Another Side of Parallel Trade on Pharmaceuticals: Price, Supply and Social Welfare in the Exporting Country

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Abstract

In recent years, there are growing concerns on the issue of parallel trade on pharmaceuticals. It is an existing issue in European Union and an emerging issue in the North America and Asia. In the existing studies, the attentions are mainly focused on the price and social welfare in the importing country. If parallel trade was legally permitted, what would happen in the exporting country is also an important issue. In this paper, a model is developed to explore the drug price, supply and social welfare in both the exporting country and importing country in the presence of parallel trade. The possible policy reactions of the government in the two countries are also discussed. Parallel trade will lead to a higher drug price and then a social welfare loss in the exporting country; under certain circumstances, the pharmaceutical firm may cut off the drug supply, which leads to a net welfare loss to the exporting country. The firm's total profit and social welfare in the importing country may increase or decrease. The later finding is contradicted to an existing study because of the relaxation on some assumptions. The results show that the negotiated price in the presence of parallel trade is sensitive to the market size of the drug and transaction cost of parallel trade. Therefore, those factors have important policy implications to the policy maker in the exporting country. With proper policy reactions, the social welfare loss could be avoided. For the importing country, the social welfare change when parallel trade is legally permitted is closely related to the firm's bargaining power in the foreign market. That should be considered by the policy maker.

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I. Introduction

In most industrialized countries, the GDP share of total health care costs has grown rapidly in recent years. Among the health care costs, pharmaceutical cost has increased at a more rapid rate than that of any others. Therefore, more and more attentions have been paid to pharmaceutical issues.

Pharmaceutical prices are varied significantly across countries even at the same development level. This price discrepancy is mainly from two sources: 1) difference on pharmaceutical price regulations across countries 2) difference on demand of pharmaceuticals across countries.

In recent years, governments have become more and more involved in the financing of health care. Under the increasing budgetary pressures, governments have strong incentives to reduce health care and pharmaceutical costs. Pharmaceutical price control in many countries is a reflection of this situation. Pharmaceutical price control can take many forms, such as direct price control (as in Canada, France, Italy and Spain), reference pricing, compulsory licensing (as in Canada before 1987), and others. Price control is commonly believed to be an important factor for the pharmaceutical price discrepancy across countries. For example, pharmaceutical prices in Canada have been regulated by Patented Medicine Price Review Board (PMPRB) since 1987. Meanwhile, there is no such regulation in the U.S. During that same period, the average U.S. prices for patented drugs are 36 percent to 67 percent above average Canadian prices[†]. Although the different characteristics of health care

[†] See the article "Prescription Drug Prices in Canada: What Are the Lessons for the U.S.?" by Gross D.

systems, income level and other country specific factors in the two countries could make contributions to this price discrepancy, many people believe that the price regulation in Canada plays an important role.

Countries are different on the characteristics of health care systems, income levels and other country specific factors such as physician and patient behaviors. Those factors lead to different demands on pharmaceuticals across countries and then the difference on drug prices.

The arbitrage opportunity resulted from the price discrepancy opens the door to parallel trade. Parallel trade is the importation of pharmaceuticals from country where prices are low to country where price are high without the authorization of a trademark, copyright, or patent holder. Parallel trade is legally permitted inside European Union. For example, in the United Kingdom, the Department of Health encourages pharmacists to buy parallel imports when they are cheaper than domestic products. Fifteen percent of domestic pharmaceutical consumption is imported from Spain and Italy. Parallel trade is used as a policy tool to contain pharmaceutical costs to the health care system. Although parallel trade is not legally permitted in the North America, it is an emerging issue. Due to the price discrepancy between the United States and Canada, more and more American buy their prescription drugs from Canadian pharmacies, either by on-line ordering or organized tours. As a result of public outrage over the drug price differential between the two countries, in 2000, the US congress passed the *Medicine Equity and Drug Safety Act*, which would allow

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Canadian drugs to be re-imported into the US. President Clinton vetoed the legislation, ostensibly for safety reasons. However, this remains an important policy issue both in the US and Canada (e.g., Health Canada's crackdown on internet pharmacies this past winter).

The presence of parallel trade on pharmaceuticals will cause the strategic reactions of pharmaceutical firms, and then the price and supply of drugs in both the importing and exporting countries. The literature on this issue is growing rapidly in recent years. However, among the few existing studies, no one has focused the attentions on the low price (exporting) country yet. All their analyses are mainly about the price, welfare in the importing country and the profits of pharmaceutical manufacturers. If parallel trade was legally permitted, what would happen in the low price country is also very important. With this paper, I would like to participate in the ongoing debate over issues related to parallel trade, and pay extra attention to the low price (exporting) country. I also explicitly take into account the feature of different demands on pharmaceuticals across countries in the analysis. I will conduct my analysis through a theoretical approach.

The analysis is organized as follows. In the next section, I will review the relevant studies in this field to date; based on the review, I will identify the issues that will be explored further. The third section is the model. Then I will discuss the policy implications based on the results of the model. The final section is discussion and conclusion.

II. Literature Review

There is no large literature, but it has been growing rapidly in recent years. To date, most of them are studies from policy perspective. At first, I will review the three theoretical studies that are most related to my work; then a few other relevant studies.

Pecorino (2002*)*

This paper is a direct response to the legislation debate on whether the US should allow low price prescription drugs to be reimported from Canada. In this paper, a model is developed in which a drug is sold in both foreign and home country. When parallel trade is not allowed, the monopolistic pharmaceutical firm sets MR equal to MC in its home market to choose the optimal price; and the price in foreign country is found from the solution of the following Nash Bargaining game between the firm and the foreign government:

$$\underset{P^*}{Max}[kCS(p^*)]^{\alpha}[k\pi(p^*)]^{1-\alpha}, \qquad (*)$$

Where *CS* is the consumer surplus in the foreign country, and π is the firm's profit in foreign country. The author assumed the demands in two countries are identical in all aspects except the size, which is reflected by a scaling factor *k*. α measures the bargaining power. When parallel trade is permitted, the author assumes that there will be a uniform price on both markets. This price is found from the solution to

$$\underset{P^*}{Max}[kCS(p^*)]^{\alpha}[(1+k)\pi(p^*)-\pi^m]^{1-\alpha}, \qquad (**)$$

Where $(1+k)\pi(p^*)$ is the firm's total profit in both markets under the uniform price, and π^m is the firm's profit if the drug is sold only in home market, i.e. no supply to the foreign country. Pecorino conducted analyses for two different cases: linear

demand and constant elasticity demand. In both cases, the author found that both the firm's profit and domestic consumer surplus rise. That is because the firm bargains harder on the price under parallel trade. That means the negotiated price under parallel trade has to be higher than before, otherwise, there will be no supply to foreign market.

There are two important assumptions in this model. First, the assumption of identical demands in the two countries is crucial to the conclusion on the firm's profit. The author made this assumption based on the fact that the countries (EU, Canada, Japan, etc) in the question are all highly developed countries with similar levels of income. Therefore, the drug price discrepancy between countries is only because of the drug price control. However, price control is only one of the reasons that lead to the drug price discrepancy among countries; different demand among countries is also an important reason. For example, the drug price discrepancy between Portugal and U.K is not only caused by price regulation, income difference between two countries plays an role here. Furthermore, by considering the different characteristics of health care systems, identical demands (i.e. same demand elasticity and maximal willingness to pay) across countries is a questionable assumption even for those countries at the same development level. Therefore, identical demand could only be considered as a special case. Second, the assumption of uniform price in both countries in the presence of parallel trade may also be unrealistic. Price in the importing country is related to the parallel trader's costs, which has important policy implications.

In my model, I will relax the assumptions on identical demands and uniform price

in the presence of parallel trade in two countries, which will extend Pecorino (2002) to a more general situation. The relaxation will not only make the assumption more realistic, but also lead to important policy implications.

Ganslandt&Maskus (2004*)*

In this paper, the authors develop a model in which a manufacturer competes in its home market with parallel trade firms. The home country is the high price country and the foreign country is the low price country. In the foreign country, the pharmaceutical prices are regulated. A distinct feature of this model is that multiple parallel traders jointly choose the maximum amount of parallel trade. It is a three stage game. At the first stage, *n* symmetric parallel importers enter the market; applying a license from the authority in home country at a cost *T*. Parallel traders will enter the market if the expected profit is non-negative. At the second stage, each parallel trader chooses its own quantity based on the regulated price in foreign country and the transaction cost *t*. At the final stage, the manufacturer sets its price in the home country by taking into account the amount of parallel trade. The model is solved by backward induction. If the trade costs (*T* and *t*) are not too high, the manufacturer will accommodate the parallel trade, the number of parallel traders and quantity of parallel trade could be found in equilibrium; the price in home market is lower than before. Using data from Sweden, the authors found that the prices of drugs subject to competition from parallel trade fell relative to other drugs over the period 1994-1999. The econometric analysis confirms the theoretical prediction.

The most important feature of this model is the limited quantity of parallel trade. The quantity is jointly determined by the manufacturer and parallel traders. This will not lead to a uniform price in two countries under parallel trade as suggested in some other studies. Therefore, it makes the model more realistic.

However, this is just a "one-side" analysis. The authors only consider the price change and the reactions of the interested parties in the home market. There is nothing about the impact of parallel trade on the foreign market, i.e. the price and supply of the drug, and the social welfare in the exporting country. Moreover, it ignored the influence of foreign demand on the manufacture's decision, and the interaction between the foreign government and the manufacturer. I will try to address those issues in my model.

Jelovac&Bordoy (2005)

In this paper, the authors considered the changes of price and welfare after parallel trade is legally permitted. There are two important features of their model. First, the two countries have different demands, country *i*'s demand is $D_i = \theta_i - \alpha_i p_i$, where θ_i reflects the different value that consumers put on the drug and α_i reflects the difference in the patients' level of co-payment; second, the consumer puts a lower value on the reimported drug than that is offered by the original manufacturer, therefore, the prices are not the same. The model is a three stage game. At the first stage, the firm maximizes its profit by taking into account parallel trade. At the second stage, the parallel importer sets a price to maximize his profit. At the final stage, the

consumer in both countries chooses to consume either one unit of the drug supplied by the monopolist or by the parallel trader, depending on the price. The game is solved by backward induction. The result shows that, first, there is a tendency of price convergence under parallel trade, that is, the price in low price (exporting) country is higher and the price in high price (importing) country is lower than before; second, the effect of parallel trade on the total welfare is ambiguous except for a few extreme cases; third, the different co-payment rates have influence on parallel trade.

More attentions should be paid on two issues. The first one is price regulation. In this paper, the firm could freely set a price. Many studies argued that low price (which gives the incentive of parallel trade) is the result of price regulation. When the firm reacts to parallel trade under a price regulation circumstance and its power to freely set a price is limited, the story might be different. Second, in this paper, the total welfare is defined as $TW = CS_A + CS_B - PE_A - PE_B + \pi_m + \pi_w$, where PE is the public expenditure paid by the government, and the last two terms are the profit of the monopolist firm and parallel trader. However, in the long-run, the total welfare is much more difficult to define.

Vogel&Joish (2001)

In this paper, the author used a diagram to analyze the potential unintended economic consequence of the Medicine Equity and Drug Safety Act of 2000. In this Act, reimportation of low-priced pharmaceutical is legally permitted in the United States. The diagram is drawn in the price and quantity space. A monopolistic

pharmaceutical firm would set its marginal revenue equal to its marginal cost to decide the optimal price and quantity if there was no parallel trade. Under parallel trade, the price in home market is lower due to the reimportation, then the firm suffers a profit loss. The author concluded that in the pharmaceutical industry parallel trade would be detrimental to long-term economic efficiency. Parallel trade erodes price differences across countries and hence undermines the most efficient pricing mechanism for paying for research and development.

Grootendorst (2004)

In this paper, the author considered theoretical predictions on the effects of cross-border pharmaceutical trade on the pricing decisions of pharmaceutical manufacturers and the consequent effects on their profits and R&D decisions. In the analysis, the author used diagrams to illustrate that a representative monopolistic pharmaceutical firm would take advantage of price discrimination to determine its optimal price and quantity sold in the US and Canadian market, if there was no cross border trade. He assumed the US demand curve is greater at each price than the Canadian demand curve; that is, the Canadian consumers have a lower maximal willingness to pay and the demand is more elastic. The cross border trade will result in a pressure to equalize the international price. Then the author used diagrams to show that the equalized price results in two adverse consequences: lower Canadian consumer surplus and lower profits for the manufacture. The author used empirical data to show that the firm's R&D is positively correlated with its profits. Therefore,

cross border trade of pharmaceutical may harm the pharmaceutical firms' R&D incentives.

Danzon (2003)

This is a review article. The author reviewed the economic case for patents and the potential for differential pricing to increase affordability of on-patent drugs in developing countries while preserving incentives for innovation. She argued differential pricing, based on Ramsey pricing principles, is the second best efficient way of paying for the global joint costs of pharmaceutical R&D. Assuming demand elasticity is related to income, it would also be consistent with standard norms of equity. Therefore, parallel trade should be prevented. The most promising approach that would prevent parallel trade is for payers/purchasers on behalf of developing countries to negotiate contracts with companies that include confidential rebates. With confidential rebates, final transactions prices to purchasers can differ across markets while manufacturers sell to distributors at uniform prices, thus eliminating opportunities for parallel trade.

Danzon (1998)

This is another review article by the above author, and she expressed the same opinions on the parallel trade issue. In this paper, she argued that no efficiency gains will be achieved from parallel trade. Countries achieve low pharmaceutical prices and become parallel exporters usually through stringent price regulation or weak patent

protection, not through superior production efficiency. Indeed, price regulation may actually reduce efficiency by distorting production efficiency and distorting incentives for innovation. In the short term, the net distributive effect of parallel trade is largely to transfer revenues from manufacturers to intermediaries. In the long run, if the potential volume of parallel trade exceeds a critical level, the manufacturer's profit-maximizing strategy is to attempt to set a single, uniform price in all connected markets, and then leads to consumer losses. Finally, she recommended some policy options to prevent parallel trade such as country-specific contracts with rebates, and an exemption from the law on parallel trade, etc.

Bale (1998)

This is a policy article in which the author expresses similar concerns as Danzon. He argued that first, in the case of patented products with high fixed costs, parallel trade may decrease global economic welfare; second, rules restricting parallel trade are a necessary corollary to pharmaceutical price discrimination in favor of developing countries; finally, restriction on parallel trade in the pharmaceutical sector are necessary to protect the public against risks from inadequate supervision of the secondary market, such as risks from inappropriate repackaging and inadequate storage and counterfeit products.

In general, among the existing studies, first, very few have focused the attentions on the low price (exporting) country. Their analyses are mainly about the price,

welfare in the importing country. If parallel trade was legally permitted, what would happen in the low price country is also very important. Parallel trade will affect the profits of pharmaceutical industry. The reactions of the pharmaceutical industry could have an impact on the national pharmaceutical prices control system, on the drug supplies and more generally on price negotiations between the pharmaceutical industry and each government. If a compromise on price could not be reached, the pharmaceutical manufacturer may cut off the supply of the drug to that market. For example, in Danzon (1998) she mentioned that Glaxo delayed several years to launch its antimigraine product sumatriptan (Imigran®) in France, rather than accepting a low price that would have undercut its higher price elsewhere. In my model, the first question that I would like to explore is the drug price, supply and associated social welfare in the low price (exporting) country in the presence of parallel trade.

Secondly, I will also discuss the firm's total profit and social welfare in the importing country.

Thirdly, the optimal strategies of the firm are based on the sales in both markets. What happens in one market will influence firm's decisions on the other market. In Pecorino (2002), although the author considered both markets at the same time, the simplified assumption on identical demand in both markets might not reveal all the possible outcomes. Therefore, the second question that I would like to address in this paper is the influence of different characteristics of the demand in the two markets on firm's decision, profit and the equilibrium price in the exporting country.

Finally, the current existing studies do not pay enough attentions to the possible

policy reactions of the low price country's government. I will try to explore the potential policy options in this paper.

III. Model

Assumptions

In this model, I assume there are two countries, H and L. The pharmaceutical prices are regulated in country L. A monopolistic pharmaceutical manufacturer produces and sells a patented drug in both market H and L. Price of this drug in country H (p_H) is higher than the price in country L (p_L). The location of the firm is in H. The monopolist produces at a fixed cost *f* and a constant marginal cost *c*. This assumption is in line with the reality of pharmaceutical industry. A new drug is usually associated with a large amount of research and development cost and small marginal cost. For the ease of calculation, *c* is normalized to zero. I don't take into account the fixed cost (R&D cost) in this model since the analysis is focused on short-run effects. Both the demands and market sizes for this drug are different in the two countries. Demand is $q = 1 - p_H$ in country H, and $q_L = \alpha - p_L$ in country L. α is assumed to be smaller than 1. I use such kind of demand functions for the ease of calculation and it is also easier to figure out the influences of relative market size. For a given demand function $q = \alpha - \beta p$, the market size could be measured by α / β . Therefore, the market size is 1 in country H and α in country L. Without parallel trade, in country H, the firm acts as a monopolist, i.e. sets its marginal revenue equal to the marginal cost, and then chooses the quantity and price to maximize its profit.

For the given demand function, the optimal price for the firm is ½, q is ½ and profit (π^m) is ¼.[‡] In country L, pharmaceutical price is lower than that in country H. The price is determined in a bargaining process between the firm and the government in country L. If parallel trade was allowed, the parallel trader would purchase the drug in country L at the negotiated price p_L, and ship it to country H with a transaction cost *t*. This *t* is assumed to be less than ½, since parallel trade is clearly impossible if it is higher. Unlike the assumption of multiple parallel traders in Ganslandt&Maskus (2004), I assume there is a single parallel trader. Once again, this is for the ease of calculation[§]. Under parallel trade, the total demand in country H is $q = q_H + q_T$, where q_H is the quantity sold by the firm and q_T is the quantity sold by the parallel trader. The profit of parallel trader is denoted as π_T; the profit of the firm is denoted as π_H in country H and π_L in country L.

An equilibrium consists of the quantities q_L, q_H and q_T and the prices p_L and p_H. The equilibrium is obtained in two stages. In first stage, the firm and the government in country L negotiate on the price of the drug p_L, which is the solution of a generalized Nash Bargaining game. In the second stage, in country H, the monopolist and the parallel trader engage into a Cournot competition to work out the equilibrium price p_H, and the quantities q_H and q_T. The firm and the parallel trader, taking each other's sale as given, choose their own sales so as to maximize their own profits. The price p_H is the highest price at which all of the goods can be sold. Also, q_L is the quantity of goods demanded by the consumers in country L when the price

[‡] Please see the detail of calculation in Appendix 1.

[§] This simplification doesn't change the fundamental conclusions.

is p_L . As usual, the equilibrium is solved out by backward induction.

Cournot Competition in country H

In market *H*, if $p_L \geq \frac{1}{2} - t$, there is no parallel trade. The cost of the drug for the parallel trader is higher than the existing price in country H. The firm's profit in country H is the monopolistic profit. If $p_L < \frac{1}{2} - t$, under parallel trade, the firm's profit is $\pi = p_H q_H + p_L q_T$; the first term is the profit made from the firm's own sale in market H, and the second term is the profit made from the sale to the parallel trader. The parallel trader buys this drug at p_L in country L and sells it at p_H in country H. For the given demand function, the firm's profit is

$$\pi = \begin{cases} \left[1-(q_H+q_T)\right]q_H + p_L q_T, & if \quad p_L \leq \frac{1}{2} - t \\ (1-p_H)\,p_H, & otherwise \end{cases} \qquad (1)$$

If $p_L < \frac{1}{2} - t$, the parallel trader's profit is

$$\pi_T = \left[1-(q_H+q_T) - p_L - t\right]q_T, \text{ s.t. } \pi_T \geq 0 \qquad (2)$$

The firm and the parallel trader, taking each other's sale as given, choose their own sales so as to maximize their own profits. Solving out the Cournot equilibrium

$$q_H = \begin{cases} \frac{1+p_L+t}{3}, & if \quad p_L \leq \frac{1}{2} - t \\ \frac{1}{2}, & otherwise \end{cases} \qquad (3)$$

$$q_T = \begin{cases} \dfrac{1-2(p_L+t)}{3}, & if \quad p_L \le \dfrac{1}{2}-t \\ 0, & otherwise \end{cases} \tag{4}$$

The highest price p_H at which all of the goods can be sold

$$p_H = \begin{cases} \dfrac{1+p_L+t}{3}, & if \quad p_L \le \dfrac{1}{2}-t \\ \dfrac{1}{2}, & otherwise \end{cases} \tag{5}$$

As p_L approaches $\frac{1}{2}-t$ from below, q_H, p_H and π_H converge to the monopoly solution while q_T converges to zero. There are no discontinuities in any of the variables when the parallel trade drops out of the market.

The firm's profit in country L is

$$\pi_L = \begin{cases} (\alpha - p_L)p_L, & if \quad p_L \le \alpha \\ 0, & otherwise \end{cases} \tag{6}$$

From (3), (4) and (5), the firm's profit in country H is

$$\pi_H = \begin{cases} \left[(1+p_L+t)^2 + 3p_L(1-2p_L-2t)\right]/9, & if \quad p_L \le \dfrac{1}{2}-t \\ \dfrac{1}{4}, & otherwise \end{cases} \tag{7}$$

The Firm's total profit in both markets is $\pi = \pi_H + \pi_L$. Clearly, π_L is increasing in α and is maximized at $p_L = \frac{\alpha}{2}$ when $p_L \le \alpha$. Differentiation shows that π_H (equation (7)) is increasing in p_L and t when $p_L \le \frac{1}{2}-t$.[**] The relationship between

[**] $\frac{\partial \pi_H}{\partial p_L} = (5-10p_L-4t)/9 > 0$, if $p_L \le \frac{1}{2}-t$; $\frac{\partial \pi_H}{\partial t} = (2-4p_L+2t)/9 > 0$, if $p_L \le \frac{1}{2}-t$;

π_H and α depends on the sign of $\frac{\partial p_L}{\partial \alpha}$ ($\frac{\partial \pi_H}{\partial \alpha} = \frac{\partial \pi_H}{\partial p_L}.\frac{\partial p_L}{\partial \alpha}$). Both function of π_L and π_H are continuous; π_L is concave over the domain $0 \le p_L \le \alpha$, and π_H is concave over the entire domain. And π_H is always kinked at $p_L = \frac{1}{2} - t$.

First Stage

At the first stage, the firm and the government in country L negotiate the price p_L. I adopt Pecorino's approach: the negotiated price is determined by a generalized Nash bargaining game. The pay-off of the government in country L is the consumer surplus gained by the consumers if the good is made available in market L, and the firm's pay-off is the difference between its profits if it sells in both markets (π) and its profit if it only sells in market H (π^m). If they agree on a price, that price maximizes a weighted geometric average of their pay-offs, where the weights reflect bargaining power. If the firm cannot attain profits of at least π^m by selling in both markets, it will not agree to sell in market L.

The price chosen is determined by the following generalized Nash Bargaining game:

$$\underset{p_L}{Max}[CS(p_L)]^{\gamma}\left[\pi(p_L)-\pi^M\right]^{1-\gamma} \qquad (8)$$

For the given demand

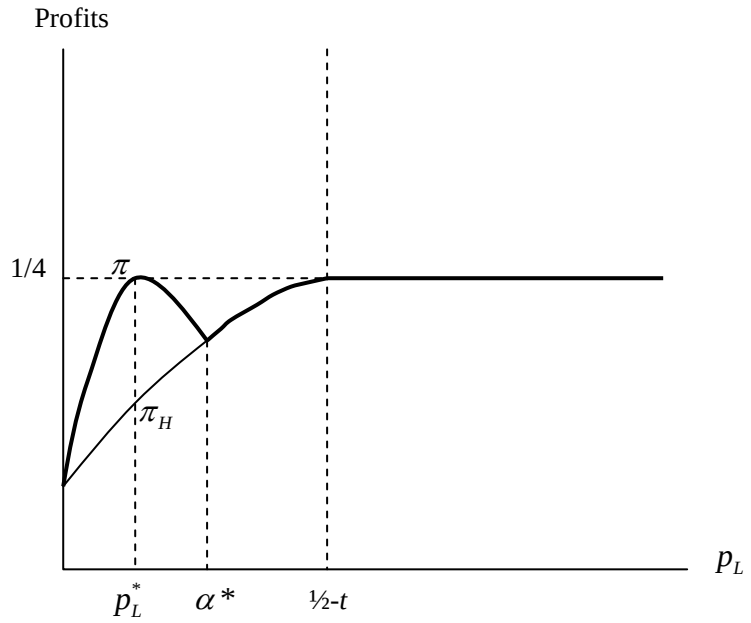
$$\text{CS}(p_L)=\frac{1}{2}(\alpha - p_L)^2 \qquad (9)$$

In equation (8), γ is the bargaining power of the government in country L, $0 < \gamma < 1$;

π^m is ¼.

For every γ, there are some circumstances in which there will be no agreement between the firm and government L. If the market size in country L (α) is too small such that the firm's best profits when it sells in both markets are smaller than π^m, the firm will cut off the supply to market L. This situation is illustrated by Figure-1. There are some α (smaller than $\frac{1}{2}-t$) such that the firm's best profits when it sells in both markets under parallel trade are just equal to π^m. Call this value α^* and let p_L^* be the profit-maximizing price. If α falls below α^*, profits are smaller at every p_L smaller than α. The firm's total profits in the two markets is smaller than π^m ;

Figure-1



therefore, the firm will cut off the supply to market L. If α rises above α^*, profits are greater at every p_L smaller than α, and there will be an agreement that benefits

both parties. Henceforth α will be assumed to lie between α^* and 1.[††]

Next, I analyze the equilibrium by three different cases: $\gamma = 0$, $\gamma = 1$ and $0 < \gamma < 1$.

$\gamma = 0$

When $\gamma = 0$, all the bargaining power resides with the firm. The generalized Nash Bargaining game is simplified to the firm's profit maximization. The firm acts as a monopolist in market L and can freely choose the price p_L to maximize $\pi - \pi^m$. There are two components in the firm's total profit π: profit in market L (π_L) and profit in market H (π_H). Based on equation (6) and (7), the solution of the firm's profit maximization is

$$p_L = \begin{cases} \dfrac{\alpha}{2}, & if \quad \alpha > 1-2t \quad (p_L > \dfrac{1}{2} - t) \\ \dfrac{1}{2} - t, & if \quad 1 - \dfrac{8}{3}t < \alpha < 1-2t \quad (p_L = \dfrac{1}{2} - t) \\ \dfrac{(5 + 9\alpha - 4t)}{28}, & if \quad \alpha < 1 - \dfrac{8}{3}t \quad (p_L < \dfrac{1}{2} - t) \end{cases} \tag{10}$$

The intuition behind equation (10) is as follows.

(a) The monopoly price in market L is $\dfrac{\alpha}{2}$. If $\dfrac{\alpha}{2}$ is greater than $\dfrac{1}{2} - t$, the profit

[††] Firm's best profit is achieved when it has all the bargaining power and can freely choose the price to maximize its profits. In this context, by setting $\pi_L + \pi_H = 1/4$, we can find $\alpha^* = \left[2\sqrt{14(5/4 - t^2 - 2t)} - 5 + 4t \right] / 9$

function looks like that in Figure 2.The firm maximizes its profits by charging the monopoly price in both markets; the gap between two monopoly prices is too small to allow the parallel trader to operate. In this case, α has to be greater than $1-2t$.

(b) If $\frac{\alpha}{2}$ is smaller than $\frac{1}{2}-t$, but the slope of π_H is greater than the slope of π_L at every point between $\frac{\alpha}{2}$ and $\frac{1}{2}-t$, the profit function looks like that in Figure-3. When the price p_L exceeds $\frac{\alpha}{2}$, firm's profit in market L begins to fall. But firm's profit in market H increases since the higher p_L reduces the quantity of parallel trade. The increase of π_H outweighs the fall of π_L. Therefore, the optimal price for the firm is to "hang up" at $\frac{1}{2}-t$. In this case, α must be in the range of $1-\frac{8}{3}t<\alpha<1-2t$.

(c) If $\frac{\alpha}{2}$ is smaller than $\frac{1}{2}-t$, and the slope of π_H is equal to the slope of π_L at a point between $\frac{\alpha}{2}$ and $\frac{1}{2}-t$, the profit function looks like that in Figure-4. The optimal price for the firm is $p_L=(5+9\alpha-4t)/28$. When the price p_L exceeds $\frac{\alpha}{2}$, firm's profit in market L begins to fall. But firm's profit in market H increases. The fall of π_L is smaller than the increase of π_H if $p_L<(5+9\alpha-4t)/28$, and greater than the increase of π_H if $p_L>(5+9\alpha-4t)/28$. At $p_L=(5+9\alpha-4t)/28$, the slopes of π_L and π_H are equal. Therefore, the optimal price for the firm is $p_L=(5+9\alpha-4t)/28$. In this case, α must be smaller than $1-\frac{8}{3}t$.

Figure-2

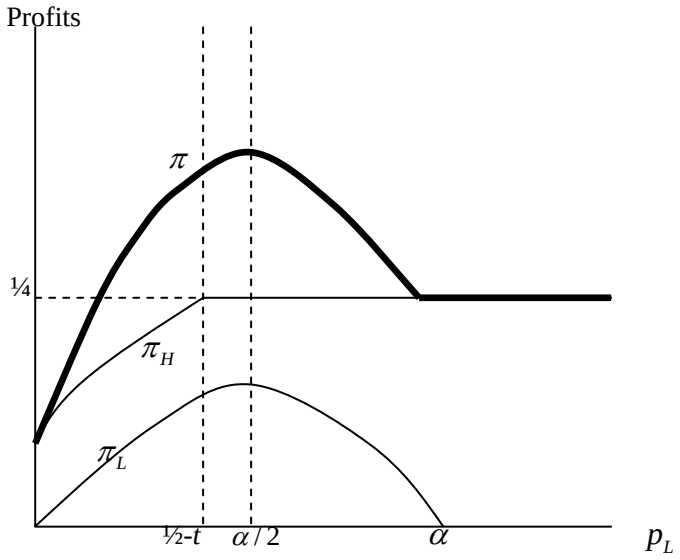


Figure-3

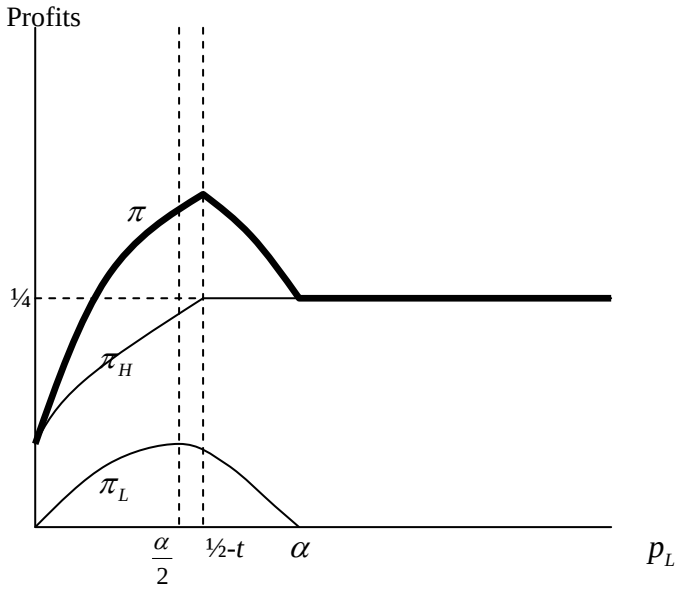
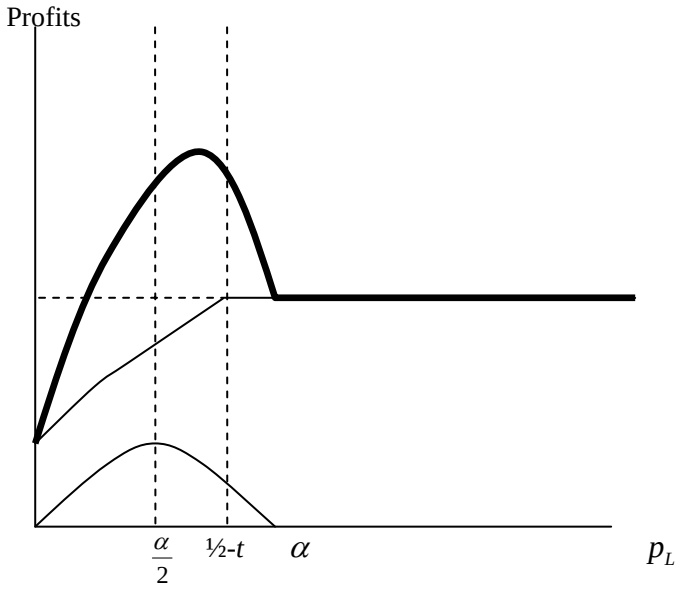


Figure-4



How does the price vary with α and *t*? Differentiation based on equation (10) shows

$$\frac{\partial p_L}{\partial \alpha}=\begin{cases}\frac{1}{2}>0, & if \quad \alpha>1-2t \quad (p_L>\frac{1}{2}-t)\\ 0, & if \quad 1-\frac{8}{3}t<\alpha<1-2t \quad (p_L=\frac{1}{2}-t)\\ \frac{9}{28}>0, & if \quad \alpha<1-\frac{8}{3}t \quad (p_L<\frac{1}{2}-t)\end{cases} \tag{11}$$

$$\frac{\partial p_L}{\partial t}=\begin{cases}0, & if \quad t>\frac{1-\alpha}{2} \quad (p_L>\frac{1}{2}-t)\\ -1<0, & if \quad \frac{3(1-\alpha)}{8}<t<\frac{1-\alpha}{2} \quad (p_L=\frac{1}{2}-t)\\ -\frac{4}{28}<0, & if \quad 0<t<\frac{3(1-\alpha)}{8} \quad (p_L<\frac{1}{2}-t)\end{cases} \tag{12}$$

An increase in α for a given *t* increases the equilibrium price p_L except when α is still in the range of $1-\frac{8}{3}t<\alpha<1-2t$, at which the equilibrium price p_L hangs up at $1/2-t$. A larger market size allows the firm to charge a higher price. In Figure-2 and Figure-4, an increase in α increases the slope of π_L and hence π at each p_L [‡‡]. So that the stationary point lies farther to the right: equilibrium p_L rises with α. Whenever α is still in the range of $1-\frac{8}{3}t<\alpha<1-2t$, the analysis in part (b) above is still held. Therefore, the equilibrium price p_L hangs up at $1/2-t$.

Similarly, a decreases in *t* (for a given α) in the presence of parallel trade makes the graph of π_H and then π steeper at each p_L [§§], shift the stationary point to the right, so the equilibrium price rises as the transaction cost falls. A falling transaction cost makes the parallel trader more of a problem, so the firm raises p_L to limit the parallel trader's activity.

What are the effects of a change in α or *t* on firm's total profits? Differentiation shows that

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‡‡ The slope of π_L is $\frac{\partial \pi_L}{\partial p_L}=\alpha-2p_L$, the effect of an increase of α on the slope of π_L is $\frac{\partial}{\partial \alpha}\left(\frac{\partial \pi_L}{\partial p_L}\right)=1$.

§§ The slope of π_H is $\frac{\partial \pi_H}{\partial p_L}=(2-4p_L+2t)/9$, the effect of an increase of *t* on the slope of π_H is $\frac{\partial}{\partial t}\left(\frac{\partial \pi_H}{\partial p_L}\right)=-4/9$.

$$\frac{\partial \pi}{\partial \alpha} = \frac{\partial \pi_L}{\partial \alpha} > 0 \tag{13}$$

$$\frac{\partial \pi}{\partial t} = \begin{cases} 0, & if \quad t \geq \frac{1-\alpha}{2} \quad (p_L > \frac{1}{2} - t) \\ -\frac{\partial \pi_L}{\partial p_L} > 0, & if \quad \frac{3(1-\alpha)}{8} < t < \frac{1-\alpha}{2} \quad (p_L = \frac{1}{2} - t) \\ (2 - 4p_L + 2t)/9 > 0, & if \quad 0 < t < \frac{3(1-\alpha)}{8} \quad (p_L < \frac{1}{2} - t) \end{cases} \tag{14}$$

An increase of α increases the firm's profit in market L at each p_L smaller than α; Graphically, the increase of α shifts the graph of π upward at each p_L smaller than α; therefore, the firm's total profit rise. Under parallel trade, an increase of *t* reduces the quantity of parallel trade, by which the firm's profit in market H increases. When $p_L = \frac{1}{2} - t$, the increase of *t* means that the firm could charge a lower price that is closer to the monopoly price $\alpha/2$ in market L, by which the firm's profit in market L increases. The increase of *t* shifts the graph of π upward at each p_L smaller than α; therefore, the firm's total profit rise.

The consumer surplus in country L is as equation (9), differentiation shows that

$$\frac{\partial CS(p_L)}{\partial \alpha} = (\alpha - p_L)(1 - \frac{\partial p_L}{\partial \alpha}) > 0, \quad if \quad p_L < \alpha \tag{15}$$

$$\frac{\partial CS(p_L)}{\partial t} = (\alpha - p_L)(-\frac{\partial p_L}{\partial t}) < 0, \quad if \quad p_L < \alpha \tag{16}$$

The effects of a change in α or *t* on consumer surplus in country L is entirely

determined by its effect on p_L. Since $\frac{\partial p_L}{\partial \alpha}$ is smaller than one in any cases, an increase of α in country L must increase the consumer surplus. Similarly, since an increase of *t* in the presence of parallel trade decreases the equilibrium price p_L, it must increase the consumer surplus in country L.

$\gamma = 1$

When $\gamma = 1$, all the bargaining power resides with the government in country L. From equation (8), we can see that the problem is simplified to the maximization of consumer surplus in country L. The government in country L will choose the lowest price that the firm will accept, which is the price that sets $\pi - \pi^m = 0$:

$$p_L = \left[(5 + 9\alpha - 4t) - \sqrt{(5 + 9\alpha - 4t)^2 + 56(t^2 + 2t - \frac{5}{4})} \right] / 28 \qquad (17)$$

This p_L is the point at which the profit function π in Figure-2, 3 and 4 cuts the line of ¼.

The effects of a change in α or *t* on the equilibrium price p_L are shown by the differentiations

$$\frac{\partial p_L}{\partial \alpha} < 0 \qquad (18)^{***}$$

$$\frac{\partial p_L}{\partial t} < 0 \qquad (19)^{\dagger\dagger\dagger}$$

*** Please see the proof in Appendix 2

††† Please see the proof in Appendix 3

If the market size in country L is bigger, the firm's lowest acceptable price would be lower. A larger market in country L is easier for the firm to compensate its profit loss in country H. Higher transaction costs reduce the quantity of parallel trade and hence the profit loss in country H; therefore, the firm's lowest acceptable price in market L is decreasing in *t*. Graphically, a increase of α or *t* shifts the graph of π upward; therefore, the cutting point of profit function π and line of ¼ moves left. The new equilibrium price is lower than before.

Since the effects of a change in α or *t* on consumer surplus in country L is entirely determined by its effect on p_L, a larger α or *t* increases consumer surplus.

$0 < \gamma < 1$

For the bargaining power between 0 and 1, it is likely to have the same three cases as we had when the firm had all the bargaining power. When the market size is large and firm has high bargaining power, the equilibrium p_L could be large enough to prohibit parallel trade. When the market size is relatively small and firm has low bargaining power, the equilibrium p_L is below $\frac{1}{2}-t$, the firm accommodates parallel trade. The intermediate case is that the firm chooses a price hanging up at $\frac{1}{2}-t$. It is difficult to explicitly figure out the equilibrium price for the general case. But we can explore the property of the equilibrium price as follows. If the price is greater than $\frac{1}{2}-t$, there will be no parallel trade. If the price has hung up at $\frac{1}{2}-t$, the objective function is not differentiable at the optimum. Therefore, I focus my analysis only on the case that price is smaller than $\frac{1}{2}-t$, i.e. the firm accommodates parallel

trade. The first and second order conditions of equation (8) are

$$\gamma CS'(p_L)\left[\pi(p_L)-\pi^m\right]+(1-\gamma)\pi'(p_L)CS(p_L)=0 \qquad (20)$$ [###]

$$\gamma CS''(p_L)\left[\pi(p_L)-\pi^m\right]-CS'(p_L)\pi'(p_L)+(1-\gamma)\pi''(p_L)CS(p_L)\equiv\Gamma<0 \qquad (21)$$

where the prime superscript denotes a derivative. Totally differentiate equation (20), we get

$$\frac{dp_L}{d\gamma}=\frac{-CS'(p_L)\left[\pi(p_L)-\pi^m\right]+\pi'(p_L)CS(p_L)}{\Gamma}<0 \qquad (22)$$

The negotiated price is decreasing in the bargaining power of the government of country L.

$$\frac{dp_L}{dt}=\frac{-\gamma CS'(p_L)\frac{d\pi(p_L)}{dt}-(1-\gamma)CS(p_L)\frac{d\pi'(p_L)}{dt}}{\Gamma}<0 \qquad (23)$$

The negotiated price is decreasing in the transaction cost of the parallel trader. With a higher transaction cost, the quantity of parallel trade is lower, which means a smaller profit loss in the high price market; therefore, the firm is more willing to accept a lower negotiated price in the low price market.

[###] The result is based on equation (6) and (7) but expressed in general equation form for simplicity.

$$\frac{dp_L}{d\alpha} = \frac{-\gamma\left[\pi(p_L)-\pi^m\right]\frac{dCS'(p_L)}{d\alpha} - \gamma CS'(p_L)\frac{d\pi(p_L)}{d\alpha} - (1-\gamma)\frac{d\pi'(p_L)}{d\alpha}CS(p_L) - (1-\gamma)\pi'(p_L)\frac{dCS(p_L)}{d\alpha}}{\Gamma} \tag{24}$$

When γ is large, $\lim_{\gamma\to 1}\frac{d\bar{p}}{d\alpha} < 0$. When γ is small, $\lim_{\gamma\to 0}\frac{d\bar{p}}{d\alpha} > 0$. That means if the government in country L has high bargaining power, a larger market size leads to a lower negotiated price. With a larger market size in country L, the firm is easier to recover its profit loss in country H. Therefore, the firm is more willing to accept a lower price in the negotiation. When the firm has high bargaining power, it will try to take the advantage of price discrimination and charge a higher price. A relatively larger market will be more likely to accept a higher price.

The effects of a change in γ, α or *t* on firm's total profit are shown by the differentiations:

$$\frac{d\pi}{d\gamma} = \pi'(p_L)\frac{dp_L}{d\gamma} < 0 \tag{25}$$

$$\frac{d\pi}{d\alpha} = p_L + \pi'(p_L)\frac{\partial p_L}{\partial \alpha} > 0 \tag{26}$$

$$\frac{d\pi}{dt} = \frac{\partial \pi_H}{\partial t} + \pi'(p_L)\frac{\partial p_L}{\partial t} > 0 \tag{27}$$

The firm's profit is decreasing in the bargaining power of government L, and increasing in the market size and the transaction costs to parallel trader. For the firm,

the benefits from an increase of α or *t* depend on its bargaining power. In both equation (26) and (27), the first term is positive and the second term is negative. $\pi'(p_L)$ is greater than zero in the relevant range. $\pi'(p_L)=0$ is only possible when firm has all bargaining power. Equation (26) and (27) are minimized to zero when the firm has zero bargaining power. The firm's profit is ¼ whatever the α or *t* is. As firm's bargaining power goes up, the equilibrium price p_L also goes up, and then $\pi'(p_L)$ is smaller. Therefore, the second terms in both equations are less negative.

Since the effects of a change in α or *t* on consumer surplus in country L is entirely determined by its effect on p_L, a larger *t* increases consumer surplus. If the government in country L has most of the bargaining power, consumer surplus is increasing in α. If the firm has most of the bargaining power, consumer surplus is decreasing in α.

IV. A comparison between parallel trade and no parallel trade regimes

In the above analysis, we assume parallel trade is legally permitted in both countries L and H. In this section, I assume that parallel trade is not legally permitted, and then compare firm's profits and social welfare of the two countries under two different regimes.

When there is no parallel trade, the firm and the government in country L solve

$$\underset{p_L^{NT}}{Max}\left[CS(p_L^{NT})\right]^{\gamma}\left[\pi_L(p_L^{NT})\right]^{1-\gamma} \tag{28}$$

where I denote the equilibrium price under no parallel trade regime as p_L^{NT}, for the

given demand, the solution of equation (28) is

$$p_L^{NT} = \frac{\alpha(1-\gamma)}{2} \tag{29}$$

The corresponding profit is

$$\pi^{NT} = \frac{1}{4} + \frac{\alpha^2(1-\gamma^2)}{4} \tag{30}$$

If the two countries move from no parallel trade regime to parallel trade regime, we are interested on the changes of firm's profits and social welfare. In country L, if the only concern of the government is consumer surplus, we just need to find out the change of equilibrium prices between two regimes. In the presence of parallel trade, in order to compensate the firm's profit loss in country H, there must be an increase of price in country L, $\Delta p_L = p_L - p_L^{NT} > 0$. And the magnitude of Δp depends on the bargaining power of each party.

$$\frac{d\Delta p_L}{d\gamma} = \frac{d(p_L - p_L^{NT})}{d\gamma} = \frac{dp_L}{d\gamma} + \frac{\alpha}{2} > 0 \tag{31}$$[§§§]

From the analysis in the last section, we know when $\gamma = 0$, there is an increase of the equilibrium price in market L in the presence of parallel trade, and we also know $\frac{d\Delta p_L}{d\gamma} > 0$; therefore, for any given value of γ, there is an increase of the negotiated price in the presence of parallel trade ($\Delta p_L > 0$). The increase of price has

[§§§] Please see the proof in appendix 4

two effects: increasing firm's profit in country L, and reduces the quantity of parallel trade. Therefore, the consumer surplus falls, and then the social welfare in country L is worse off under parallel trade. The higher the bargaining powers of the government in country L has, the larger the change on the equilibrium price, and hence the consumer surplus. Therefore, parallel trade undermines the high bargaining power of the government in country L.

For $0 < \gamma < 1$, the impact of parallel trade on firm's profit is ambiguous. Differentiating $\Delta\pi$ with respect to γ, we have

$$\frac{d\Delta\pi}{d\gamma} = \frac{d(\pi - \pi^{NT})}{d\gamma} = \frac{d\pi}{d\gamma} - (-\frac{\gamma\alpha^2}{2}) \qquad (32)$$

where $\frac{d\pi}{d\gamma} = \pi'(p_L)\frac{dp_L}{d\gamma} < 0$

The firm's profit is decreasing in the bargaining power of government L in both regimes: with or without parallel trade. Therefore, both the first and second term in equation (32) are negative. From the above analysis, we know the impact of parallel trade on firm's profit at two extreme cases. When firm has all bargaining power ($\gamma = 0$), it suffers a profit loss. The firm cannot fully take the advantage of price discrimination in the presence of parallel trade. When firm has no bargaining power at all ($\gamma = 1$), its profit is unchanged in the presence of parallel trade. Therefore, we have

$$\lim_{\gamma \to 0} \frac{d\Delta\pi}{d\gamma} < 0, \quad \lim_{\gamma \to 1} \frac{d\Delta\pi}{d\gamma} = 0 \tag{33}$$

Firm tends to have a larger profit when it has high bargaining powers ($\gamma \to 0$), since its ability of price discrimination is undermined by the parallel trade. If the firm's bargain power is low ($\gamma \to 1$), the impact of parallel trade on firm's profit is small.

Under parallel trade, the consumer surplus in country H is better off. The quantity of supply goes up and price goes down with parallel trade. If the social welfare in country H is simply defined as the sum of firm's profit and consumer surplus, it could be better off under parallel trade when the firm has low or no bargaining power in country L. When the firm has high bargaining power in country L, the consumer surplus in country H is still better off, but the firm will suffer higher profit loss; therefore, the total social welfare in country H is ambiguous.

V. Policy Implications

The government in country L

Under certain circumstance, the firm may cut off the drug supply to country L. That is, if the market size of the drug in country L is too small to compensate the profit loss incurred from parallel trade in the high price country, the firm may be better off by only supplying the drug to the high price country. The decision is sensitive to α and t. If the market size is large enough and the firm decides to accommodates parallel trade; as shown in last section, the negotiated price is also sensitive to α and t. Therefore, those factors have strong policy implications to the

government in country L.

When the government in country L has high bargaining power, the firm's minimum acceptable price in the presence of parallel trade is decreasing in α. The government in country L has the power to influence α. For example, the government could subsidize the target population of the drug in the question; manipulate the consumer's insurance status and co-payment rates; and put the drug on the formulary of a public drug plan. Those actions will increase the maximal willingness to pay and decrease the demand elasticity for the drug, then the market will be more important and attractive to the firm; therefore, it will be willing to accept a lower price in the negotiation. When the government in country L has low bargaining power, the firm's optimal price in the presence of parallel trade is increasing in α. If the goal is a lower price level, the government in country L could remove the drug from the formulary of a public drug plan, or reduce the subsidy to the target population of this drug. A more straightforward option in all cases is to manipulate the transaction cost to the parallel trader. This action could achieve the same goal on the negotiated price without affecting the demand and supply of the drug. An increase in the unit transaction cost to the parallel traders will reduce the quantity of parallel trade, and then lead to a lower price which is acceptable to the firm. One option is a unit tax (or regulation fee) on the parallel exportation.

The government in country H

Before the presence of parallel trade, when the government in country L has all

the bargaining power, the firm obtains very little profit from market L. In the presence of parallel trade, in order to induce the firm to supply the drug, the government in country L has to offer a higher price. The firm's total profit is the same as before. However, the consumer surplus is increased in country H. That is similar to a transfer of consumer surplus from country L to country H. The social welfare is higher in country H in the presence of parallel trade. Therefore, if the drug price is strictly regulated in country L, legalization of parallel trade could be a policy option for the government in country H to undermine the foreign drug price regulation.

Before the presence of parallel trade, if the firm has high bargaining power in the low price country and the demands are different in the two markets. The firm can take the advantage of price discrimination to maximize its profit. If parallel trade is legalized in the high price country, the firm's ability of price discrimination is undermined. Therefore, it will suffer a profit loss. But the consumer surplus in country H will go up. The total short run social welfare is ambiguous. If we take into account the consideration on firm's R&D, the long-run social welfare in country H is more likely to be worse off. Therefore, the policy maker should be more cautious on the legalization of parallel trade.

VI. Discussion and Conclusion

Country L's social welfare function

In this paper, I consider a very basic form of short-run social welfare function for the government in country L in which only includes consumer surplus. However, the

policy maker very rarely uses such a social welfare function. In reality, there are many other concerns in the price negotiation process, such as the research and development of pharmaceuticals, health care cost containing and maybe some other vague political factors. It is difficult to clearly define a social welfare function if we take into account those long run concerns. Moreover, the social welfare function could change after the presence of parallel trade. For example, the social welfare function may contain consideration on the R&D of pharmaceuticals before the presence of parallel trade. In the presence of parallel trade, consumer surplus may become the only concern of the policy maker in country L due to the higher drug price and budget pressure. If the social welfare function has other components before the presence of parallel trade, the negotiated price is not the lowest price that the firm will accept. For example, when the bargaining power all resides with the government in country L, the equilibrium price would be higher than the firm's marginal cost. If this is the case, the social welfare in country L is not necessarily worse off in the presence of parallel trade.

Profit of Parallel Trader

Moreover, country L has the chance to increase social welfare by extracting profits from the parallel trader. To induce the firm continues to supply in market L, the negotiated price in the presence of parallel trade has to be increased. This will lead to a certain level of social welfare loss, however, if the loss can be compensated by the profit extracted from the parallel trader, country L still could be better off.

Bargaining Power

Another issue need to be further explored is the impact of parallel trade on the bargaining power of each party in the negotiation.

The above questions deserve further study. However, the model in this paper shows some basic effects of parallel trade.

In the presence of parallel trade, the pharmaceutical firm has to compete with the parallel trader in the high price market. The profit of the firm falls. In order to compensate the loss in the high price market, the firm will bargain harder with the government in the low price country. The price of drug in the low price country goes up. If the main concern of the government in the low price country is the consumer surplus in that country both before and after the presence of parallel trade, then there will be a social welfare loss incurred from parallel trade.

When the demands are different in two markets and the pharmaceutical firm has high bargain power in the price negotiation. The firm's profits suffer a loss since its ability of price discrimination is undermined by parallel trade. The firm's total profit is maximized if it can fully take the advantage of price discrimination. The result in Pecorino (2002) is the outcome of identical demands in two markets. When the price differential is resulted from different demands in two markets, the firm suffers a profit loss under parallel trade.

When the firm earns very little profit from the low price market due to low bargaining power, the impact of parallel trade on its profit won't be large. Under

parallel trade, the consumer surplus in the high price country goes up. Therefore, the short run social welfare of the high price country could be better off if the firm's bargaining power in the low price country is low.

The policy implication to the government in the low price country from this model is that the firm's decision and negotiated price is sensitive to the market size of that drug (α) and the transaction cost to the parallel trader (t). Therefore, the welfare loss could be avoided by manipulating those factors. To the government in the high price country, if the firm has strong bargaining power in the low price country, legalization of parallel trade is not a good strategy since it will undermine the firm's ability of price discrimination. If there is a strict price regulation mechanism in the low price country and firm's bargaining power is weak, then legalization of parallel trade could be used to undermine the foreign price regulation.

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Appendix

1. $q = 1 - p$

$MR = 1 - 2p = MC = 0$

$p^* = \frac{1}{2}; q^* = \frac{1}{2}; \pi^m = (1 - p^*)p^* = 1/4$

2. $\frac{\partial p_L}{\partial \alpha} = \frac{9}{28}\left\{1 - \frac{(5 + 9\alpha - 4t)}{\sqrt{(5 + 9\alpha - 4t)^2 + 56(t^2 + 2t - \frac{5}{4})}}\right\}$

$\because \alpha > 0$, $t < \frac{1}{2}$

$\Rightarrow 5 + 9\alpha - 4t > 1$

and $t^2 + 2t - \frac{5}{4} < 0$

$\Rightarrow \frac{(5 + 9\alpha - 4t)}{\sqrt{(5 + 9\alpha - 4t)^2 + 56(t^2 + 2t - \frac{5}{4})}} > 1$

Therefore

$\frac{\partial p_L}{\partial \alpha} < 0$

3. $\frac{\partial p_L}{\partial t} = -\frac{4}{28}\left\{1 - \frac{(5 + 9\alpha - 4t) - 14(t + 1)}{\sqrt{(5 + 9\alpha - 4t)^2 + 56(t^2 + 2t - \frac{5}{4})}}\right\}$

$\because \frac{(5 + 9\alpha - 4t) - (5 + 9\beta)(t + 1)}{\sqrt{(5 + 9\alpha - 4t)^2 + 4(5 + 9\beta)(t^2 + 2t - \frac{5}{4})}} < -1$ (As shown below)

$$\therefore \frac{\partial p_L}{dt} < 0$$

$$\frac{(5+9\alpha-4t)-14(t+1)}{\sqrt{(5+9\alpha-4t)^2+56(t^2+2t-\frac{5}{4})}} < -1$$

Proof:

$$\because \ [(5+9\alpha-4t)-14(t+1)]^2-[(5+9\alpha-4t)^2+56(t^2+2t-\frac{5}{4})]$$

$$\Rightarrow t^2-2\alpha(t+1)+(t^2+2t+1)>0 \text{, because } \alpha<1$$

$$\therefore \ \left|(5+9\alpha-4t)-14(t+1)\right| > \sqrt{(5+9\alpha-4t)^2+56(t^2+2t-\frac{5}{4})}$$

Because of the same condition $\alpha<1$, we have

$$(5+9\alpha-4t)-14(t+1)<0$$

$$\therefore \frac{(5+9\alpha-4t)-(5+9\beta)(t+1)}{\sqrt{(5+9\alpha-4t)^2+4(5+9\beta)(t^2+2t-\frac{5}{4})}} < -1$$

4. $\frac{d\Delta p_L}{d\gamma}=\frac{d(p_L-p_L^{NT})}{d\gamma}=\frac{dp_L}{d\gamma}+\frac{\alpha}{2}$ is minimized at $\gamma=1$ when $0<\gamma<1$

Since

$$\frac{d(\frac{dp_L}{d\gamma})}{d\gamma}=\frac{-\left\{Q(p_L)\left[\pi(p_L)-\pi^m\right]+\pi'(p_L)CS(p_L)\right\}.\left\{\beta\left[\pi(p_L)-\pi^m\right]-\pi''(p_L)CS(p_L)\right\}}{\Gamma^2}<0$$

we know

$$\lim_{\gamma \to 1} \frac{d\Delta p_L}{d\gamma} > 0$$

Therefore

$$\frac{d\Delta p_L}{d\gamma} > 0 \quad \text{for} \quad 0 < \gamma < 1$$