)(4-\alpha)^2},$$

$$cs^N = \frac{(5\alpha+4)\bar{\theta}}{2(4-\alpha)^2},\ E^N = \frac{\gamma(1-\alpha)(4+\alpha)\bar{\theta}}{(1-\gamma)(4-\alpha)^2},$$

$$sw^N = \frac{\left(1-\gamma^*\right)\left(12-2\alpha^2+\alpha\right)\bar{\theta}+8(1+\alpha)}{2\left(1-\gamma^*\right)(4-\alpha)^2}.$$

Direct calculations lead to the following results:

$$\frac{\partial \Pi^N}{\partial \gamma} = \frac{4\bar{\theta}(1-\alpha)}{(4-\alpha)^2(1-\gamma)^2} > 0,\ \frac{\partial \tilde{\pi}^N}{\partial \gamma} = \frac{\alpha\bar{\theta}(1-\alpha)}{(4-\alpha)^2(1-\gamma)^2} > 0,$$

$$\frac{\partial E^N}{\partial \gamma} = \frac{\bar{\theta}(1-\alpha)(4+\alpha)}{(4-\alpha)^2(1-\gamma)^2} > 0,\ \frac{\partial cs^N}{\partial \gamma} = 0,\ \frac{\partial sw^N}{\partial \gamma} = 0.$$

Appendix 2. Results for section 3.2 and Proof of Lemma 2

The results with ERP are as:

$$\pi^E = \frac{4(1-\alpha)\left[\alpha(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]\bar{\theta}}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^2},\ \tilde{\pi}^E = \frac{4\alpha(1-\alpha)(1-\gamma)\bar{\theta}}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^2},$$

$$\pi^{*E} = \frac{4(1-\alpha)\left[(4-\alpha)(1-\gamma)+\alpha\left(1-\gamma^*\right)\bar{\theta}\right]\bar{\theta}}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^2},\ E^E = \frac{4\gamma(1-\alpha)\left[(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}+2\alpha(1-\gamma)\right]\bar{\theta}}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^2},$$

$$cs^E = \frac{\left\{\left[(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}+\alpha(1-\gamma)\right]\left[(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}+5\alpha(1-\gamma)\right]+4\alpha(1-\gamma)^2\right\}\bar{\theta}}{2(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^2},$$

$$sw^E = \frac{(4-\alpha)^2\left(1-\gamma^*\right)^2\bar{\theta}^2+\left[4(4-\alpha)-2\alpha^2\gamma^*-(\alpha+8)\gamma\right]\bar{\theta}+\left[\left(14\gamma+11\gamma^2-3\right)\alpha^2-20\left(1-\gamma^2\right)\alpha+32(1-\gamma)\right]}{2(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^2}.$$

Direct calculations lead to:

$$\frac{\partial \pi^E}{\partial \gamma} = \frac{4\bar{\theta}(1-\alpha)\left[(8-3\alpha)\left(1-\gamma^*\right)\bar{\theta} + \alpha(1-\gamma)\right]}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^3} > 0,$$

$$\frac{\partial \pi^{*E}}{\partial \gamma} = -\frac{4\bar{\theta}(1-\alpha)\left[(4-3\alpha)\left(1-\gamma^*\right)\bar{\theta} - (4-\alpha)(1-\gamma)\right]}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^3} < 0,$$

$$\frac{\partial \tilde{\pi}^E}{\partial \gamma} = -\frac{4\alpha\bar{\theta}(1-\alpha)\left[\left(1-\gamma^*\right)\bar{\theta} - (1-\gamma)\right]}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^2} < 0,$$

$$\frac{\partial cs^E}{\partial \gamma} = \frac{4\bar{\theta}^2(1-\alpha)\left(1-\gamma^*\right)\left[\alpha(1-\gamma)+\left(1-\gamma^*\right)(2-\alpha)\bar{\theta}\right]}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^3} > 0, \quad \frac{\partial E^E}{\partial \gamma} > 0,$$

$$\frac{\partial sw^E}{\partial \gamma} = \frac{4\bar{\theta}(1-\alpha)\left[\left(1-\gamma^*\right)(4-3\alpha)\bar{\theta} - (4-\alpha)(1-\gamma)\right]}{(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]^3} \gtreqless 0 \text{ if}$$

$$\gamma \lesseqgtr \check{\gamma} = \frac{4-\alpha}{(4-\alpha)+(4-3\alpha)\left(1-\gamma^*\right)\bar{\theta}}.$$

It is easy to show $0<\check{\gamma}<1$. In addition, $\left.\frac{\partial sw^E}{\partial \gamma}\right|_{\gamma=0} > 0$ and $\left.\frac{\partial sw^E}{\partial \gamma}\right|_{\gamma=1} < 0.$ Therefore, sw^E is a concave function of $\gamma \in (0,1)$.

Appendix 3. Proof of Proposition 1

By using sw^N and sw^E, we obtain $sw^N - sw^E > 0$ if $\gamma > \bar{\gamma} = \frac{M}{N}$, where $M = 9(4-3\alpha)\left(1-\gamma^*\right)^2\bar{\theta}^2 - (4-\alpha)\left(1-\gamma^*\right)\bar{\theta} + 8$ and $N = 3(4-3\alpha)\left(1-\gamma^*\right)\bar{\theta} + 8$. Precisely, we have $M>0$, and $M-N = -\left(1-\gamma^*\right)\left[(4-3\alpha)\left(1-\gamma^*\right)+8(1-\alpha)\right]\bar{\theta} < 0$, implying $\bar{\gamma} \in (0,1)$. Proposition 1 is realized.

Appendix 4. Results for Section 4

Results without ERP (Section 4.1):

$$cs^n = \frac{(5\alpha+4)\bar{\theta}}{2(4-\alpha)^2},\ E^n = \frac{\gamma(1-\alpha)(\alpha+4)\bar{\theta}}{(1-\gamma)(4-\alpha)^2},$$

$$\Pi^n = \frac{(1-\alpha)\left[(1-\gamma)(4-\alpha)+4\left(1-\gamma^*\right)(2-\alpha)\bar{\theta}\right]}{\left(1-\gamma^*\right)(1-\gamma)(2-\alpha)(4-\alpha)^2},\ \tilde{\pi}^n = \frac{\alpha(1-\alpha)\bar{\theta}}{(1-\gamma)(4-\alpha)^2}.$$

Results with EFP ERP (Section 4.2):

$$cs^d = \frac{(2-\alpha)\left[(4-\alpha)(1-\gamma)+4\left(1-\gamma^*\right)\bar{\theta}\right]\left[\left(4+8\alpha-\alpha^2\right)(1-\gamma)+4(2-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]\bar{\theta}+\alpha(6-\alpha)^2(1-\gamma)^2\bar{\theta}}{8(2-\alpha)^2\left[(4-\alpha)(1-\gamma)+2\left(1-\gamma^*\right)\bar{\theta}\right]^2},$$

$$E^d = \frac{\gamma(6-\alpha)(1-\alpha)\bar{\theta}\left[\left(8-2\alpha-\alpha^2\right)(1-\gamma)+8(2-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]}{8(2-\alpha)^2\left[(4-\alpha)(1-\gamma)+2\left(1-\gamma^*\right)\bar{\theta}\right]^2},$$

$$\Pi^d = \frac{(1-\alpha)(6-\alpha)^2\bar{\theta}}{4(2-\alpha)(4-\alpha)\left[(4-\alpha)(1-\gamma)+2\left(1-\gamma^*\right)\bar{\theta}\right]},\ \tilde{\pi}^d = \frac{\alpha(1-\alpha)(6-\alpha)^2(1-\gamma)\bar{\theta}}{4(2-\alpha)^2\left[(4-\alpha)(1-\gamma)+2\left(1-\gamma^*\right)\bar{\theta}\right]^2}.$$

Results with PPP ERP (Section 4.3):

$$cs^r = \frac{(2-\alpha)\left[4\left(1-\gamma^*\right)\bar{\theta}-(2-\alpha)(1-\gamma)\right]\left[\left(12\alpha-3\alpha^2-4\right)(1-\gamma)+\left(8-6\alpha-\alpha^2\right)\left(1-\gamma^*\right)\bar{\theta}\right]\bar{\theta}+\alpha(4-\alpha)^2(1-\gamma)^2\bar{\theta}}{2(2-\alpha)^2\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]^2},$$

$$E^r = \frac{\gamma(4-\alpha)(1-\alpha)\bar{\theta}\left[\left(8-12\alpha+3\alpha^2\right)(1-\gamma)+2\left(8-6\alpha+\alpha^2\right)\left(1-\gamma^*\right)\bar{\theta}\right]}{8(2-\alpha)^2\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]^2},$$

$$\Pi^r = \frac{2(1-\alpha)\left[(2-\alpha)(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]}{(2-\alpha)\left(1-\gamma^*\right)\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]},\ \tilde{\pi}^r = \frac{\alpha(1-\alpha)(4-\alpha)^2(1-\gamma)\bar{\theta}}{(2-\alpha)^2\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]^2}.$$

Appendix 5. Proof of Proposition 2

Let $\Delta\prod^{Ed}$ and $\Delta\prod^{Er}$ denote the profit differences between direct and indirect sales channel. We have:

$$\begin{cases} \Delta\prod^{Ed} = \prod^{E} - \prod^{d} \\ \Delta\prod^{Er} = \prod^{E} - \prod^{r} \end{cases}.$$

By using $\prod^{E}$ and $\prod^{d}$, we obtain:

$$\Delta\prod^{Ed} = \frac{(1-\alpha)I}{2(2-\alpha)(4-\alpha)^2\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]\left[(1-\gamma)(4-\alpha)+2\left(1-\gamma^*\right)\bar{\theta}\right]}.$$

$\Delta\prod^{Ed}$ depends on the sign of $I \equiv \left[\left(\alpha^3+16\alpha^2-108\alpha+112\right)(1-\gamma)-\left(16\alpha^2+16-\alpha^3-20\alpha\right)\left(1-\gamma^*\right)\bar{\theta}\right]$. Mathematically, $\Delta\prod^{Ed}<0$ if $\gamma>\gamma^D=1-\frac{A}{B}$, where $A=\left(16\alpha^2+16-\alpha^3-20\alpha\right)\left(1-\gamma^*\right)\bar{\theta}>0$ and $B=\alpha^3+16\alpha^2-108\alpha+112>0$ Clearly, $\frac{A}{B}<1$ since $A-B=-\left(20\alpha+16-\alpha^3-16\alpha^2\right)\left(1-\gamma^*\right)\bar{\theta}<0.$ Therefore, $0<\gamma^D<1.$

By using $\prod^{E}$ and $\prod^{r}$, we obtain:

$$\Delta\prod^{Er} = \frac{2(1-\alpha)H}{(2-\alpha)(4-\alpha)^2\left(1-\gamma^*\right)\left[(1-\gamma)+\left(1-\gamma^*\right)\bar{\theta}\right]\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]}.$$

$\Delta\prod^{Er}$ depends on the sign of $H \equiv \left[\left(10\alpha^2+32-\alpha^3-32\alpha\right)(1-\gamma)^2\right]-\alpha^2\left(1-\gamma^*\right)^2\left[2(1-\gamma)+(4-\alpha)\left(1-\gamma^*\right)\bar{\theta}\right]\bar{\theta}.$ H is a convex function of γ since $\frac{\partial^2 H}{\partial\gamma^2}=2(2-\alpha)(4-\alpha)^2>0.$ Solving H = 0 yields two roots, γ^H and γ^R, where $\gamma^H>\gamma^R$, as follows:

$$\gamma^R = \frac{32(1-\alpha)+(10-\alpha)\alpha^2-\alpha\left(1-\gamma^*\right)\left(\alpha+\sqrt{\alpha^4-14\alpha^3+73\alpha^2-160\alpha+128}\right)}{(2-\alpha)(4-\alpha)^2},$$

$$\gamma^H = \frac{32(1-\alpha)+(10-\alpha)\alpha^2-\alpha\left(1-\gamma^*\right)\left(\alpha-\sqrt{\alpha^4-14\alpha^3+73\alpha^2-160\alpha+128}\right)}{(2-\alpha)(4-\alpha)^2}.$$

We have $H|_{\gamma=1} < H|_{\gamma=\gamma^H}$ since $H|_{\gamma=1} = -\alpha^2(4-\alpha)\left(1-\gamma^*\right)^2 \bar{\theta}^2 < 0$. Moreover, $H|_{\gamma=0} > H|_{\gamma=\gamma^R}$ since $H|_{\gamma=0} > 0$. Thus, we have $0 < \gamma^R < 1 < \gamma^H$. Given that $H < 0$ if $\gamma > \gamma^R$, therefore $\Delta\prod^{Er} < 0$ if $\gamma > \gamma^R$. In short, $\Delta\prod^{Ed}\left(\Delta\prod^{Er}\right) < 0$ if $\gamma > \gamma^D\left(\gamma^R\right)$.

Appendix 6. Proof of Proposition 3

Let Δsw^{rd} denote the difference in social welfare between PPP ERP and EFP ERP. We then have:

$$\Delta sw^{rd} = sw^r - sw^d.$$

By some calculations, we find that $\Delta sw^{rd} = 0$ has a root, say γ^s. Since $\Delta sw^{rd}\big|_{\gamma=0} < 0$ and $\Delta sw^{rd}\big|_{\gamma=1} > 0$, thus $0 < \gamma^s < 1$. In addition, $\left.\frac{\partial \Delta sw^{rd}}{\partial \gamma}\right|_{\gamma=0} > 0$ and $\left.\frac{\partial \Delta sw^{rd}}{\partial \gamma}\right|_{\gamma=1} > 0$ indicate that Δsw^{rd} is an increasing function of $\gamma \in [0,1)$. Therefore, $\Delta sw^{rd} > 0$ if $\gamma > \gamma^s$; otherwise, $\Delta sw^{rd} < 0$. Proposition 3 is proven.

Appendix 7. Proof of Proposition 4

Let $\Delta sw^{nd}(\Delta sw^{nr})$ denote the differences in social welfare without and with EFP (PPP) ERP. We then have:

$$\begin{cases} \Delta sw^{nd} = sw^n - sw^d \\ \Delta sw^{nr} = sw^n - sw^r \end{cases}.$$

Solving $\Delta sw^{nd} = 0$ yields two roots, i.e., $\gamma = \gamma_1 = -\left[\frac{2(2-\alpha)\left(1-\gamma^*\right)\bar{\theta}}{4-\alpha} + 1\right] < 0$ and $\gamma = \gamma^d$. Solving $\frac{\partial \Delta sw^{nd}}{\partial \gamma} = 0$ yields $\gamma^o = \frac{K}{L}$, where $K \equiv \left(1-\gamma^*\right)\left(16-\alpha^3-8\alpha^2-4\alpha\right)\bar{\theta} + \left(64-48\alpha+12\alpha^2-\alpha^3\right) > 0$ and $L \equiv \left(1-\gamma^*\right)\left(48-68\alpha+28\alpha^2-3\alpha^3\right)\bar{\theta} + \left(64-48\alpha+12\alpha^2-\alpha^3\right) > 0$. We find that $K < L$, so $\gamma_1 < 0 < \gamma^o < \gamma^d$. In addition, $\left.\frac{\partial \Delta sw^{nd}}{\partial \gamma}\right|_{\gamma=\gamma_1} = -\frac{(1-\alpha)(4-3\alpha)}{(2-\alpha)(4-\alpha)(6-\alpha)\left(1-\gamma^*\right)} < 0$ implies that Δsw^{nd}

is a convex function. Since $\Delta sw^{nd}\Big|_{\gamma=1} = \dfrac{\left(1-\gamma^{*}\right)\left(16-12\alpha+6\alpha^{2}\right)\bar{\theta}+\left(64-48\alpha+12\alpha^{2}-\alpha^{3}\right)}{4(2-\alpha)(4-\alpha)^{2}\left(1-\gamma^{*}\right)} > 0,$

$\Delta sw^{nd}\Big|_{\gamma=1} > \Delta sw^{nd}\Big|_{\gamma=\gamma^{d}}$ or $\gamma^{d} < 1$. Therefore, $\Delta sw^{nd} < 0$ for all $0 \le \gamma \le \gamma^{d}$, and $\Delta sw^{nd} > 0$ for all $\gamma > \gamma^{d}$.

Proceeding similar directions as ones shown in Δsw^{nd}, we find that $\Delta sw^{nr} > 0$ if $\gamma > \gamma^{r}$. Proposition 4 is thus realized.

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