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# Strategic trade policy, cost uncertainty and FDI determinants

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**Strategic trade policy, cost uncertainty and FDI determinants**

by

**Yan Guo**

A dissertation submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of  
DOCTOR OF PHILOSOPHY

Major: Economics

Program of Study Committee:  
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Ames, Iowa  
2013

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## ABSTRACT

The focus of my dissertation is in two areas: the relationship between optimal trade policy and demand / cost variances when the timing of investment is endogenous, and analysis of robust FDI determinants with endogenous exchange rate in the presence of model uncertainty and selection bias. In the first stream, I seek to explore the relationship by theoretical derivation and simulation. In the second stream, I examine the FDI equation by empirical analyses.

My second Chapter "Strategic Trade Policy and the Investment Timing under Cost Uncertainty" seeks to examine the optimal trade policy under both demand uncertainty and cost uncertainties when the timing of investment is endogenous. Based on Albaek (1990), this Chapter adds stochastic cost structure into Dewit and Leahy (2004)'s model. An interesting result was found that when demand variance is small and there is no cost variance to the foreign firm, the home government would like to enforce home firm delay before enforcing foreign firm delay when the home firm's cost variance increases.

My third Chapter "Strategic Trade Policy and the Investment Timing under Cost Uncertainty with Private Information" studies the optimal trade policy and the timing of investment under cost uncertainties and private information. It is assumed that cost random components are only observed privately by each firm and kept unknown to the other when firms decide how much to invest. We found a

striking result that when there is no correlation among cost shocks, as demand uncertainty rises the government may enforce foreign firm commitment when home firm's cost variance is smaller than foreign firm's cost variance.

My fourth Chapter "Robust FDI determinants with endogenous exchange rate in the presence of model uncertainty and selection bias" explores the robust FDI determinants in a general equilibrium framework with endogenous exchange rate. An empirical model of FDI decisions in a general equilibrium framework is set up, and HeckitBMA methodology is adopted suggested in Eicher et al. (2012) to deal with model uncertainty and selection bias. It is found that a monetary expansion in the host country is shown to deter new investments (extensive margin) from foreign countries.

## **CHAPTER 1**

### **INTRODUCTION**

#### **1. Research Topic**

The timing of investment under uncertainty is an interesting topic which has been studied for a long time. However, there have been relatively few papers which study optimal trade policy when the timing of investment is endogenous. Since firms may invest too early or too late based on a social welfare criterion, it is important for the government to consider how its policy affect investment timing when choosing strategic policy in an uncertain world.

#### **2. Literature Review**

##### *2.1 Strategic Trade Policy Study of Oligopolistic Firms*

The literature on strategic trade policy is divided into different categories based on different assumptions. The first category is the well-known strategic trade theory which assumes imperfect competition in the goods market, and the firms are assumed to be immobile. In most cases, government chooses trade policies (e.g. an export subsidy) and their levels before firms choose their outputs or investments, and the common conclusion is that unilateral trade policies could increase the welfare of the subsidizing country if firms compete in imperfectly



competitive markets (Brander & Spencer (1985), Dixit (1984) and Spencer & Brander (1983)). In international noncooperative competition, export subsidies can improve the relative position of the domestic firm compared to foreign firms, and allow it to expand market share and earn greater profits. Eaton and Grossman (1986) provided an integrative treatment of the welfare effects of trade policy under oligopoly, and characterized the form of the optimal policy intervention under various assumptions on market structure and conduct. They show that for the trade policy of the home country, a subsidy is generally optimal under Cournot competition and a tax is optimal under Bertrand competition when all output is exported. Brander (1995) did a survey on the strategic trade policy literature, where trade policies are studied in two basic models: “third-market” model where oligopolistic firms in two exporting nations export the good to a third country; and reciprocal-markets model where firms in two countries compete in each other’s’ markets.<sup>1</sup> The paper points out that slight change in model structure may cause much different optimal trade policies, and the main result of the survey is that imperfect competition of the oligopoly type almost always creates unilateral incentives for intervention.

However, Karp and Perloff (1995) set up a model where a government chooses its export subsidy before two oligopolistic firms produce but after they invest in a third market. A conclusion is drawn that strategic policy may decrease domestic welfare below the free trade level if the firms can substantially change

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<sup>1</sup> Strategic export subsidies are studied in the “third-market” model; while strategic rent-shifting tariffs, subsidies and other instruments are considered in the reciprocal-markets model.

their investments to influence the trade policy.<sup>2</sup> On the contrary, Goldberg (1995) justified using the time-consistent trade policy by showing that accounting for the sunk cost of the capacity installment, the time-consistent optimal subsidy is actually positive, though generally lower than the optimal level with precommitment. This result is derived from the shift of the reaction curves due to the sunk cost of capacity and the capacity constraints for the firms.

Neary and Sullivan (1999) compared adversarial with cooperative trade policies when a home and foreign firm compete dynamically in R&D investment (with spillover effect) and output. They have shown that export subsidy will generate higher welfare than cooperation<sup>3</sup> if the government can commit to it; otherwise, subsidization may yield much lower welfare than cooperation, even lower than free trade.

The second category of the literature on strategic trade policy is tax competition theory which assumes firms (or capital) are mobile in response to tax differences across countries and the markets are perfectly competitive. Because the governments have the same incentive to use export subsidies to shift profits from foreign firms to the domestic firms, the result is a wasteful subsidy race.

Then, the third category assumes both imperfect competition and mobility of firms. Janeba (1998) shows that laissez-faire is a perfect equilibrium<sup>4</sup> of the multi-stage noncooperative game, and each country's welfare is higher in

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<sup>2</sup> The key assumption for this conclusion is that the government can not commit to its trade policies; it will attempt to revise the policy to be ex post optimal.

<sup>3</sup> Cooperation on R&D means firms cooperate in their choice of R&D so as to maximize the sum of their joint profits.

<sup>4</sup> It means that laissez-faire is the best equilibrium in this game.

laissez-faire equilibrium than in the situation when firms are subsidized. Other important assumptions the paper makes are: it is impossible for the governments to discriminate against the foreign firm and domestic consumption is small;<sup>5</sup> governments maximize net surplus; firms compete in quantities rather than in prices; governments set tax policy before firms make their location and output decisions.

Several variations of the strategic trade policy models are also developed. For example, Ishikawa (1999) studied strategic trade policy with an imported intermediate product. It is assumed that there is Cournot competition in intermediate goods supply, since an export subsidy aimed at shifting rents from foreign to domestic final-good producers may also shift rents to foreign suppliers, there will be less incentive for the government to use a subsidy. Neary and Leahy (2000) developed a general approach to the design of optimal trade policy towards dynamic oligopolies. Three distinct motives for intervention are identified in the paper. First is the standard profit-shifting motive. Since the firms compete in more than one period, there is inter- as well as intra-temporal profit-shifting. The second motive is to counteract the strategic behavior of the home firm vis-à-vis its rival. The third motive is to counteract the home firm's strategic behavior vis-à-vis the government's own future actions. In all, the government should use its power of commitment both to shift profits (inter- and intratemporally) and to prevent the home firm from making socially wasteful

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<sup>5</sup> The government would like to subsidize its own firm if the subsidy to the foreign firm could be avoided.

commitments.

This paper uses the same assumptions (imperfect competition and immobility of the firms) as the literature of the first category; however, the trade policy tool (subsidy) is studied with the firms' investment timing decisions under uncertainty. In particular, the response of the subsidy level to the changes in the level of uncertainty are studied in order to explore how government actions affect oligopoly firms' strategic investment decisions in the presence of both demand and cost uncertainty.

## *2.2 Strategic Trade Policy with Endogenous Timing of Decisions*

The literature about the influence of strategic trade policy on the timing decisions of firms (especially the timing decisions on investment) is small; however, there is a huge literature on firms' timing decisions of investment under uncertainty (demand or cost uncertainty).

Based on the irreversibility of the investment,<sup>6</sup> Dixit and Pindyck (1994) systematically explained the basic theory of irreversible investment under uncertainty based on the interaction between three important characteristics of investment decisions: irreversibility, uncertainty and choice of timing. Specifically, they used the real option approach to describe having an opportunity to invest, and they argue that the value of the unit must exceed the purchase and installation cost, by an amount equal to the value of keeping the investment

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<sup>6</sup> This literature includes Arrow (1968), McDonald and Siegel (1986), Bertola (1988), Pindyck (1988, 1991), Dixit (1991, 1992) and Dixit and Pindyck (1994).

option alive (opportunity cost). They derived the optimal investment rules from methods developed for pricing options in financial markets and the mathematical theory of optimal sequential decisions under uncertainty---dynamic programming. They find that greater uncertainty increases the value of a firm's investment opportunity, but decreases the amount of actual investing that the firm will do. In other words, uncertainty makes waiting more valuable and discourages immediate investment.

The oligopolistic industry case is also discussed in their stochastic dynamic setting. Their general point is: on the one hand, uncertainty and irreversibility imply an option value of waiting and therefore greater hesitancy in a firm's investment decisions; on the other hand, the fear of preemption by a rival suggests the need to act quickly. Which of these considerations is more important depends on the parameters of the problem and the current state of the underlying shock.

Based on different sources of uncertainties, they examined the investment decisions when there is uncertainty on the payoff (or price of the product) of the project and also the cost of the investment. They prove that a mean-preserving spread in the distribution for price increases the incentive to wait. However, when it comes to cost uncertainty of a project, things become more complicated and depend on whether investment provides information about cost (called shadow value in the book). If the resolution of uncertainty is independent of the investment (uncertainty of input cost and government regulations), it has almost

the same effect as uncertainty over the payoff from investing, and creates an incentive to wait. But if the uncertainty can be partially resolved by investing (technical uncertainty), the effect will be opposite.<sup>7</sup>

On the other hand, Spencer and Brander (1992) found an important factor which can alter the attractiveness of capital commitment relative to flexibility in the case of an incumbent firm facing a potential entrant firm with cost uncertainty<sup>8</sup>. They obtained a surprising result that an increase in the flexibility-reducing effect<sup>9</sup> of capital investment in the cost function would actually make the strategy of commitment more attractive than delaying the investment by the incumbent firm.

Following the irreversible investment literature, Abel et al (1996) showed more generally how the incentive to invest can be decomposed into the returns to existing capital and the marginal value of the options to invest and disinvest. More importantly, the investment decision is based on the interaction of two options: the option to invest (the call option) and the option to disinvest (the put option). Because the values of both options increases with uncertainty and the two options have opposing effects on investment decision, the net effect of uncertainty can not be determined for sure.<sup>10</sup>

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<sup>7</sup> It is also mentioned that keeping variances of price and cost uncertainty fixed, the increase of the covariance between the two uncertainties will increase the incentive to wait.

<sup>8</sup> They have shown that when the variance of the cost uncertainty (of the potential entrant) is sufficiently high, the incumbent firm will choose to delay the investment (act as a flexible Cournot firm).

<sup>9</sup> Flexibility-reducing effect happens when the slope of the marginal cost function is increasing in capital investment, so more investment means less flexible technologies.

<sup>10</sup> The call option reduces the firm's incentive to invest; while the put option increases the incentive to invest, the interaction of these two options is actually the net effect of expandability and reversibility of a firm on the relationship of uncertainty and investment.

### *2.3 Trade Policy Study with Oligopoly Firms and Uncertainty*

Various forms of trade policies were compared in the literature on trade policy under imperfect competition with uncertainty. Moner-Colonques (1998) compared free trade with autarky for countries when oligopolistic firms from two countries produce homogenous goods under private cost information. They prove that as long as there is a certain degree of firm heterogeneity and a sufficient amount of uncertainty, the oligopolistic firms would prefer international free trade to autarky. The key element in obtaining the result is the convexity of profits as a function of costs. When the variance of costs is large enough, free trade gives firms a “lucky draw” (below average costs) to gain more profits within a larger market area, while firms with an “unlucky draw” (above average costs) are also able to reduce their loss (relative to expected costs) by selling in a larger market.

On the other hand, Cooper and Riezman (1989) compared direct quantity control by the governments in each of two countries with subsidy in an uncertain world (demand uncertainty) with imperfectly competitive firms in two countries,<sup>11</sup> with the result that the governments in the two countries would choose subsidies instead of direct quantity control when uncertainty is sufficiently high.

As for the timing of the strategic trade policy under demand uncertainty, Arvan (1991) studied a tax-subsidy game played between two governments, and the resulting equilibrium is that one government sets trade policy before demand

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<sup>11</sup> The governments select policy mode and levels both before realization of the demand uncertainty and firms selecting outputs.

uncertainty is resolved and the other delays its commitment until after observing the actual demand. Wong and Chow (1997) has a similar conclusion that the timing in the strategic trade policy game is determined by the magnitude of the demand uncertainty. When demand uncertainty is low, the home government will choose its import tariff before the foreign government and before the uncertainty is resolved; otherwise, the foreign government would set its export subsidy before the home government.

Different from other trade policy studies under imperfect competition with uncertainty, Dewit and Leahy (2004) studied the influence of the strategic trade policy on the timing of the oligopoly firms' investments (which is endogenous) under uncertainty. The specific novelty of their paper is that they combine strategic trade policy and investment timing under uncertainty. They set up a two-period oligopoly model (large country case) to study optimal trade policy when the timing of firms' investment decisions is endogenous and can be manipulated by the home government, and demand is uncertain. In the model, there is no asset market and the possibility of international risk sharing is absent. There is a trade-off between strategic commitment and flexibility in the firms' investment decisions. They show that the government, which sets its subsidy at the beginning of the game before firms decide when and how much to invest, will adjust its policy to affect the investment timing decision of firms; in particular, it will choose its policy to deter investment commitment by the home or the foreign firm. The home government can affect the investment timing decision of firms by



adjusting the level of the export subsidy in stage one. The subsidy increases the relative attractiveness of investment (capital commitment) to the home firm since it widens the home firm's price–cost gap, and raises the return to the output expansion resulting from capital commitment. On the contrary, the subsidy lowers the relative attractiveness of investment to the foreign firm since the subsidy narrows their price–cost gap (as home output increases, the price falls), and reduces the return to their investment.

The details of the model in Dewit and Leahy (2004) follow:

### *2.3.1. Model Setup in Dewit and Leahy (2004)*

Suppose a home and a foreign firm invest in capital and export to the same third market, where they compete (Cournot competition) against each other. The third market has demand uncertainty. The stochastic demand function is given by:

$$p = a - Q + u \tag{1}$$

where  $p$  is the price in the third market,  $Q = x + y$  is total output,  $x$  and  $y$  are outputs of the home and foreign firm.  $u$  is the stochastic component, defined over the interval  $[\underline{u}, \bar{u}]$  with mean zero ( $Eu = 0$ ) and variance  $\sigma^2$ .

Investment in capital by the home and foreign firm are represented by  $k$  and  $k^*$ . It is assumed that the firms' total cost functions ( $TC, TC^*$ ) are:

$$TC = (c_0 - k)x + \frac{k^2}{2\eta} \quad (2a)$$

$$TC^* = (c_0^* - k^*)y + \frac{k^{*2}}{2\eta} \quad (2b)$$

where  $c_0$  and  $c_0^*$  are constants;  $c_0 - k$  and  $c_0^* - k^*$  represent the marginal cost of production for the home and the foreign firm. The capital cost for each firm is represented by the second terms in Eqs. (2a) and (2b);  $\eta$  is a constant and is assumed to be identical for both firms.<sup>12</sup>

The two-period four-stage game is like this: in the first period (stage 1 to 3), players face uncertainty about future demand in the export market. In stage one, the home government sets an export subsidy. In stage two, firms decide the investment timing and then commit to this decision. In stage three, firms that are committed to invest choose their actual capital level. In the second period (stage 4), uncertainty is resolved, firms choose outputs and capital levels if they have not chosen those. This game is depicted in Fig. 1.  $C$  represents commitment, while  $D$  represents delay, superscript star means foreign firm decisions.

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<sup>12</sup> As indicated in Dewit and Leahy (2004), this cost specification is commonly used in the process R&D literature.

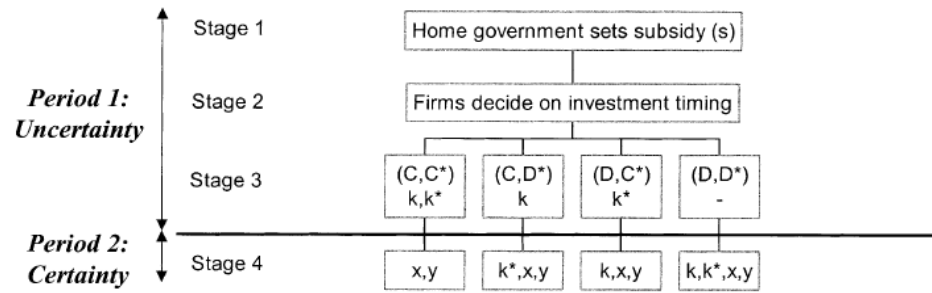


Fig. 1.<sup>13</sup> The sequence of moves in the game<sup>14</sup>

Based on the assumptions of the model, we can derive the profit functions for the home and foreign firm as:

$$\pi = (p + s)x - TC \quad (3a)$$

$$\pi^* = py - TC^* \quad (3b)$$

where  $s$  denotes the home government's export subsidy.

### 2.3.2. Solving the Four-Stage Model

Backward induction is used to solve the game. In the *last* stage, optimal outputs for the home and the foreign firm should satisfy the first order conditions of the second-period profits given by (3a) and (3b).

<sup>13</sup> Refer to Dewit and Leahy (2004).

<sup>14</sup> Stage 2 and 3 are separated because in stage 2 the firms decide on investment timing based on the comparison of the expected profits for all the investment timing combinations, and in stage 3, the a firm actually make capital investment if it chooses to commit, otherwise wait till the second period.

$$x = (2A - A^* + 2s + 2k - k^* + u) / 3 \quad (4a)$$

$$y = (2A^* - A - s + 2k^* - k + u) / 3 \quad (4b)$$

Here,  $A \equiv a - c_0$ ,  $A^* \equiv a - c_0^*$  and firms' costs are assumed the same ( $A = A^*$ ).

Besides, firms that delayed investment also choose investment levels in the last stage, which should also satisfy the first order conditions of the second-period profits<sup>15</sup>.

In stage *three*, firms which choose investment commitment determine optimal investment levels by maximizing expected profits with respect to capital. Optimal investment decisions for the different investment timing combinations made by the firms are summarized in Table 1.

---

<sup>15</sup> See (3A) and (3b).

Table 1<sup>16</sup>Optimal capital levels for the different investment timing combinations<sup>17</sup>

	$C, C^*$	$C, D^*$	$D, C^*$	$D, D^*$
$k$	$k^{cc^*} = \frac{4}{3}\eta Ex^{cc^*}$	$k^{cd^*} = \frac{2(2-\eta)}{3-2\eta}\eta Ex^{cd^*}$	$k^{dc^*}(u) = \eta x^{dc^*}(u)$	$k^{dd^*}(u) = \eta x^{dd^*}(u)$
$k^*$	$k^{*cc^*} = \frac{4}{3}\eta Ey^{cc^*}$	$k^{*cd^*}(u) = \eta y^{cd^*}(u)$	$k^{*dc^*} = \frac{2(2-\eta)}{3-2\eta}\eta Ey^{dc^*}$	$k^{*dd^*}(u) = \eta y^{dd^*}(u)$

Here  $\eta$  is the common constant related to the capital cost for both firms in Eqs. (2a) and (2b).

In the table, the first superscript on the variables refers to commitment (c) or delay (d) by the home firm, and the second superscript denotes commitment (c\*) or delay (d\*) by the foreign firm. From (4a), (4b) and Table 1, we can see that compared to commitment, investment delay reinforces the variability (flexibility) of the output by adding its own variability. From Table 1, we can also see the following capital-output ranking:  $k^{cd^*} / Ex^{cd^*} > k^{cc^*} / Ex^{cc^*} > k^{dc^*} / x^{dc^*} = k^{dd^*} / x^{dd^*}$ .

In stage *two*, firms will choose the investment timing combination that generates the largest expected profits (see Table 2). Firms will prefer delaying the investment generally since investment delay increases the variability (flexibility) of the output (mentioned above) and more output flexibility will increase expected profits<sup>18</sup>. However, firms may also choose to commit to capital when 1<sup>st</sup> mover advantage gain exceeds the loss caused by foregoing flexibility.

<sup>16</sup> Refer to Dewit and Leahy (2004).

<sup>17</sup> Note that capital is a function of the actual demand realization (u) if the firm delays the investment, however, if the firm makes a capital commitment, optimal capital investment does not depend on u.

<sup>18</sup> It has been proved that the profit function is convex in output, so the expected profit increases when variance of the output increases.

Table 2<sup>19</sup>

Maximized expected profits for the different investment timing combinations

	$C, C^*$	$C, D^*$	$D, C^*$	$D, D^*$
$E\pi$	$\gamma \left( E x^{cc^*} \right)^2 + \frac{1}{9} \sigma^2$	$\zeta \left( E x^{cd^*} \right)^2 + \left( \frac{1-\eta}{3-2\eta} \right)^2 \sigma^2$	$\varphi \left( E x^{dc^*} \right)^2 + \frac{1-\eta/2}{(3-2\eta)^2} \sigma^2$	$\varphi \left( E x^{dd^*} \right)^2 + \frac{1-\eta/2}{(3-\eta)^2} \sigma^2$
$E\pi^*$	$\gamma \left( E y^{cc^*} \right)^2 + \frac{1}{9} \sigma^2$	$\varphi \left( E y^{cd^*} \right)^2 + \frac{1-\eta/2}{(3-2\eta)^2} \sigma^2$	$\zeta \left( E y^{dc^*} \right)^2 + \left( \frac{1-\eta}{3-2\eta} \right)^2 \sigma^2$	$\varphi \left( E y^{dd^*} \right)^2 + \frac{1-\eta/2}{(3-\eta)^2} \sigma^2$

we define:  $\gamma \equiv 1 - (8/9)\eta$ ,  $\zeta \equiv 1 - 2\eta[(2-\eta)/(3-2\eta)]^2$  and  $\varphi \equiv 1 - \eta/2$ .

In stage *one*, the government chooses the subsidy to maximize expected welfare  $EW$ :

$$EW = E\pi - sEx \quad (5)$$

There are two reasons why the government wants to use subsidies. One basic reason is that the subsidy is a profit-shifting strategic trade policy instrument; for each possible investment timing combination, there is an optimal rent-shifting subsidy [see Table 3]. More importantly, the government can also change the firms' investment timing by changing the subsidy levels<sup>20</sup> in order to get the maximum expected welfare. But it will deviate from the optimal rent-shifting policy.<sup>21</sup> So the subsidy which is used to change the investment timing of firms will only be used if it has a higher expected welfare level than the

<sup>19</sup> Refer to Dewit and Leahy (2004).

<sup>20</sup> Increasing the subsidy alters the relative advantage of investment flexibility; it increases the relative attractiveness of commitment to the home firm, and lowers it to the foreign firm.

<sup>21</sup> It means that it will be different from the optimal rent-shifting subsidy.

optimal rent-shifting policy.

Table 3<sup>22</sup>

Optimal rent-shifting subsidies for all possible investment timing combinations

$s^{cc*}$	$\frac{1-(4/9)\eta[2-(4/3)\eta]}{2-(4/3)\eta} E\chi^{cc*}$
$s^{dc*}$	$\frac{3-2\eta}{2[3-4\eta+\eta^2]} E\chi^{dc*}$
$s^{cd*}$	$\frac{(3-2\eta)^2-2\eta(2-\eta)^2}{(3-2\eta)^2(2-\eta)} E\chi^{cd*}$
$s^{dd*}$	$\frac{E\chi^{dd*}}{2-\eta}$

Note:  $s^{dc*} > s^{dd*} > s^{cc*} > s^{cd*}$  for  $A = A^*$ .

### 2.3.3 Government's Optimal Trade Policy

The author studied the home government's optimal export subsidy numerically when both firms' investment timing choices are endogenous (see Fig. 2a and 2b). More specifically, the author studied the pattern for the optimal subsidy levels the home government chooses when underlying parameters change.

Fig. 2a depicts the optimal subsidy at different  $\sigma^2$  levels keeping  $\eta$  constant. It shows that when uncertainty is very low, both firms have low incentive to delay the investment, and the government would choose the optimal rent-shifting subsidy  $s^{cc*}$  to maximize the expected welfare. As uncertainty rises firms' relative valuation of commitment falls, the government chooses to deter

<sup>22</sup> Refer to Dewit and Leahy (2004).

foreign commitment by using subsidy  $s^{cr^*}$ , which is the lowest possible subsidy that deters foreign commitment when the home firm commits. The new subsidy starts at point  $e$ , where it jumps discretely to a higher level, then it gradually decreases as the level of uncertainty rises, until at point  $f$  in Fig. 2a it equals the optimal rent-shifting subsidy  $s^{cd^*}$ . As uncertainty continues to go up, firms' incentive to delay the investment is stronger, and commitment deterrence for home firm becomes more attractive to the government. So, when  $EW(s^{td^*}; D, D^*) > EW(s^{cd^*}; C, D^*)$ , the government will choose  $s^{td^*}$ . Specifically, in Fig. 2a, at point  $g$ , the optimal subsidy level drops, to the minimum deviation<sup>23</sup> necessary to enforce flexibility for the home firm. Furthermore,  $s^{td^*}$  gradually increases as the level of uncertainty rises, until at point  $h$  in Fig. 2a it equals the optimal rent-shifting subsidy  $s^{dd^*}$ ; when uncertainty level exceeds point  $h$ , the government sets  $s^{dd^*}$  and both firms delay.<sup>24</sup>

---

<sup>23</sup> Deviation means deviation from the optimal rent-shifting subsidy.

<sup>24</sup> Since the main purpose of Dewit and Leahy (2004) is to study strategic trade policy, only output subsidy is studied, other subsidy choices such as investment subsidy are omitted.



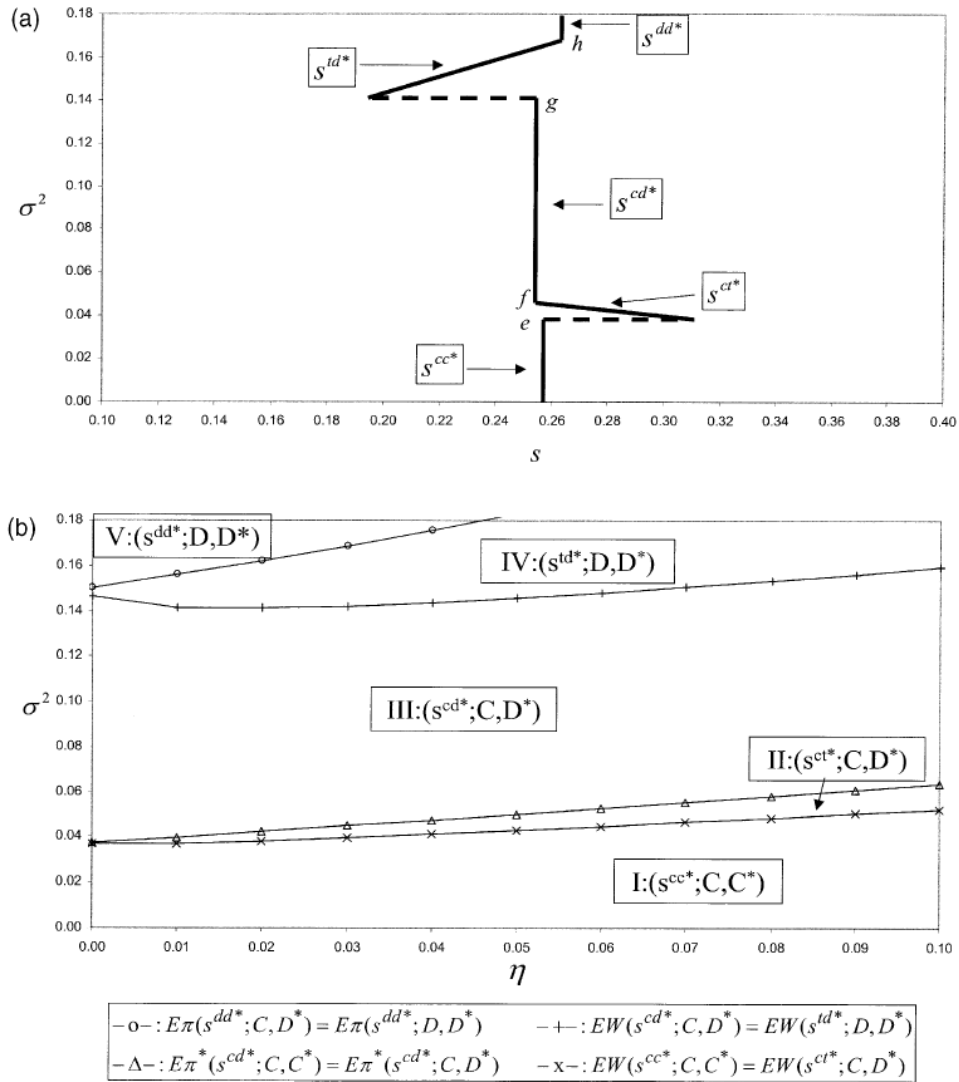


Fig. 2.<sup>25</sup> (a) Optimal subsidization when both firms choose investment timing in  $(\sigma^2, s)$  ( $A = A^* = 1$ ;  $\eta = 0.03$ ). (b) Optimal subsidization when both firms choose investment timing in  $(\sigma^2, \eta)$ -space ( $A = A^* = 1$ ).

Fig. 2b expresses the same idea as 2a except it is drawn in a two

<sup>25</sup> Cited from Dewit and Leahy (2004).

dimensional  $(\sigma^2, \eta)$  space, and it shows which policy is optimal in each domain. Area I in Fig. 2b correspond to parameter values such that it is optimal for the home government to choose  $s^{cc^*}$  as policy. Similarly, area II in Fig. 2b corresponds to parameter values such that it is optimal for the home government to choose  $s^{ci^*}$  as policy and so on. From the outcomes of the numerical study, we can see that the government tends to induce both the home and the foreign firm to delay investment if possible, but the deviation of the subsidy from the optimal rent-shifting level should be as small as possible to accomplish this change in timing. In addition, Fig. 2a and 2b also shows that, as uncertainty rises, deterrence of foreign commitment occurs before deterrence of home commitment. Because the subsidy widens the home firm's price-cost gap, it increases the relative attractiveness of commitment for the home firm and lowers it for the foreign firm. Therefore, it is easier for the foreign firm to accept investment delay than the home firm.

### 3. Contribution to this Research Area

While Dewit and Leahy (2004) extended trade policy studies under imperfect competition with uncertainty, they ignored the cost or technological uncertainty and focused only on demand uncertainty. As with demand, firms may also be uncertain about their own and rival's future costs. And for cost uncertainty, asymmetric information is a special issue since generally firms know more about

their own cost than their rival's. The government may have different incentives to encourage or discourage investment commitment by firms after uncertainty is added into the firms' cost structure. With asymmetric information, investment could be a signal of one firm's cost to the other firm, so it also has information value. By encouraging investments by both firms welfare may be increased in home country. The next Chapter will extend Dewit and Leahy (2004)'s two period model and add stochastic components into firm's cost structure based on Albaek (1990). The new cost structure treats all distributional aspects of the random components as public information in the first period and the random components are realized and observed by both firms in the second period. We explore the changes on the way a government with commitment power affects the firms' strategic investment decisions for an export market where both demand and cost uncertainties exist in those three scenarios.

In this revised game, backward induction is still used to solve the two period four stage model, except that three assumptions on the stochastic marginal cost function will be considered separately, and different equilibrium results and optimal trade policy levels will be compared.

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## CHAPTER 2

### STRATEGIC TRADE POLICY AND THE INVESTMENT TIMING UNDER COST UNCERTAINTY

#### 1. Relevant Literature on Timing Decision & Cost Uncertainty

The literature on firms' timing decisions of investment or output under cost uncertainty can be divided into five categories.

The first category focuses on the relationship between uncertainty and the current investment and showed that higher uncertainty leads to a higher current rate of investment. Hartman (1972) was among the earliest papers to examine the effects of uncertainties in output prices, wage rates, and investment costs on the quantity of investment undertaken by a risk-neutral competitive firm. Hartman showed that with a linearly homogeneous production function, increased uncertainty in future output prices and wage rates leads the competitive firm to increase its current investment.<sup>26</sup> Afterwards, Abel (1983) demonstrated that Hartman's results continue to hold in continuous-time model<sup>27</sup>. Specifically, given the current price of output, higher uncertainty leads to a higher current rate of investment regardless of the curvature of the marginal adjustment cost function. In all, it is called the pure uncertainty effect<sup>28</sup>.

The second category represented by Dixit and Pindyck (1994) got different

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<sup>26</sup> However, he also showed that current investment is invariant to increased uncertainty in future investment costs.

<sup>27</sup> In Pindyck's continuous-time model, the current price is known but the future evolution of prices is stochastic.

<sup>28</sup> By Small (1999).

results based on whether investment provides information about cost. Waiting is preferred if the resolution of uncertainty is independent of the investment, otherwise, commitment is favorable if the uncertainty can be partially resolved by investing.

The third category (represented by Abel et al (1996)) has the result that uncertainty has two opposing effects on investment decision (encourage and discourage investments) and the net effect can not be determined for sure.

The fourth category posits that there is no relationship between the magnitude of the cost uncertainty and the timing decision of the investment at all. Small (1999) decomposed the investment problem into decisions over scale and timing with convex adjustment costs. Finally, it was shown that the timing of the investment is determined by the expected trajectory of capital prices relative to the firm's discount rate.

The fifth category investigates firms' timing decisions of output under cost uncertainty. Albaek (1990) analyzed the role choice (leader or follower) by the duopolists in a model with cost uncertainty where direct information sharing is prohibited. Under certain conditions, the duopolists would prefer a Natural Stackelberg Situation (NSS) where the firms agree on the assignment of roles and neither prefers the (Bayesian) Nash equilibrium. The firm with the greater cost variance will be the leader in NSS. This result comes from the idea that duopoly firms may share information by choosing the sequential choice structure instead of a simultaneous one in order to allow one firm to condition on the



strategic decision of the other.

## 2. The Setup of the Model

The two-period four-stage game in Dewit and Leahy (2004) is: in the first period (stage 1 to 3), players face uncertainty about future demand in the export market. In stage one, the home government sets an export subsidy. In stage two, firms decide the investment timing and then committed to this decision. In stage three, firms that are committed to invest choose their actual capital level. In the second period (stage 4), uncertainty is resolved, firms choose outputs and capital levels if they have not chosen those.<sup>29</sup> The demand function and the original cost functions for both firms are:

$$p = a - Q + u \quad (1)$$

$$TC = (c_0 - k)x + \frac{k^2}{2\eta} \quad (2a)$$

$$TC^* = (c_0^* - k^*)y + \frac{k^{*2}}{2\eta} \quad (2b)$$

Keeping the setup of the model in Dewit and Leahy (2004), our paper adds

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<sup>29</sup> Refer to figure 1 in the first Chapter.

cost uncertainty into their model based on two random cost structures. This cost structure is a simple structure where it is assumed that the total cost functions of home and foreign firm  $(TC, TC^*)$  are:

$$TC = (c_0 - k + v)x + \frac{k^2}{2\eta} \quad (5a)$$

$$TC^* = (c_0^* - k^* + v^*)y + \frac{k^{*2}}{2\eta} \quad (5b)$$

where  $v$  and  $v^*$  are stochastic cost components which have the following properties<sup>30</sup>:

- (i)  $E(v) = 0$ ,  $E(v^*) = 0$ ;
- (ii)  $Var(v) = V_1$ ,  $Var(v^*) = V_2$ ,  $V_1$  &  $V_2 \geq 0$ ;
- (iii)  $Cov(v, v^*) = 0$ ,  $Cov(u, v) = 0$ ,  $Cov(u, v^*) = 0$ ;
- (iv)  $v \in R$ ,  $v^* \in R^*$ ,  $R$  and  $R^*$  are bounded intervals.

In the first period, both the firms only know the distribution of  $v$  and  $v^*$ , and the distribution of the random variables are common knowledge. In the second period,  $v$  and  $v^*$  are observed by both firms.

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<sup>30</sup> Similar to the assumptions in Albaek (1990).

### 3. The Solution to the New Cost Structure with Uncertainty

Based on the assumptions of the new cost structure discussed above, we are going to work out the optimal outputs for both firms, investment levels for both firms and government subsidy for each investment timing combination using backward induction, as well as the maximized expected profits for both firms and the maximized expected welfare for the home country.

#### 3.1 Optimal Output Decisions

Based on the assumptions of the cost structure discussed above, following the same procedure (backward induction) with Dewit and Leahy (2004), we first work out the optimal outputs for the home and the foreign firm in the second period by maximizing second period profits:

$$\text{Max} \left\{ \pi = (a - x - y + u + s)x - (c_0 - k + v)x - \frac{k^2}{2\eta} \right\} \quad (6a)$$

$$\text{Max} \left\{ \pi^* = (a - x - y + u)y - (c_0^* - k^* + v^*)y - \frac{k^{*2}}{2\eta} \right\} \quad (6b)$$

The first order conditions for  $x$  and  $y$  are:

$$A - 2x - y + u + s + k - v = 0 \quad (7a)$$

$$A^* - 2y - x + u + k^* - v^* = 0 \quad (7b)$$

where still,  $A \equiv a - c_0, A^* \equiv a - c_0^*$ . It can also be expressed in matrix form as:

$$\begin{pmatrix} 2 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} A + u + s + k - v \\ A^* + u + k^* - v^* \end{pmatrix} \quad (8)$$

Solve for  $x$  and  $y$  we have:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \frac{1}{3} \begin{pmatrix} 2 & -1 \\ -1 & 2 \end{pmatrix} \begin{pmatrix} A + u + s + k - v \\ A^* + u + k^* - v^* \end{pmatrix} = \frac{1}{3} \begin{pmatrix} 2A - A^* + 2s + 2k - k^* + u - 2v + v^* \\ 2A^* - A - s + 2k^* - k + u - 2v^* + v \end{pmatrix} \quad (9)$$

From (7a) and (7b) we also find the actual profit functions for both firms can be expressed as:

$$\pi = x^2 - \frac{k^2}{2\eta} \quad (10a)$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} \quad (10b)$$

We can see that the only differences of the optimal output between this paper and Dewit & Leahy (2004) are the cost random variables of the two oligopoly firms. It is obviously seen that the optimal outputs in stage four are affected by

both the demand and the cost uncertainties.

### 3.2 Optimal Investment Decisions

The next step is to determine the optimal capital levels for different investment timing combinations. If delay is chosen, the investment level is chosen in the last stage<sup>31</sup>; otherwise, it is chosen in stage 3 (in period 1) by maximizing the expected profits.

#### A. Delay, Delay Case

If both firms delay investment into the second period, they maximize their second period profits simultaneously by choosing optimal outputs and capital choices in the second period, so the first order conditions for choosing investment levels are:

$$x - \frac{k}{\eta} = 0 \quad (11a)$$

$$y - \frac{k^*}{\eta} = 0 \quad (11b)$$

Then we can easily solve  $x$ ,  $y$ ,  $k$  and  $k^*$  in terms of  $(s, u, v, v^*)$  using equations (11a), (11b) and (9). (see Table 4)

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<sup>31</sup> By maximizing second period profits.

Table 4

Optimal output and investment choices in delay, delay case under both demand & cost uncertainties

$D, D^*$	
$x$	$x^{dd*} = \frac{v^* + (1-\eta)u + (2-\eta)(s + A - v) - A^*}{(1-\eta)(3-\eta)}$
$y$	$y^{dd*} = \frac{v + (1-\eta)u + (2-\eta)(A^* - v^*) - s - A}{(1-\eta)(3-\eta)}$
$k$	$k^{dd*} = \frac{\eta}{(1-\eta)(3-\eta)} [v^* + (1-\eta)u + (2-\eta)(s + A - v) - A^*]$
$k^*$	$k^{*dd*} = \frac{\eta}{(1-\eta)(3-\eta)} [v + (1-\eta)u + (2-\eta)(A^* - v^*) - s - A]$

In this case, the actual profit functions for both firms are:

$$\pi = x^2 - \frac{k^2}{2\eta} = \left(1 - \frac{\eta}{2}\right) x^{dd*2} \quad (12)$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} = \left(1 - \frac{\eta}{2}\right) y^{dd*2} \quad (13)$$

### B. Commitment, Delay Case

Next, consider the case: commit, defer (home firm invests in the first period,

and foreign firm defers investment into the second period). In period 2,  $u$ ,  $v$  and  $v^*$  are known to both firms, and  $k$  (also  $s$ ) is exogenous. Thus, we solve equation (11b) and (9) at the same time and get:

$$\begin{pmatrix} x^{cd^*} \\ y^{cd^*} \\ k^{*cd^*} \end{pmatrix} = \frac{1}{3-2\eta} \begin{pmatrix} v^* + (1-\eta)u + (2-\eta)(A+s+k-v) - A^* \\ 2A^* - A - s - k + u - 2v^* + v \\ \eta[2A^* - A - s - k + u - 2v^* + v] \end{pmatrix} \quad (13)$$

where the values of  $x$ ,  $y$  and  $k^*$  will depend on  $s$ ,  $k$ ,  $u$ ,  $v$  and  $v^*$ . Going back to stage 3, firm 1 has to decide optimal investment level  $k^{cd^*}$  by maximizing its expected profit in the second period:

$$\begin{aligned} & \text{Max}_k \{E\pi\} \\ & \Leftrightarrow E \left\{ \text{Max}_k \left\{ \pi = (a-x-y+u+s)x - (c_0 - k + v)x - \frac{k^2}{2\eta} \right\} \right\} \\ & \Leftrightarrow E \left\{ \pi_k + \pi_x x_k^{cd^*} + \pi_y y_k^{cd^*} \right\} = 0 \quad (\text{from F.O.C., } \pi_x = 0) \\ & \Leftrightarrow E \left\{ \left( x - \frac{k}{\eta} \right) + (-x) \times \frac{-1}{3-2\eta} \right\} = 0 \\ & \Leftrightarrow k^{cd^*} = \frac{2(2-\eta)}{3-2\eta} \eta E x^{cd^*} \quad (14) \end{aligned}$$

From the result we got in (13),  $Ex^{cd^*}$  can be calculated as:

$$\begin{aligned}
 Ex^{cd^*} &= \frac{1}{3-2\eta} E\{v^* + (1-\eta)u + (2-\eta)(A+s+k-v) - A^*\} \\
 &= \frac{1}{3-2\eta} [E(v^*) + (1-\eta)E(u) - (2-\eta)E(v) + (2-\eta)(A+s+k) - A^*] \\
 &= \frac{2-\eta}{3-2\eta} (A+s+k^{cd^*}) - \frac{A^*}{3-2\eta} \tag{15}
 \end{aligned}$$

(expectations of the random variables are zero due to the assumption)

Finally, we can solve  $k^{cd^*}$  by equation (14) and (15):

$$\begin{aligned}
 k^{cd^*} &= \frac{2(2-\eta)}{3-2\eta} \eta Ex^{cd^*} = \frac{2\eta(2-\eta)}{3-2\eta} \left[ \frac{2-\eta}{3-2\eta} (A+s+k^{cd^*}) - \frac{A^*}{3-2\eta} \right] \\
 \Leftrightarrow k^{cd^*} &= \frac{2\eta(2-\eta)[(2-\eta)(A+s) - A^*]}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \tag{16}
 \end{aligned}$$

In the end, the optimal choices ( $x^{cd^*}$ ,  $y^{cd^*}$  and  $k^{*cd^*}$ ) can be decided in terms of

$s$ ,  $u$ ,  $v$  and  $v^*$  when  $k^{cd^*}$  is plugged in. (see Table 5)



Table 5

Optimal output and investment choices in commitment, delay case under both demand & cost uncertainties

$C, D^*$	
$x$	$x^{cd*} = \frac{1}{3-2\eta} [v^* + (1-\eta)u - (2-\eta)v + \frac{(2-\eta)(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2}]$
$y$	$y^{cd*} = \frac{1}{3-2\eta} [u - 2v^* + v - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + 2(1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2})A^*]$
$k$	$k^{cd*} = \frac{2\eta(2-\eta)[(2-\eta)(A+s) - A^*]}{(3-2\eta)^2 - 2\eta(2-\eta)^2}$
$k^*$	$k^{*cd*} = \frac{\eta}{3-2\eta} [u - 2v^* + v - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + 2(1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2})A^*]$

In this case, the actual profit functions for both firms are:

$$\pi = x^2 - \frac{k^2}{2\eta} = x^2 - \left(\frac{1}{2\eta}\right) \left(\frac{2(2-\eta)}{3-2\eta} \eta Ex\right)^2 = x^2 - 2\eta \left(\frac{2-\eta}{3-2\eta}\right)^2 (Ex^{cd*})^2 \quad (17a)^{32}$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} = \left(1 - \frac{\eta}{2}\right) y^{cd*2} \quad (17b)$$

<sup>32</sup> From this equation, we can also conclude that  $E(\pi) = \left(\frac{(3-2\eta)^2 - 2\eta(2-\eta)^2}{(3-2\eta)^2}\right) (Ex)^2 + Var(x)$ , which can be used later in calculating the maximized expected profits for both firms.

### C. Delay, Commitment Case

When home firm delays investment to the second period, and foreign firm commits investment in the first period, the optimal choices ( $x^{dc^*}$ ,  $y^{dc^*}$ ,  $k^{dc^*}$  and  $k^{*dc^*}$ ) can be decided in terms of  $s$ ,  $u$ ,  $v$  and  $v^*$  by following similar steps as in the Commitment, Delay Case. (see Table 6)

Table 6

Optimal output and investment choices in delay, commitment case under both demand & cost uncertainties

	$D, C^*$
$x$	$x^{dc^*} = \frac{1}{3-2\eta} \left[ u - 2v + v^* + 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) (A+s) - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$y$	$y^{dc^*} = \frac{1}{3-2\eta} \left[ v + (1-\eta)u - (2-\eta)v^* - \frac{(3-2\eta)^2 (A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{(2-\eta)(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$k$	$k^{dc^*} = \frac{\eta}{3-2\eta} \left[ u - 2v + v^* + 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) (A+s) - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$k^*$	$k^{*dc^*} = \frac{2\eta(2-\eta)[(2-\eta)A^* - (A+s)]}{(3-2\eta)^2 - 2\eta(2-\eta)^2}$

In this case, the actual profit functions for both firms are:

$$\pi = x^2 - \frac{k^2}{2\eta} = \left( 1 - \frac{\eta}{2} \right) x^{dc^* 2} \quad (18)$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} = y^2 - \left(\frac{1}{2\eta}\right) \left(\frac{2(2-\eta)}{3-2\eta} \eta E y\right)^2 = y^{dc*2} - 2\eta \left(\frac{2-\eta}{3-2\eta}\right)^2 \left(E y^{dc*}\right)^2 \quad (18)$$

#### D. Commitment, Commitment Case

If both firms commit their investments in the first period, in the second period they only choose their optimal outputs given the investment level they chose in the first period by maximizing their second period profits. (see equation (9))

Back in stage 3, firms have to decide optimal investment level ( $k^{cc*}, k^{*cc*}$ ) by maximizing their expected profits in the second period based on their choices of optimal outputs:

$$\begin{aligned} & \text{Max}_k \{E\pi\} \\ \Leftrightarrow & E \left\{ \text{Max}_k \left\{ \pi = (a - x - y + u + s)x - (c_0 - k + v)x - \frac{k^2}{2\eta} \right\} \right\} \\ \Leftrightarrow & E \left\{ \pi_k + \pi_x x_k^{cc*} + \pi_y y_k^{cc*} \right\} = 0 \quad (\text{from F.O.C., } \pi_x = 0) \\ \Leftrightarrow & E \left\{ \left(x - \frac{k}{\eta}\right) + (-x) \times \left(-\frac{1}{3}\right) \right\} = 0 \\ \Leftrightarrow & k^{cc*} = \frac{4}{3} \eta E x^{cc*} \quad (19) \end{aligned}$$

$$\begin{aligned} & \text{Max}_{k^*} \{E\pi^*\} \\ \Leftrightarrow & E \left\{ \text{Max}_{k^*} \left\{ \pi^* = (a - x - y + u)y - (c_0^* - k^* + v^*)y - \frac{k^{*2}}{2\eta} \right\} \right\} \end{aligned}$$

$$\begin{aligned}
&\Leftrightarrow E\left\{\pi_{k^*}^* + \pi_x^* x_{k^*}^{cc^*} + \pi_y^* y_{k^*}^{cc^*}\right\} = 0 && \text{(from F.O.C., } \pi_y^* = 0) \\
&\Leftrightarrow E\left\{\left(y - \frac{k^*}{\eta}\right) + (-y) \times \left(-\frac{1}{3}\right)\right\} = 0 \\
&\Leftrightarrow k^{*cc^*} = \frac{4}{3}\eta E y^{cc^*} && (20)
\end{aligned}$$

Plug optimal investment levels  $(k^{cc^*}, k^{*cc^*})$  into equation (9), and take expectations on both sides of the equation, we can get:

$$\begin{aligned}
E\begin{pmatrix} x^{cc^*} \\ y^{cc^*} \end{pmatrix} &= \frac{1}{3} \begin{pmatrix} 2A - A^* + 2s + 2 \times \frac{4}{3}\eta E x^{cc^*} - \frac{4}{3}\eta E y^{cc^*} + Eu - 2Ev + Ev^* \\ 2A^* - A - s + 2 \times \frac{4}{3}\eta E y^{cc^*} - \frac{4}{3}\eta E x^{cc^*} + Eu - 2Ev^* + Ev \end{pmatrix} \\
\Leftrightarrow \begin{pmatrix} E x^{cc^*} \\ E y^{cc^*} \end{pmatrix} &= \frac{1}{3} \begin{pmatrix} 2A - A^* + 2s + 2 \times \frac{4}{3}\eta E x^{cc^*} - \frac{4}{3}\eta E y^{cc^*} \\ 2A^* - A - s + 2 \times \frac{4}{3}\eta E y^{cc^*} - \frac{4}{3}\eta E x^{cc^*} \end{pmatrix} \\
\Leftrightarrow \begin{pmatrix} E x^{cc^*} \\ E y^{cc^*} \end{pmatrix} &= \frac{1}{(3-4\eta)(9-4\eta)} \begin{pmatrix} 6(3-2\eta)(A+s) - 9A^* \\ 6(3-2\eta)A^* - 9(A+s) \end{pmatrix} && (21)
\end{aligned}$$

From (15), (16) and (17) we can easily solve for  $k^{cc^*}$  and  $k^{*cc^*}$ . Then,  $x^{cc^*}$  and  $y^{cc^*}$  will be solved automatically by equation (9) when we plug in  $k^{cc^*}$  and  $k^{*cc^*}$ . (see Table 7)

Table 7

Optimal output and investment choices in commitment, commitment case under both demand & cost uncertainties

$C, C^*$	
$x$	$x^{cc^*} = \frac{6(3-2\eta)(A+s) - 9A^*}{(3-4\eta)(9-4\eta)} + \frac{u-2v+v^*}{3}$
$y$	$y^{cc^*} = \frac{6(3-2\eta)A^* - 9(A+s)}{(3-4\eta)(9-4\eta)} + \frac{u-2v^*+v}{3}$
$k$	$k^{cc^*} = \frac{4\eta[2(3-2\eta)(A+s) - 3A^*]}{(3-4\eta)(9-4\eta)}$
$k^*$	$k^{*cc^*} = \frac{4\eta[2(3-2\eta)A^* - 3(A+s)]}{(3-4\eta)(9-4\eta)}$

In this case, the actual profit functions for both firms are:

$$\pi = x^2 - \frac{k^2}{2\eta} = x^2 - \left(\frac{1}{2\eta}\right) \left(\frac{4\eta}{3} Ex^{cc^*}\right)^2 = x^{cc^*2} - \frac{8\eta}{9} (Ex^{cc^*})^2 \quad (22a)^{33}$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} = y^2 - \left(\frac{1}{2\eta}\right) \left(\frac{4\eta}{3} Ey^{cc^*}\right)^2 = y^{cc^*2} - \frac{8\eta}{9} (Ey^{cc^*})^2 \quad (22b)$$

<sup>33</sup> So, the expected value of the profit for the home firm can be expressed as:

$$E(\pi) = \left(1 - \frac{8\eta}{9}\right) (Ex^{cc^*})^2 + Var(x^{cc^*}).$$

### 3.3 Optimal Expected Profits

Going backward to stage two, firms will choose the investment timing which yields the higher expected profit. So we take the expectations of the profits for both firms using the optimal choices above for each investment timing combination.

For Commitment, Commitment Case, the expected profit for the home firm is:

$$\begin{aligned}
 E\pi^{cc^*} &= E \left\{ (a - x^{cc^*} - y^{cc^*} + u + s)x^{cc^*} - (c_0 - k^{cc^*} + v)x^{cc^*} - \frac{(k^{cc^*})^2}{2\eta} \right\} \\
 &= E \left\{ (A - x^{cc^*} - y^{cc^*} + u + s + k^{cc^*} - v)x^{cc^*} - \frac{(k^{cc^*})^2}{2\eta} \right\} \\
 &= E \left\{ (x^{cc^*})^2 - \frac{(k^{cc^*})^2}{2\eta} \right\} \quad \text{(From F.O.C. of the optimal outputs)} \quad (23) \\
 &= \text{var } x^{cc^*} + (Ex^{cc^*})^2 - \frac{(k^{cc^*})^2}{2\eta}
 \end{aligned}$$

It is easily seen from Table 7 that:

$$Ex^{cc^*} = E \left\{ \frac{6(3-2\eta)(A+s) - 9A^*}{(3-4\eta)(9-4\eta)} + \frac{u-2v+v^*}{3} \right\} = \frac{6(3-2\eta)(A+s) - 9A^*}{(3-4\eta)(9-4\eta)}$$

$$\begin{aligned}\text{var } x^{cc^*} &= \text{var} \left\{ \frac{6(3-2\eta)(A+s)-9A^*}{(3-4\eta)(9-4\eta)} + \frac{u-2v+v^*}{3} \right\} \\ &= \frac{\text{var } u + 4 \text{ var } v + \text{var } v^*}{9} = \frac{\sigma^2 + 4V_1 + V_2}{9}\end{aligned}$$

So, the expected profit can be calculated as:

$$\begin{aligned}E\pi^{cc^*} &= \frac{\sigma^2 + 4V_1 + V_2}{9} + \left[ \frac{6(3-2\eta)(A+s)-9A^*}{(3-4\eta)(9-4\eta)} \right]^2 - \frac{1}{2\eta} \left\{ \frac{4\eta[2(3-2\eta)(A+s)-3A^*]}{(3-4\eta)(9-4\eta)} \right\}^2 \\ &= (9-8\eta) \left[ \frac{2(3-2\eta)(A+s)-3A^*}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2 + 4V_1 + V_2}{9}\end{aligned}$$

Similarly, the expected profit for the foreign firm is derived as:

$$\begin{aligned}E\pi^{*cc^*} &= E \left\{ (y^{cc^*})^2 - \frac{(k^{*cc^*})^2}{2\eta} \right\} \tag{24} \\ &= (9-8\eta) \left[ \frac{2(3-2\eta)A^* - 3(A+s)}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2 + 4V_2 + V_1}{9}\end{aligned}$$

Table 8 gives the maximized expected profits for all different investment timing combinations under demand and cost uncertainties.

Table 8

Maximized expected profits for the different investment timing combinations under demand & cost uncertainties

	$E\pi$
$C, C^*$	$(9-8\eta) \left[ \frac{2(3-2\eta)(A+s)-3A^*}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2 + 4V_1 + V_2}{9}$
$C, D^*$	$\frac{[(2-\eta)(A+s)-A^*]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{(1-\eta)^2 \sigma^2 + (2-\eta)^2 V_1 + V_2}{(3-2\eta)^2}$
$D, C^*$	$(1-\frac{\eta}{2}) \left[ \frac{2(1-\eta)(3-\eta)(A+s)-(3-2\eta)A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2 + \frac{1-\frac{\eta}{2}}{(3-2\eta)^2} (\sigma^2 + 4V_1 + V_2)$
$D, D^*$	$(1-\frac{\eta}{2}) \left[ \frac{(2-\eta)(A+s)-A^*}{(1-\eta)(3-\eta)} \right]^2 + \frac{1-\frac{\eta}{2}}{(3-\eta)^2} (\sigma^2 + \frac{V_2}{(1-\eta)^2} + \frac{(2-\eta)^2}{(1-\eta)^2} V_1)$

Table 8 (cont'd)

	$E\pi^*$
$C, C^*$	$(9-8\eta) \left[ \frac{2(3-2\eta)A^* - 3(A+s)}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2 + 4V_2 + V_1}{9}$
$C, D^*$	$(1-\frac{\eta}{2}) \left[ \frac{2(1-\eta)(3-\eta)A^* - (3-2\eta)(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2 + \frac{1-\frac{\eta}{2}}{(3-2\eta)^2} (\sigma^2 + 4V_2 + V_1)$
$D, C^*$	$\frac{[(2-\eta)A^* - (A+s)]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{(1-\eta)^2 \sigma^2 + (2-\eta)^2 V_2 + V_1}{(3-2\eta)^2}$
$D, D^*$	$(1-\frac{\eta}{2}) \left[ \frac{(2-\eta)A^* - (A+s)}{(1-\eta)(3-\eta)} \right]^2 + \frac{1-\frac{\eta}{2}}{(3-\eta)^2} (\sigma^2 + \frac{V_1}{(1-\eta)^2} + \frac{(2-\eta)^2}{(1-\eta)^2} V_2)$



Compared with the case where only demand uncertainty is concerned, the existence of the cost uncertainties increases the expected profits of both firms for all the investment timing combinations.

In order to look at the impact of the cost uncertainty on the possible equilibrium choices the firms will make, we will look at how the cost uncertainty affects each of:  $E\pi^{d,c^*} - E\pi^{c,c^*}$  ;  $E\pi^{d,d^*} - E\pi^{c,d^*}$  ;  $E\pi^{*c,d^*} - E\pi^{*c,c^*}$  and  $E\pi^{*d,d^*} - E\pi^{*d,c^*}$  , since those differences determines each firm's best response given the strategy of the other firm.

$$E\pi^{d,c^*} - E\pi^{c,c^*} = \left(1 - \frac{\eta}{2}\right) \left[ \frac{2(1-\eta)(3-\eta)(A+s) - (3-2\eta)A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2 - (9-8\eta) \left[ \frac{2(3-2\eta)(A+s) - 3A^*}{(3-4\eta)(9-4\eta)} \right]^2 + \left[ \frac{1-\frac{\eta}{2}}{(3-2\eta)^2} - \frac{1}{9} \right] (\sigma^2 + 4V_1 + V_2) \quad (25)$$

Given the foreign firm choosing commitment, when  $\frac{1-\frac{\eta}{2}}{(3-2\eta)^2} - \frac{1}{9} > 0$  (or  $\eta < \frac{15}{8}$ ),

for the home firm the relative advantage of delay to commitment is increasing as demand or cost variances ( $\sigma^2$ ,  $V_1$ ,  $V_2$ ) go up. Furthermore, the difference of the expected profits is more responsive to  $V_1$  than  $V_2$ .

$$\begin{aligned}
E\pi^{d,d^*} - E\pi^{c,d^*} &= (1 - \frac{\eta}{2}) \left[ \frac{(2-\eta)(A+s) - A^*}{(1-\eta)(3-\eta)} \right]^2 - \frac{[(2-\eta)(A+s) - A^*]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \\
&+ \left[ \frac{1-\frac{\eta}{2}}{(3-\eta)^2} - \frac{(1-\eta)^2}{(3-2\eta)^2} \right] \sigma^2 + \left[ \frac{(1-\frac{\eta}{2})(2-\eta)^2}{(3-\eta)^2(1-\eta)^2} - \frac{(2-\eta)^2}{(3-2\eta)^2} \right] V_1 + \left[ \frac{(1-\frac{\eta}{2})}{(3-\eta)^2(1-\eta)^2} - \frac{1}{(3-2\eta)^2} \right] V_2
\end{aligned} \tag{26}$$

Given the foreign firm choosing delay, for the home firm the change of the relative advantage of choosing delay over commitment depends upon the individual coefficients for the variances ( $\sigma^2$ ,  $V_1$ ,  $V_2$ ). It changes in the same direction with the variances with positive coefficients and in the opposite direction with the variances with negative coefficients.

$$\begin{aligned}
E\pi^{*c,d^*} - E\pi^{*c,c^*} &= (1 - \frac{\eta}{2}) \left[ \frac{2(1-\eta)(3-\eta)A^* - (3-2\eta)(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2 - (9-8\eta) \left[ \frac{2(3-2\eta)A^* - 3(A+s)}{(3-4\eta)(9-4\eta)} \right]^2 \\
&+ \left[ \frac{1-\frac{\eta}{2}}{(3-2\eta)^2} - \frac{1}{9} \right] (\sigma^2 + 4V_2 + V_1)
\end{aligned} \tag{27}$$

Given the home firm choosing commitment, when  $\frac{1-\frac{\eta}{2}}{(3-2\eta)^2} - \frac{1}{9} > 0$  (or  $\eta < \frac{15}{8}$ ), for the foreign firm the relative advantage of delay to commitment is increasing as demand or cost variances ( $\sigma^2$ ,  $V_1$ ,  $V_2$ ) go up. Furthermore, the difference of the

expected profits is more responsive to  $V_2$  than  $V_1$ .

$$\begin{aligned}
E\pi^{*d,d^*} - E\pi^{*d,c^*} &= \left(1 - \frac{\eta}{2}\right) \left[ \frac{(2-\eta)A^* - (A+s)}{(1-\eta)(3-\eta)} \right]^2 - \frac{[(2-\eta)A^* - (A+s)]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \\
&+ \left[ \frac{1-\frac{\eta}{2}}{(3-\eta)^2} - \frac{(1-\eta)^2}{(3-2\eta)^2} \right] \sigma^2 + \left[ \frac{(1-\frac{\eta}{2})(2-\eta)^2}{(3-\eta)^2(1-\eta)^2} - \frac{(2-\eta)^2}{(3-2\eta)^2} \right] V_2 + \left[ \frac{(1-\frac{\eta}{2})}{(3-\eta)^2(1-\eta)^2} - \frac{1}{(3-2\eta)^2} \right] V_1
\end{aligned} \tag{28}$$

Given the home firm choosing delay, for the foreign firm the change of the relative advantage of choosing delay to commitment also depends upon the individual coefficients for the variances ( $\sigma^2$ ,  $V_1$ ,  $V_2$ ). It changes in the same direction with the variances with positive coefficients and in the opposite direction with the variances with negative coefficients.

In the end, the four rent-shifting subsidies for all the investment timing combination can be decided in the first stage by the government by maximizing the expected welfare of the home country:

$$Max\{EW\} = Max\{E\pi - sEx\}$$

The optimal rent-shifting subsidy given a particular investment timing combination is calculated by maximizing the expected welfare of the home

country for that particular investment timing combination.<sup>34</sup> In this cost structure, the optimal rent-shifting subsidies for all possible investment timing combinations are summarized in Table 9. The optimal rent-shifting subsidies are predicated upon the equilibrium of the game (once the investment timing is decided, so is the rent-shifting subsidy), however, the equilibrium of the game (investment timing decisions for both firms) are affected by the subsidy.<sup>35</sup>

Table 9

Optimal rent-shifting subsidies for all possible investment timing combinations

$s^{cc^*}$	$\frac{2(3-2\eta)[3(3-4\eta)(9-4\eta)-4(9-8\eta)(3-2\eta)]A+3[3(3-4\eta)(9-4\eta)+4(9-8\eta)(3-2\eta)]A^*}{4(3-2\eta)[2(9-8\eta)(3-2\eta)-3(3-4\eta)(9-4\eta)]}$
$s^{cd^*}$	$\frac{(2-\eta)A-(7-4\eta)A^*}{2(2-\eta)(1-\eta)}$
$s^{dc^*}$	$\left\{ \frac{2[(3-2\eta)^2-2\eta(2-\eta)^2][(3-2\eta)^2-2\eta(2-\eta)^2+\eta(2-\eta)]}{4(1-\eta)^2(2-\eta)(3-\eta)^2(3-2\eta)-4[(3-2\eta)^2-2\eta(2-\eta)^2][(3-2\eta)^2-2\eta(2-\eta)^2+\eta(2-\eta)]} - 1 \right\} A$ $+ \frac{(3-2\eta)^2 \{ 2(1-\eta)(2-\eta)(3-\eta) - (3-2\eta)^2 + 2\eta(2-\eta)^2 \} A^*}{4(1-\eta)^2(2-\eta)(3-\eta)^2(3-2\eta) - 4[(3-2\eta)^2 - 2\eta(2-\eta)^2][(3-2\eta)^2 - 2\eta(2-\eta)^2 + \eta(2-\eta)]}$
$s^{dd^*}$	$\frac{[(1-\eta)(2-\eta)(3-\eta)-(2-\eta)^3]A+A^*}{(2-\eta)^3-2(1-\eta)(2-\eta)(3-\eta)}$

<sup>34</sup> For example, the rent-shifting subsidy for “Commitment, Commitment” case ( $s^{cc^*}$ ) is calculated by  $Max_s \{ E\pi^{c,c^*} - sEx^{c,c^*} \}$ .

<sup>35</sup> The change in the level of the subsidy may change the relative attractiveness of commitment and delay, which may change firms’ investment timing decisions.

### 3.4 Optimal Trade Policy Analysis

The purpose of the optimal trade policy analysis is to investigate the equilibrium strategy (optimal subsidy) for the government when the variance of one uncertainty changes while the variances of the other uncertainties are fixed at some level. Here, both the variances of the uncertainties and the choice of optimal subsidy can affect the equilibrium investment timing decisions of the firms, because the expected profits for different investment timing combinations are not only affected by the variances of the uncertainties (Table 8), but the change of the subsidy (especially deviation from the rent-shifting subsidy level) may also affect the relative attractiveness of commitment and delay.

In order to ease the exposition of the timing manipulation by the policy maker of the home country, we use similar diagrams to those used in Dewit and Leahy (2004)<sup>36</sup>. In most of the figures,  $A$  and  $A^*$  are still normalized at unity, and  $\eta$ <sup>37</sup> is still set to be 0.03. The figures of optimal subsidization when both firms choose investment timing are depicted in  $(\sigma^2, s)$ ,  $(V_1, s)$  or  $(V_2, s)$ , and the figure of corresponding optimal investment timing choice in each diagram is depicted in  $(\sigma^2, t)$ ,  $(V_1, t)$  or  $(V_2, t)$  where 1 represents “Commitment, Commitment” (both home firm and foreign firm Commit their investments) ; 2 represents “Delay, Commitment” (home firm delays and foreign firm commits); 3 represents

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<sup>36</sup> Shown in Fig. 2(a) in Chapter One.

<sup>37</sup> As proved in Dewit and Leahy (2004), varying the levels of  $\eta$  does not change the qualitative relationship between uncertainty and the export subsidy.

“Commitment, Delay” (home firm commits and foreign firm delays) and 4 represents “Delay, Delay” (both home firm and foreign firm delay).

The Matlab codes used for the graphs are in the Appendix. The basic idea is that given a specific value of the variance, the home government will try to find a subsidy level which can maximize the expected welfare of the home country. But we know that it is not simply the rent-shifting subsidies which matter, since the equilibrium investment timing choices by the firms are not given beforehand<sup>38</sup>; actually, the firms’ investment timing choices are affected by the level of the subsidy the home government chooses in the first stage. Therefore, given the government subsidy and the variances of the uncertainties, firms compare the expected profits under each timing choice, and a Nash Equilibrium arises, so that neither firm has an incentive to depart from the equilibrium. Then the expected welfare of the home country will be decided depending on the equilibrium investment timing decision, which determines the expected profit and expected output of the home firm. But the government can change the subsidy level which may lead to another Nash Equilibrium, and the new equilibrium determines a new expected welfare for the home country. In the end, the maximum expected welfare the home country can get and the corresponding optimal subsidy will be found after we try different subsidy levels in a reasonable range<sup>39</sup>. Because

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<sup>38</sup> The rent-shifting subsidies are calculated given the investment timing choices by the firms.

<sup>39</sup> According to Dewit and Leahy (2004), although changing the equilibrium investment timing choice can have benefit on the expected welfare for the home country, deviating from the optimal rent-shifting subsidies would incur a welfare cost, and it increases as the deviation increases, eventually, the benefit by manipulating the timing choices will be dominated by the lost rent-shifting welfare. Therefore, the optimal subsidy choices would be in a range around the optimal rent-shifting subsidies.

different values of the variance cause different values of the expected profits for both firms in each investment timing combination, it may change the firms' investment timing preferences; therefore, the maximized expected welfare and the optimal subsidy could be changed. What's more, the optimal subsidy depends not only on variances ( $\sigma^2$ ,  $V_1$  and  $V_2$ ), but all the other parameters in Table 8 ( $A$ ,  $A^*$  and  $\eta$ ), since the expected profits for both firms in each investment timing combination will change, hence change the firms' investment timing preferences.

### 3.4.1 Optimal Subsidy and the Demand Variance

We study the changes in the optimal subsidy as the variance of the demand shock changes, for different assumptions about the variances of the cost shocks of the two firms. Case one assumes that the variances of the cost shocks of the two firms are equal; as the cost variance increases, we study the change in the optimal subsidy. Case two assumes unequal cost variance, and we study the impact of increasing the difference between the cost variances of the two firms on the optimal subsidy. Both situations of  $V_1 > V_2$  and  $V_1 < V_2$  are studied.

#### A. Case One: $V_1 = V_2$

When the cost variances are very small:  $V_1 = V_2 = 10^{-3}$ ,<sup>40</sup> we get very similar

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<sup>40</sup> The numerical values chosen for the cost variances are decided by gradually increasing the cost variance level from zero (usually by a factor of 10) and record the level when the pattern for the optimal subsidy has a big change. The

figures as in Dewit and Leahy (2004); which means tiny cost variances will not change the optimal subsidy and investment timing decisions very much. (see figure 3)

When the demand variance is very low, the government chooses rent-shifting subsidy  $s^{cc^*}$  and both firms choose to commit their investments. As the variance increases to the level near 0.04, the government increases its optimal subsidy (we call it  $s^{cf^*}$ ) enough to induce the foreign firm to delay its investment. This regime switch occurs at the point where  $EW(s^{cf^*}; C, D^*) = EW(s^{cc^*}; C, C^*)$ <sup>41</sup>. The increase of the subsidy increases the relative attractiveness of commitment by the home firm, and lowers it for the foreign firm. The reason is that: for the home firm, the return to the output expansion which results from capital commitment increases since the increase of the subsidy widens the output price and cost gap; for the foreign firm, the subsidy decreases the price–cost gap, therefore reducing the return to investment commitment. So when the subsidy increases enough, the benefit of delay outweighs commitment for the foreign firm, and hence induces it to delay. As the variance increases, the lowest subsidy which can induce the foreign firm to delay decreases, since the flexibility benefit is increasing with the increase of the

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specific values chosen for the cost variance does not affect the conclusion on the analysis for the changing pattern of the optimal subsidy.

<sup>41</sup> This means that the government is indifferent in choosing  $s^{cf^*}$  and  $s^{cc^*}$ , but the firms are not indifferent in choosing  $(C, C^*)$  or  $(C, D^*)$  (The horizontal segment in the timing graph does not mean that the firms are indifferent in choosing either  $(C, C^*)$  or  $(C, D^*)$ ). The firms' decisions depend upon which subsidy the government choose, if the government chooses  $s^{cc^*}$ , the firms will choose  $(C, C^*)$ , otherwise,  $(C, D^*)$  will be chosen.



variance. Finally, it reaches the rent-shifting subsidy  $s^{cd^*}$ . The same thing happens when the variance reaches the point just below 0.14. The sudden decrease of the subsidy (we call it  $s^{td^*}$ ) increases the relative attractiveness of delay to the home firm, and lowers it to the foreign firm; hence the decrease of the subsidy induces the home firm to delay. This regime switch occurs at the point where  $EW(s^{cd^*}; C, D^*) = EW(s^{td^*}; D, D^*)$ . As the variance increases further, the highest subsidy which can induce the home firm to delay increases, and finally merges into the rent-shifting subsidy  $s^{dd^*}$ . From the analysis above, we can see that there are two equilibria at each variance level where the optimal subsidy has a break.

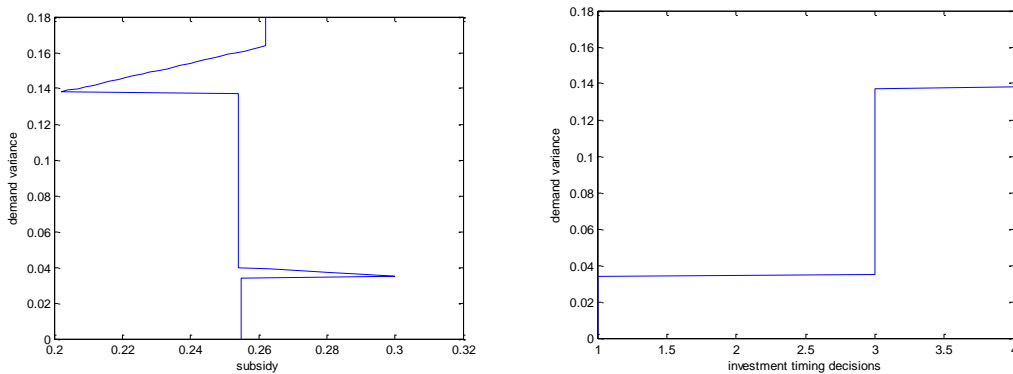


Fig. 3. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = V_2 = 10^{-3}$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

When the cost variances increase by a factor of ten, the firms are more willing to delay their investments and they will not choose to commit at the same

time, no matter how big the variance of the demand shock is, which means the “Commitment, Commitment” interval vanishes. Therefore, the government will not choose  $s^{cc^*}$  and it does not need to use  $s^{ct^*}$  to induce the foreign firm to delay investment. (see figure 4)

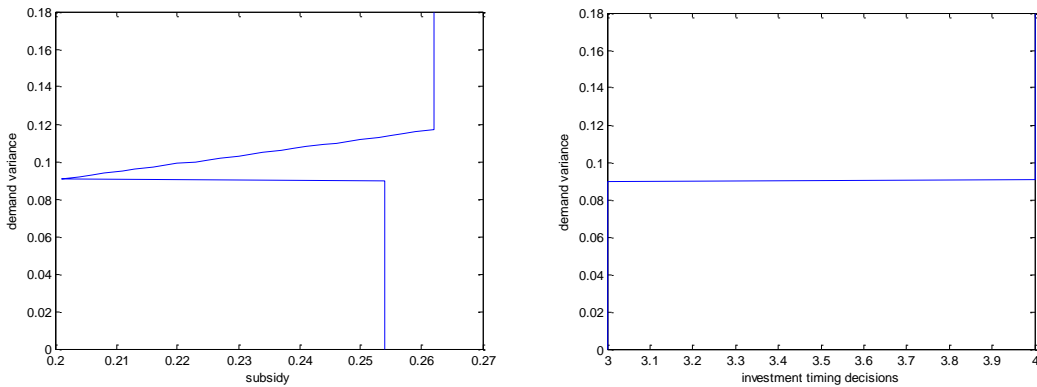


Fig. 4. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = V_2 = 10^{-2}$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

When the cost variances increase by another factor of 10, the firms will only choose “Delay, Delay” and neither firm would like to commit its investment even if there is no uncertainty on the demand side. Accordingly, the government will keep its subsidy level at the rent-shifting subsidy  $s^{dd^*}$ . (see figure 5)

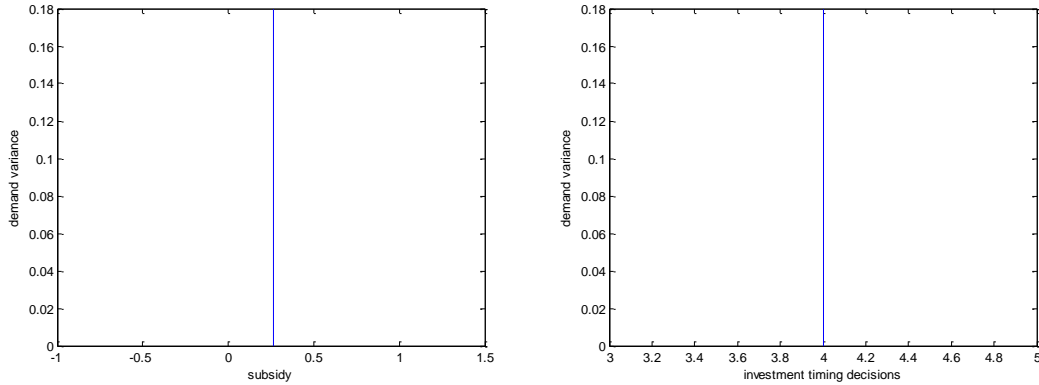


Fig. 5. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = V_2 = 10^{-1}$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

In fact, as the cost variances increase, the firms and the home government are more willing to delay the investments of both firms. It seems like the original graph in Dewit and Leahy (2004) (when cost variances are zero) gradually moves downwards to the horizontal axis. However, the government still wants to delay the investment of the foreign firm first.

If we allow cost asymmetry ( $A \neq A^*$  or  $c_0 \neq c_0^*$ ), and the home firm has a cost advantage ( $A > A^*$  or  $c_0 < c_0^*$ ), it is easier for the government to enforce foreign firm delay and it is harder for the government to enforce home firm delay. For example, in the case where  $V_1 = V_2 = 10^{-3}$ , if we set  $A = 1.01$  and  $A^* = 0.99$ , the graphs become:

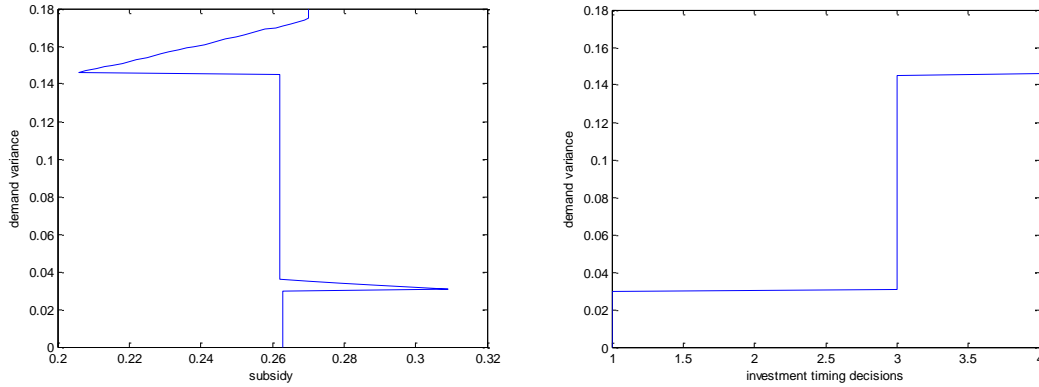


Fig. 6. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = V_2 = 10^{-3}$ ,  $A = 1.01$  and  $A^* = 0.99$ . ( $\eta = 0.03$ )

Comparing with figure 3, we can see the point where the government enforce the foreign firm delay drops and the point where it enforces home firm delay increases.

However, the result is opposite when the home firm has a cost advantage ( $A < A^*$  or  $c_0 > c_0^*$ ), it is harder for the government to enforce foreign firm delay and easier for the government to enforce home firm delay. For the case where  $V_1 = V_2 = 10^{-3}$ , we set  $A = 0.99$  and  $A^* = 1.01$ , and the graphs become:

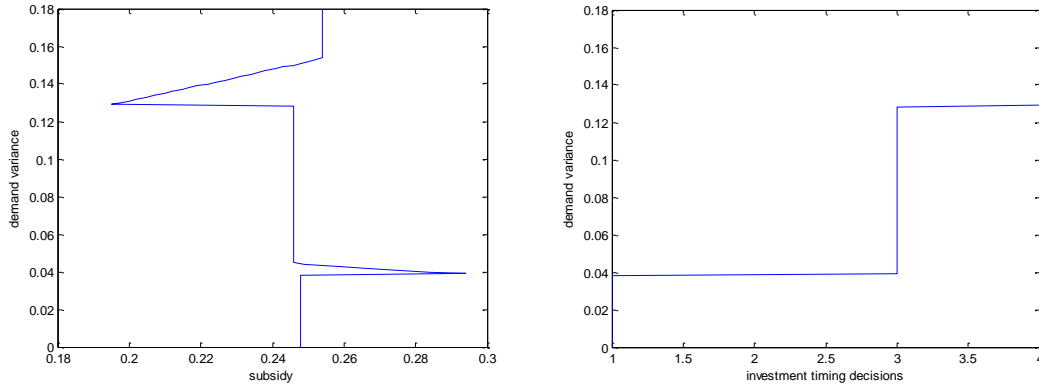


Fig. 7. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = V_2 = 10^{-3}$ ,  $A = 0.99$  and  $A^* = 1.01$ . ( $\eta = 0.03$ )

This time, the point where the government enforce the foreign firm delay increases and the point where it enforces home firm delay drops.

### B. Case Two: $V_1 \neq V_2$

In order to better understand the impact of increasing the difference of the cost variances of the two firms on the changing pattern of the optimal subsidy, we increase the difference of their cost variance at each level of the variances as used in the case when the variances were equal. Then, we will compare the graph after we increase the difference of their cost variance with the one which keeps the difference zero.

If the cost variance of the home firm is bigger than the foreign firm ( $V_1 > V_2$ ), where we pick  $V_1 = 5 \times 10^{-3}$  and  $V_2 = 5 \times 10^{-4}$ , the graphs become figure 8.

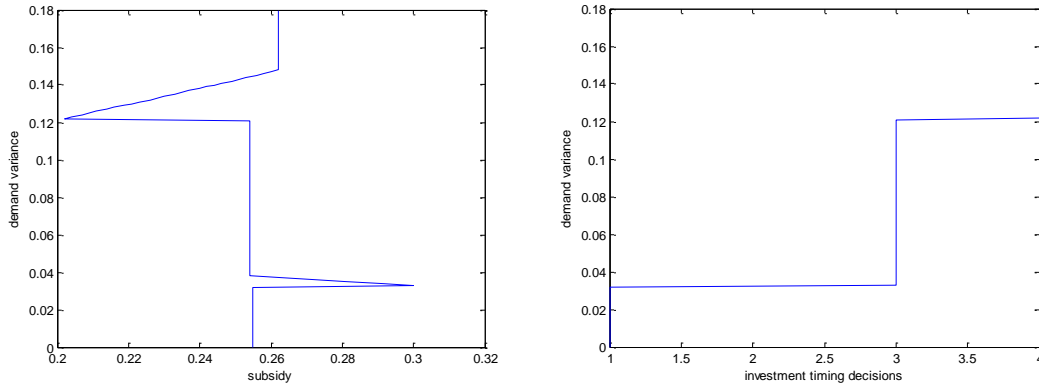


Fig. 8. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = 5 \times 10^{-3}$  and  $V_2 = 5 \times 10^{-4}$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

Compared with figure 3, the whole graph of the optimal subsidization moves down. In particular, the demand variance at which the government starts to induce home commitment deterrence and foreign commitment deterrence occurs at a lower level of. However, the point where the government starts to make the home commitment deterrence drops more rapidly than the point where the government starts to make the foreign commitment deterrence. This means that although the increase of the difference of the cost variance gives both firms more incentives to delay their investment, it is easier for the government to enforce home firm flexibility when  $V_1 > V_2$  because when the home firm has a relatively high cost variance than the foreign firm, the home firm has a lower commitment value than the foreign firm.

When we increase the difference of their cost variance on the level of  $10^{-2}$  and set  $V_1 = 5 \times 10^{-2}$  and  $V_2 = 5 \times 10^{-3}$ , the results are shown in figure 9.

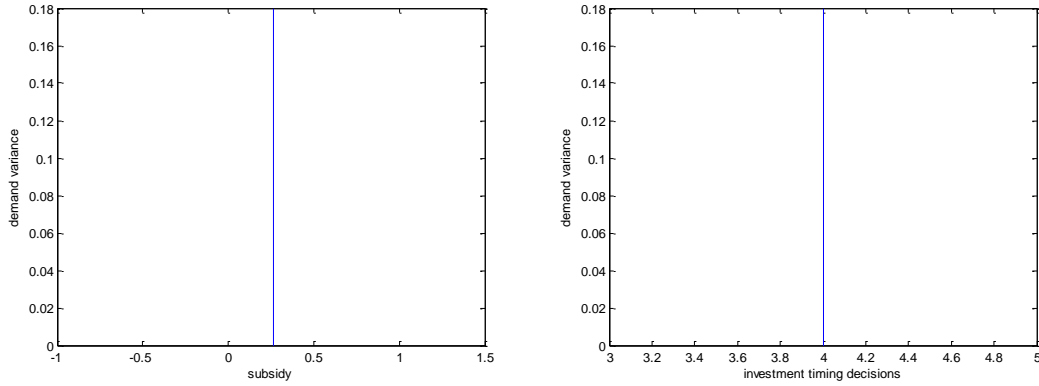


Fig. 9. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = 5 \times 10^{-2}$  and  $V_2 = 5 \times 10^{-3}$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

Compared with figure 4, the increase of the difference of the cost variances between the firms makes delay the only choice for the home firm, and the government only needs to set subsidy  $s^{dd^*}$ .

Considering the case when the cost variance of the home firm is smaller than the foreign firm ( $V_1 < V_2$ ), we first study the chance when  $V_1 = 5 \times 10^{-4}$  and  $V_2 = 5 \times 10^{-3}$ . In this case, the graphs become:

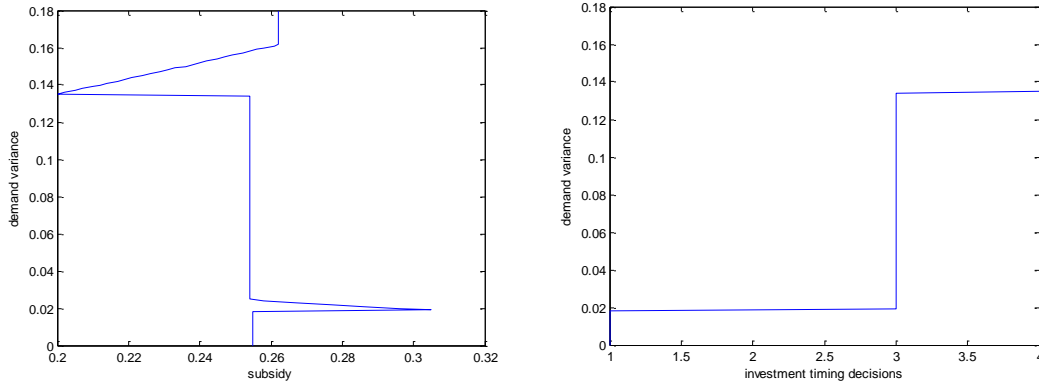


Fig. 10. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = 5 \times 10^{-4}$  and  $V_2 = 5 \times 10^{-3}$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

As in the situation where the cost variance of the home firm is bigger than the foreign firm ( $V_1 > V_2$ ), the increase of the difference of the cost variances makes the whole graph (figure 3) of the optimal subsidization moves down. However, in this situation where  $V_1 < V_2$ , the point where the government starts to induce the foreign commitment deterrence drops more than the point where the government starts to induce the home commitment deterrence. This means that, although the increase of the difference of the cost variance gives both firms more incentives to delay, it is easier for the government to enforce foreign firm flexibility when  $V_1 < V_2$ .

Next, we increase the difference of their cost variance to the level of  $10^{-2}$  and set  $V_1 = 5 \times 10^{-3}$  and  $V_2 = 5 \times 10^{-2}$ . The results are shown in figure 11.



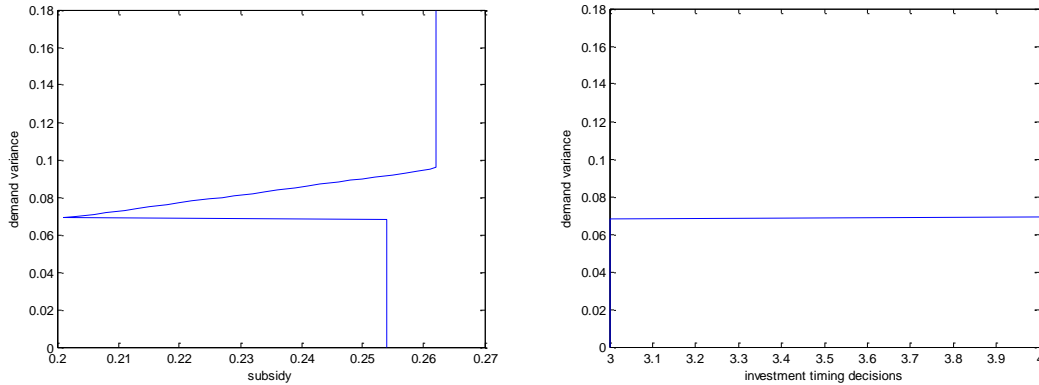


Fig. 11. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1 = 5 \times 10^{-3}$  and  $V_2 = 5 \times 10^{-2}$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

Compared with figure 4, the increase of the difference of the cost variances between the firms moves down the point where the government starts to make the home commitment deterrence, which means that it is easier for the government to force the home firm to delay its investment.

As earlier, the increase in the cost variances makes firms more willing to delay their investments, and it is easier for the government to induce the “commitment deterrence” to both firms. Likewise, the increase in the difference of the cost variances gives both firms more incentives to delay, no matter which firm has larger variance. However, it is easier for the government to enforce flexibility for the firm which has the higher cost variance; as the commitment has a lower value for the firm which has a larger variance.

### 3.4.2 Optimal Subsidy and the Cost Variances

The changes of the optimal subsidization as the variance of the cost shock changes will be analyzed separately for the cost variance of the home firm ( $V_1$ ) and the cost variance of the foreign firm ( $V_2$ ).

#### A. Optimal Subsidy and $V_1$

First, assuming there is no cost variance for the foreign firm ( $V_2 = 0$ ), we will analyze the change in the optimal subsidy as we increase the level of demand variance from 0 to 0.1. (See Figures 12-15)

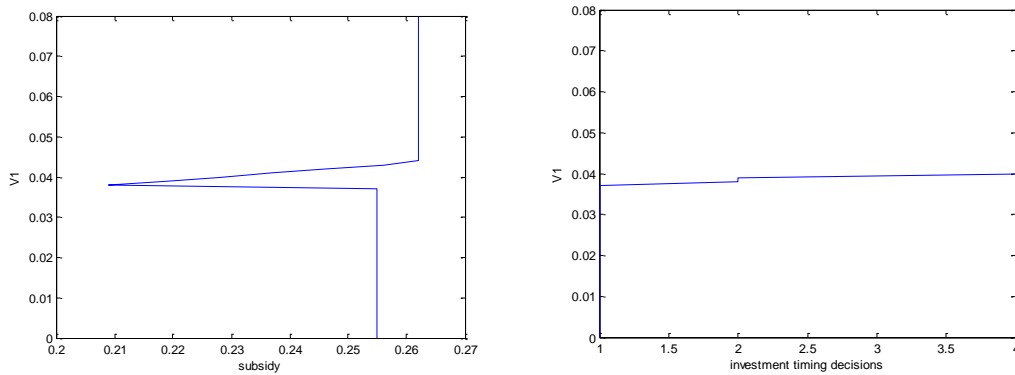


Fig. 12. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_2 = 0$  and  $\sigma^2 = 0$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

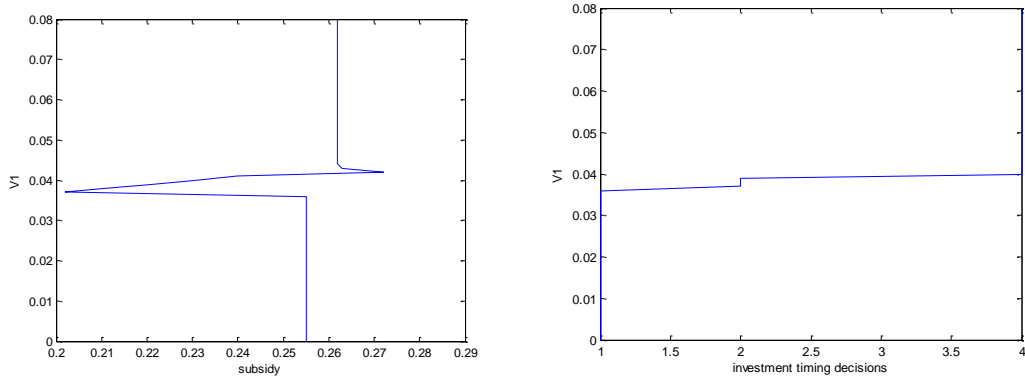


Fig. 13. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_2 = 0$  and  $\sigma^2 = 0.001$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

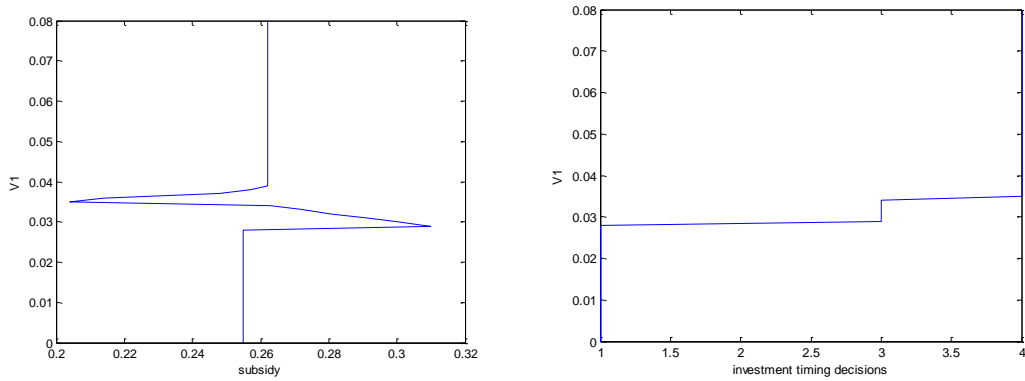


Fig. 14. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_2 = 0$  and  $\sigma^2 = 0.01$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

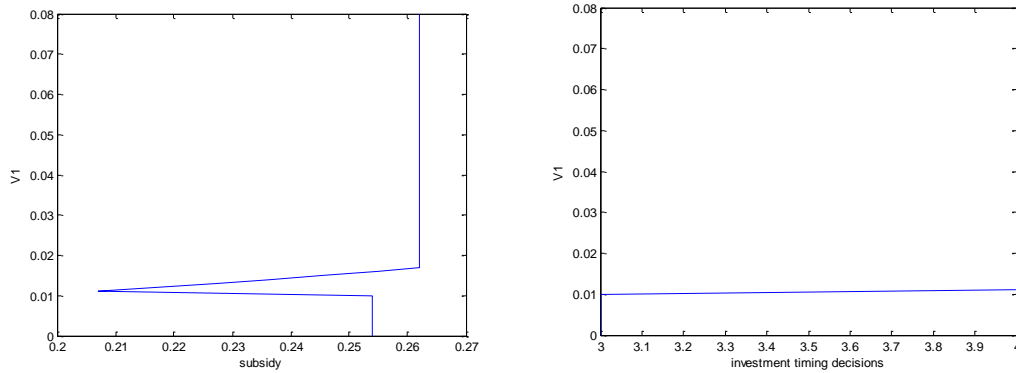


Fig. 15. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_2 = 0$  and  $\sigma^2 = 0.1$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

The figures above reveal an interesting result: when demand variance ( $\sigma^2$ ) is very low (near zero)<sup>42</sup>, a new equilibrium ( $D, C^*$ ) appears (instead of ( $C, D^*$ )) between ( $C, C^*$ ) and ( $D, D^*$ ), and it does not exist when we study the change of the optimal subsidy with the change of the demand variance. The new equilibrium implies that when demand variance is small and there is no cost variance for the foreign firm, the home government would like to enforce home firm delay before enforcing foreign firm delay as the home firm's cost variance increases. However, when demand variance is relatively large, the home government would still want to enforce foreign firm delay first. We can also conclude from the figures above that the point (the level of the demand variance) where the home government starts to enforce delay to at least one firm decreases as the demand variance increases.

<sup>42</sup> See Figure 12 and Figure 13.

What is more, Figure 16 shows the changes of all the important variables affected by the subsidy as  $V_1$  changes, when  $V_2 = 0$  and  $\sigma^2 = 0$ :

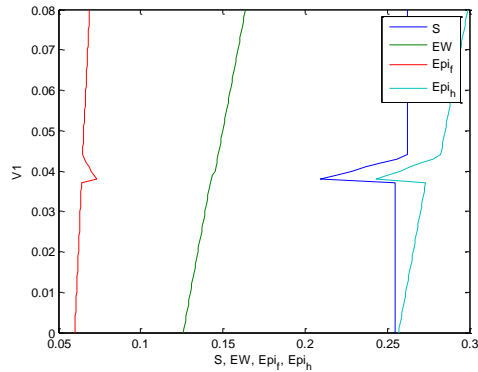


Fig. 16. Optimal subsidization, expected welfare for the home country, expected profit for the foreign and home firm when both firms choose investment timing. ( $V_2 = 0$  and  $\sigma^2 = 0$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

As  $V_1$  increases, the expected profit for the foreign firm has an increasing trend, even though the foreign government does not subsidize. Similarly, the expected profit for the home firm has an increasing trend, with a larger slope than for the foreign firm. Expected welfare for the home country is steadily increasing with the increase of home firm's cost variance. So, basically, both firms and the home government benefit from the increase of the home firm's cost uncertainty. However, when  $V_1$  approaches to the point near 0.04, the best way for the home government to maximize the welfare of its country is to decrease the subsidy. The subsidy drop reduces the expected profit of the home firm and at the same time

increases the expected profit of the foreign firm, because the home firm loses its advantage relative to the foreign firm. Therefore, the subsidy shifts “rent” from the home firm to the foreign firm. However, as  $V_1$  continues to increase from that point, the home government will raise the subsidy level which increases the expected profit of the home firm and cuts down the expected profit of the foreign firm. Here, the subsidy shifts “rent” from the foreign firm to the home firm. (Graphs for the changes of the important variables including the subsidy as  $V_1$  changes are shown in Appendix)

Secondly, assuming there is no demand uncertainty ( $\sigma^2 = 0$ ), we look at the change in the pattern of the optimal subsidy as we increase the level of the foreign firm’s cost variance ( $V_2$ ) from 0.001 to 0.1. (See Figures 17-19)

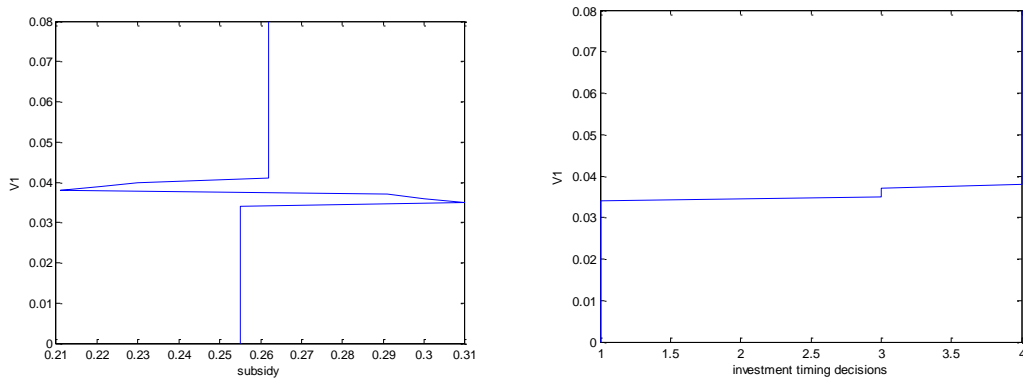


Fig. 17. Optimal subsidization and investment timing choice when both firms choose investment timing when  $\sigma^2 = 0$  and  $V_2 = 0.001$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

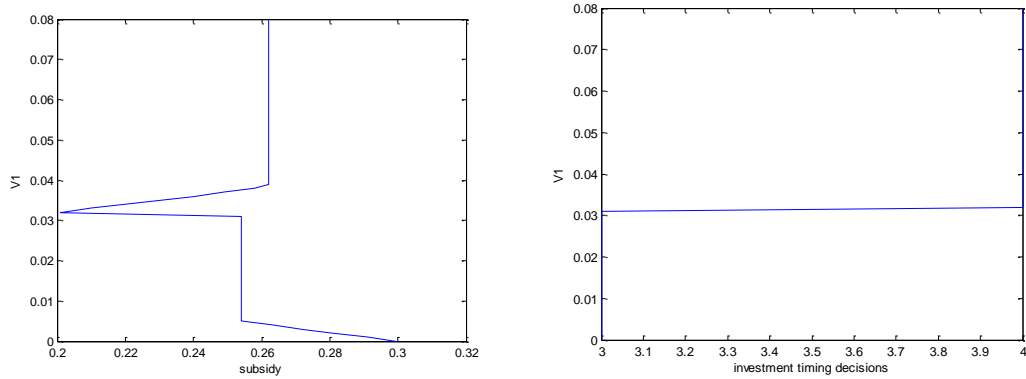


Fig. 18. Optimal subsidization and investment timing choice when both firms choose investment timing when  $\sigma^2 = 0$  and  $V_2 = 0.01$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

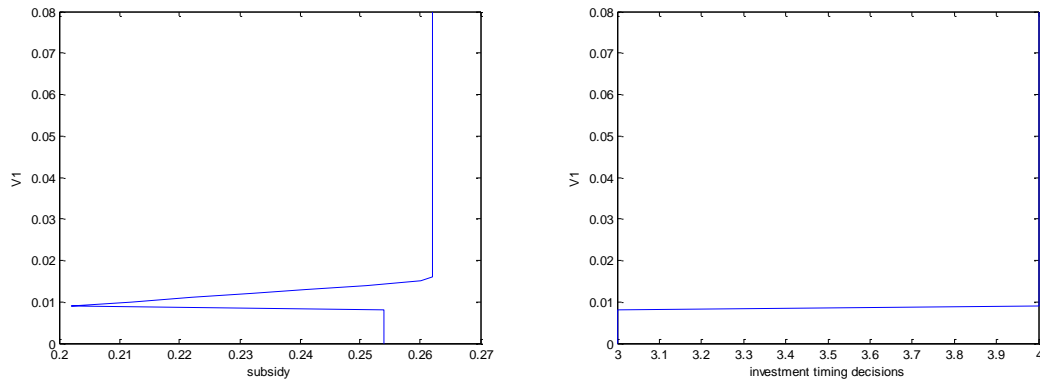


Fig. 19. Optimal subsidization and investment timing choice when both firms choose investment timing when  $\sigma^2 = 0$  and  $V_2 = 0.1$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

As expected, the increase of the cost variance for the foreign firm makes it easier for the home government to enforce at least one firm delay.

## B. Optimal Subsidy and $V_2$

The analysis on the optimal subsidy and foreign firm's cost variance ( $V_2$ ) is similar to part A above. First, suppose there is no cost variance for the home firm ( $V_1 = 0$ ), we analyze the change in the pattern of the optimal subsidy as we increase the level of demand variance from 0 to 0.1. Next, suppose there is no demand uncertainty ( $\sigma^2 = 0$ ), we look at the change in the changing pattern of the optimal subsidy as we increase the level of the home firm's cost variance ( $V_1$ ) from 0.001 to 0.1. (See Appendix for the graphs)

The changing pattern of the optimal subsidy as foreign firm's cost variance varies is similar to the changing pattern of the optimal subsidy as demand variance varies. The home government still wants to enforce foreign firm delay before enforcing home firm delay. Furthermore, keeping other things unchanged, the increase of either demand variance or home firm's variance would make it easier for the home government to enforce delay to at least one firm.

## 4. Conclusion

From the analysis of the optimal subsidy and the demand variance, we learn that both the increase of the level and the difference of the cost variances makes the firms more willing to delay, and it is easier for the government to induce "commitment deterrence" for both firms. Also, it is easier for the government to induce flexibility to the firm with higher cost variance.



From the analysis of the optimal subsidy and the home firm's cost variance, we found that under small demand variance and zero cost variance for the foreign firm, when the home firm's cost variance increases the home government would like to enforce home firm delay before enforcing foreign firm delay. As the demand variance increases, it is easier for the home government to enforce delay to at least one firm. The increase of the foreign firm's cost variance makes it easier for the home government to enforce at least one firm delay.

Finally, the changing pattern of the optimal subsidy as foreign firm's cost variance varies is similar to the changing pattern of the optimal subsidy as demand variance varies. Besides, the increase of either demand variance or home firm's variance would make it easier for the home government to enforce at least one firm delay.

There are several limitations of this paper. First, for simplicity this paper ignores covariance among the shocks. Since cost shocks depend upon the price of tradable raw materials, the covariance of these shocks is worth studying further. What's more, this paper does not consider time consistency problem. The government may have an incentive to change the subsidy after the uncertainties are realized, a capital policy rather than just an output policy should also be considered. In addition, the cost structure in the paper does not contain private information, which is important since the firms always know less about their rivals' cost than their own. This problem will be addressed in the next Chapter.

## APPENDIX A

1. Graphs for optimal subsidy and foreign firm's cost variance ( $V_2$ ) when  $V_1$  or  $\sigma^2$  is changed:

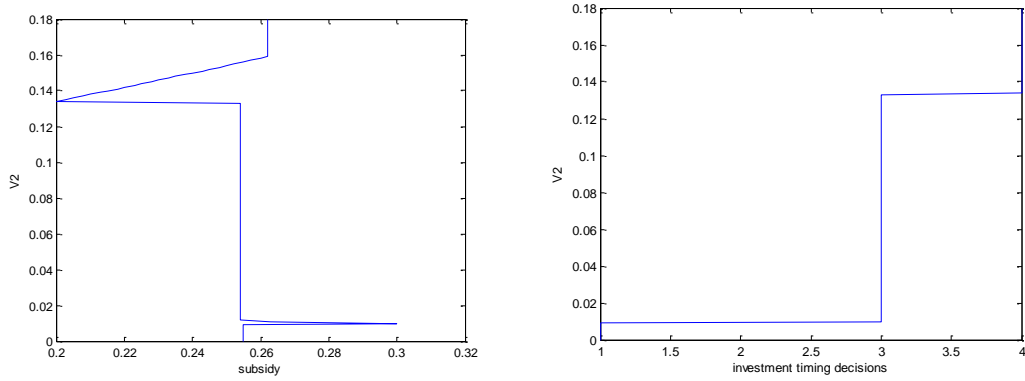


Fig. 1. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1=0$  and  $\sigma^2=0$ . ( $A=A^*=1$ ;  $\eta=0.03$ )

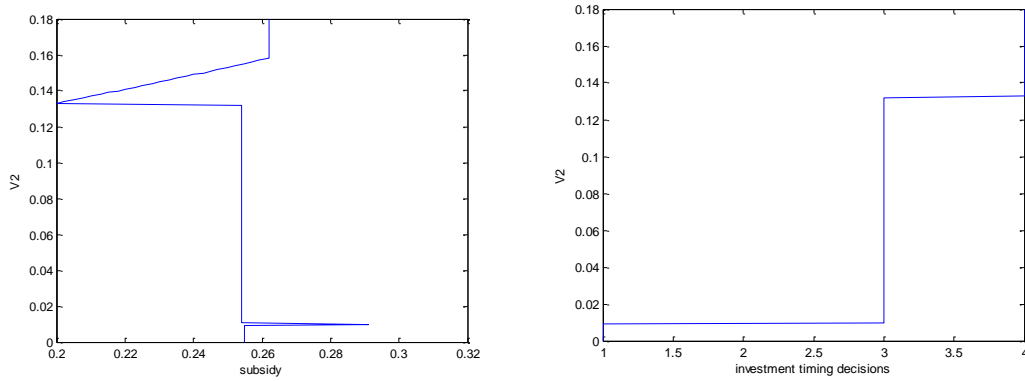


Fig. 2. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1=0$  and  $\sigma^2=0.001$ . ( $A=A^*=1$ ;  $\eta=0.03$ )

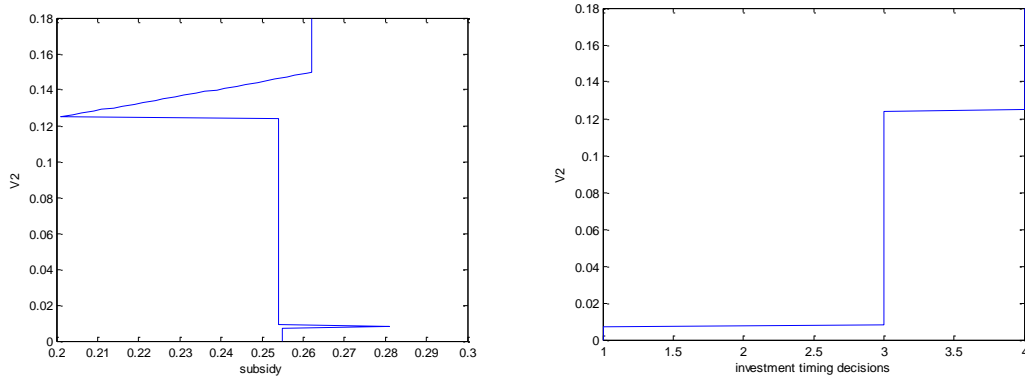


Fig. 3. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1=0$  and  $\sigma^2=0.01$ . ( $A=A^*=1$ ;  $\eta=0.03$ )

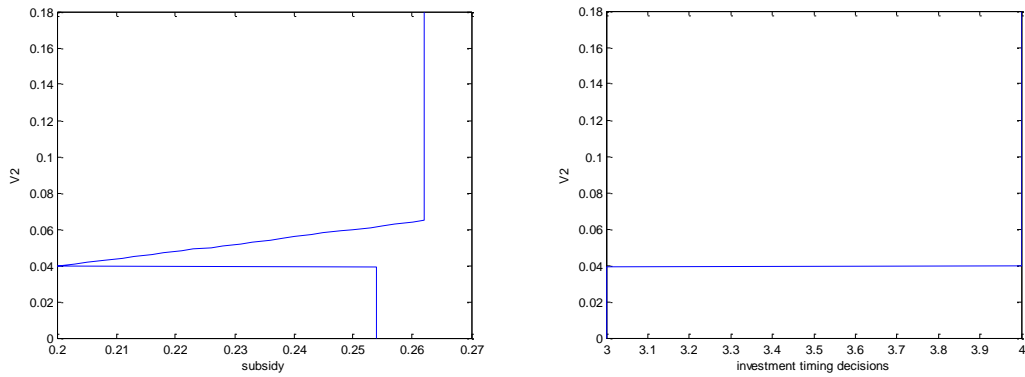


Fig. 4. Optimal subsidization and investment timing choice when both firms choose investment timing when  $V_1=0$  and  $\sigma^2=0.1$ . ( $A=A^*=1$ ;  $\eta=0.03$ )

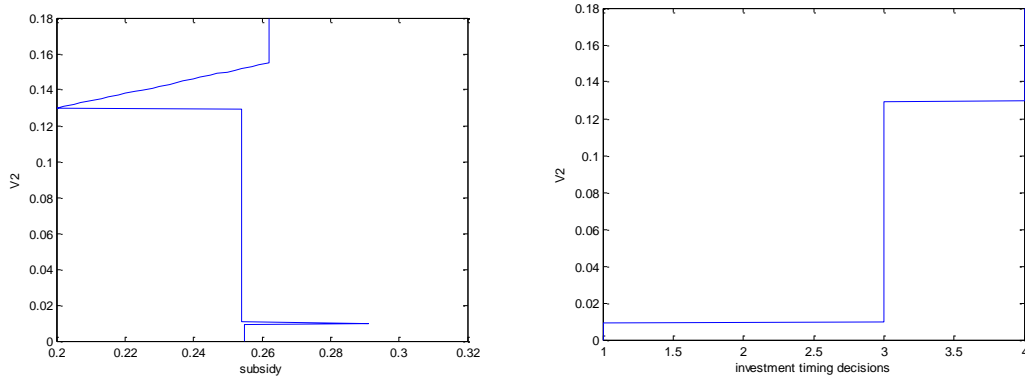


Fig. 5. Optimal subsidization and investment timing choice when both firms choose investment timing when  $\sigma^2 = 0$  and  $V_1 = 0.001$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

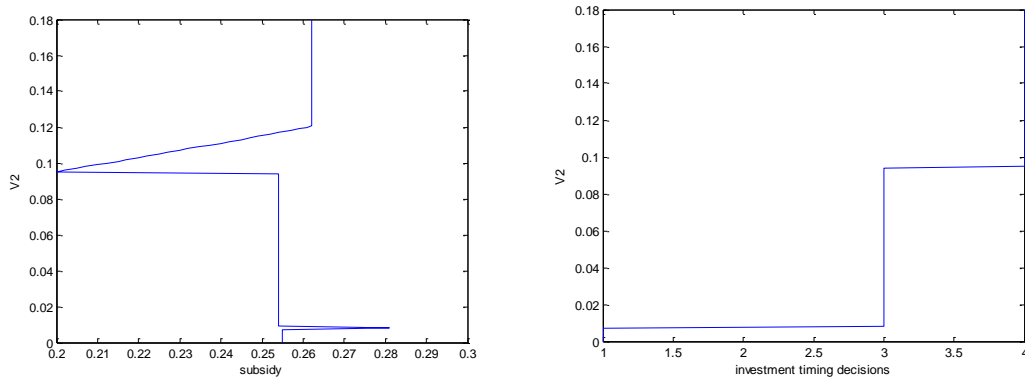


Fig. 6. Optimal subsidization and investment timing choice when both firms choose investment timing when  $\sigma^2 = 0$  and  $V_1 = 0.01$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

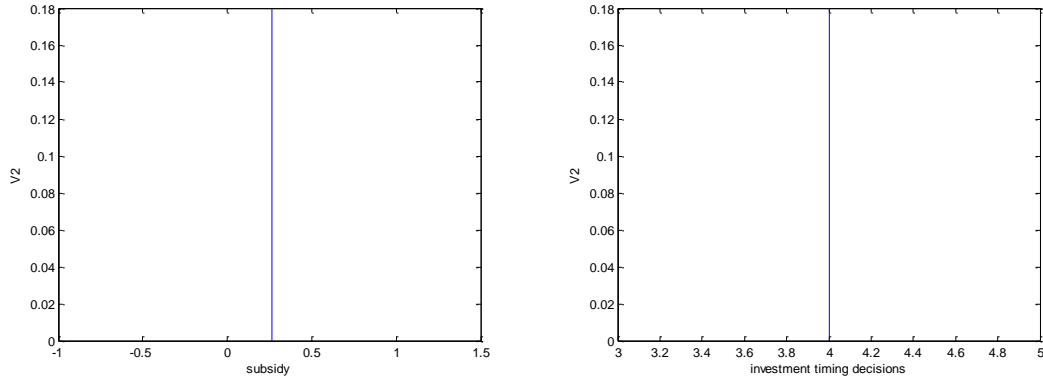


Fig. 7. Optimal subsidization and investment timing choice when both firms choose investment timing when  $\sigma^2 = 0$  and  $V_1 = 0.1$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

2. Graphs for the changes of some important variables including the subsidy as  $V_1$  changes:

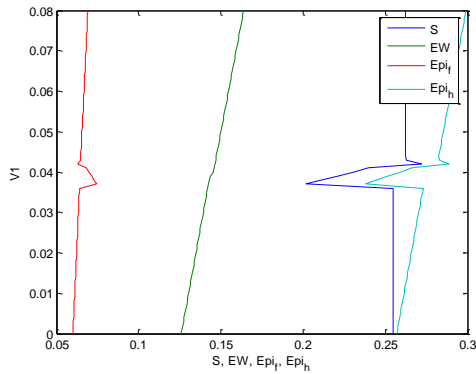


Fig. 8. Changes of some important variables including the subsidy as  $V_1$  changes when  $V_2 = 0$  and  $\sigma^2 = 0.001$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )

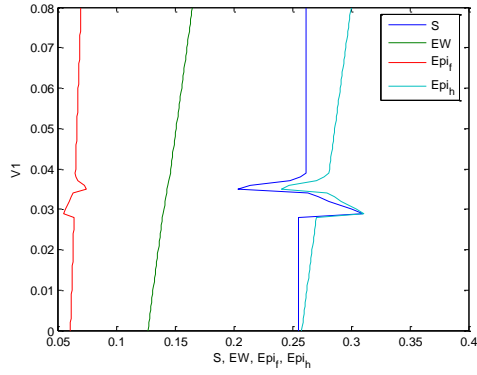


Fig. 9. Changes of some important variables including the subsidy as  $V_1$  changes when  $V_2=0$  and  $\sigma^2=0.01$ . ( $A=A^*=1$ ;  $\eta=0.03$ )

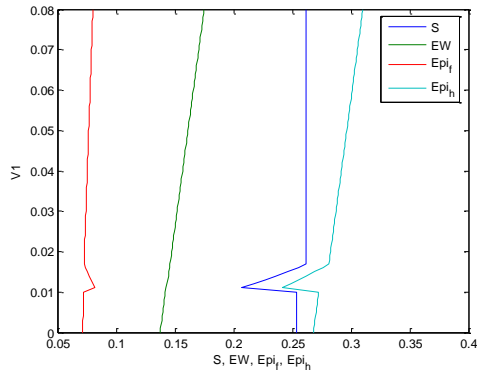


Fig. 10. Changes of some important variables including the subsidy as  $V_1$  changes when  $V_2=0$  and  $\sigma^2=0.1$ . ( $A=A^*=1$ ;  $\eta=0.03$ )

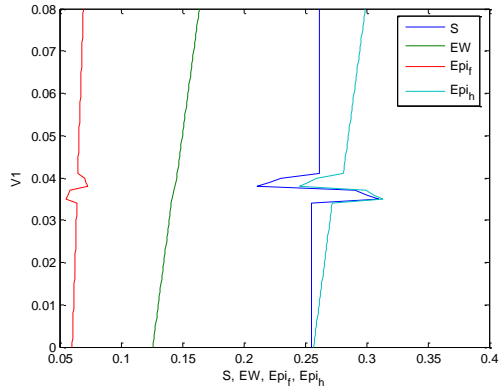


Fig. 11. Changes of some important variables including the subsidy as  $V_1$  changes when

$$\sigma^2 = 0 \text{ and } V_2 = 0.001. (A = A^* = 1; \eta = 0.03)$$

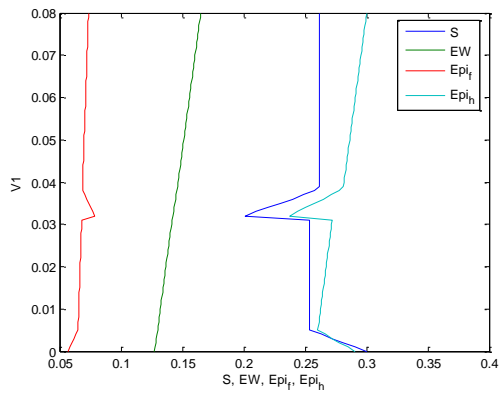


Fig. 12. Changes of some important variables including the subsidy as  $V_1$  changes when

$$\sigma^2 = 0 \text{ and } V_2 = 0.01. (A = A^* = 1; \eta = 0.03)$$

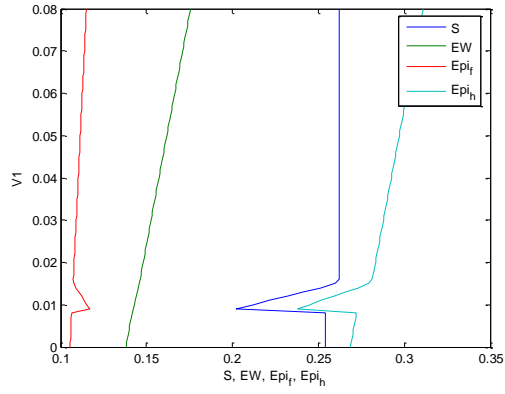


Fig. 13. Changes of some important variables including the subsidy as  $V_1$  changes when

$\sigma^2 = 0$  and  $V_2 = 0.1$ . ( $A = A^* = 1$ ;  $\eta = 0.03$ )



## CHAPTER 3

### STRATEGIC TRADE POLICY AND THE INVESTMENT TIMING UNDER COST UNCERTAINTY WITH PRIVATE INFORMATION

In this Chapter, we assume in the first period, home government sets a subsidy in stage 1, then in stage 2 both firms decide their investment timing choices based only on the public distributional information of the demand uncertainty and firms' cost uncertainties. Private cost information is introduced in stage 3 when the cost random components are only observed privately by each firm and kept unknown to the other. This assumption is based on the fact that oligopoly firms may know less about their rival's costs than their own (asymmetric information) and they are not allowed to share information with each other about their costs. What is more, covariance among the shocks will also be studied in this structure since cost shocks of the two firms depend upon the price of tradable raw materials. In the last stage (period two), firms learn all the uncertainties. With private information revealed in stage 3, a firm may have more incentive to commit as its cost uncertainty increases since the information value for the firm is higher with higher cost variances.

#### 1. The Setup of the Model

The two-period four-stage game with this cost structure is: in stage one and two, home government and both firms face uncertainties on both future demand

in the export market and firms' costs (however, the players know all the distributional aspects of  $u$ ,  $v$  and  $v^*$ , which are common knowledge to all the players). In stage one the home government sets an export subsidy knowing the demand function of the third country and both firms' cost functions. In stage two, firms make decisions on their investment timing and then committed to this decision knowing only the distribution of the demand and cost uncertainties. In stage three,  $v$  and  $v^*$  are observed by each firm privately, but each firm still only knows the distributional aspects of  $v$  or  $v^*$  for the other firm as well as their correlation. Firms that have committed to investing choose their actual capital level. In the second period (stage 4), all the uncertainties are resolved and observed by both firms, that is, firms observe both  $u$  and the cost realization for the other firm. In this period, firms choose outputs and capital levels if they have not previously chosen those.

This two-period four-stage game could be summarized as:

In Period 1:

Stage 1: Home government sets subsidy  $s$ .

Stage 2: Firms decide on investment timing knowing the distribution of the demand and the distribution, but not the actual values, of their own and the rival's cost.

Stage 3: Based on their investment timing decisions in Stage 2, Firms that have been committed to investing choose their actual capital level, knowing their own cost random components privately and not sharing their cost information.

In Period 2 (Stage 4): Firms choose outputs and capital levels if they have not chosen those observing the realization of all the random components.

It is assumed that the total cost functions of home and foreign firm ( $TC, TC^*$ ) are:

$$TC = (c_0 - k + v)x + \frac{k^2}{2\eta} \quad (\mathbf{a})$$

$$TC^* = (c_0^* - k^* + v^*)y + \frac{k^{*2}}{2\eta} \quad (\mathbf{b})$$

where  $v$  and  $v^*$  are stochastic cost components which have the following properties<sup>43</sup>:

(i)  $E(v) = 0, E(v^*) = 0$ ;

(ii)  $Var(v) = V_1, Var(v^*) = V_2, V_1 \text{ \& } V_2 \geq 0$ ;

(iii)  $Cov(v, v^*) = V_c$ <sup>44</sup>,  $Cov(u, v) = 0, Cov(u, v^*) = 0, V_c \geq 0$ ;

(iv)  $v$  and  $v^*$  are jointly normally distributed:  $(v, v^*)^T \sim N(\mu, \Sigma)$ , where  $\mu = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$ ,

and  $\Sigma = \begin{pmatrix} V_1 & V_c \\ V_c & V_2 \end{pmatrix}$ , which is symmetric and positive-definite.

<sup>43</sup> Similar to the assumptions in Albaek (1990).

<sup>44</sup> We define correlation coefficient  $\rho = \frac{V_c}{\sqrt{V_1}\sqrt{V_2}}$ .

(v)  $v \in R, v^* \in R^*$ .

## 2. The Solution to the Second Cost Structure with Uncertainty

Based on the assumptions of the second cost structure, we solve for the optimal outputs, investment levels for the firms and the optimal government subsidy for each investment timing combination using backward induction, as well as the maximized expected profits for both firms and the maximized expected welfare for the home country.

### 2.1 Optimal Output Decisions

In stage 4, the information of costs and demand are the same as for the full information structure in previous Chapter, so firms have same solution in this stage:

$$\text{Max} \left\{ \pi = (a - x - y + u + s)x - (c_0 - k + v)x - \frac{k^2}{2\eta} \right\} \quad (2a)$$

$$\text{Max} \left\{ \pi^* = (a - x - y + u)y - (c_0^* - k^* + v^*)y - \frac{k^{*2}}{2\eta} \right\} \quad (2b)$$

Then, the optimal outputs for the home and the foreign firm can be expressed as:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \frac{1}{3} \begin{pmatrix} 2A - A^* + 2s + 2k - k^* + u - 2v + v^* \\ 2A^* - A - s + 2k^* - k + u - 2v^* + v \end{pmatrix} \quad (3)$$

Here,  $A \equiv a - c_0$ ,  $A^* \equiv a - c_0^*$ . Also, the actual profit functions for both firms can be expressed as:

$$\pi = x^2 - \frac{k^2}{2\eta} \quad (4a)$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} \quad (4b)$$

## 2.2 Optimal Investment Level Decisions

The next step for the firms is to decide the optimal capital levels (either in period two or stage three) given their decision on the investment timing combination in stage two. What is important and different in this cost structure is the private information: each firm observes the realization of its own cost uncertainty in stage three, which is unknown to the other firm. However, conditional on the realization of its own cost uncertainty, each firm can update its information on the distribution of the cost uncertainty for the other firm since  $v$  and  $v^*$  are assumed to be correlated and jointly normally distributed.

---

### A. Delay, Delay Case

If both firms delay their investments into the second period, the FOCs for choosing the investment levels are the same as in the previous chapter, when there is complete information about costs:

$$x - \frac{k}{\eta} = 0 \tag{5a}$$

$$y - \frac{k^*}{\eta} = 0 \tag{5b}$$

The optimal choices for  $x$ ,  $y$ ,  $k$  and  $k^*$  in terms of  $(s, u, v, v^*)$  are the same as in Table 1 for the case of delay-delay.

Table 1

Optimal output and investment choices in delay, delay case under both demand & cost uncertainties with private information

$D, D^*$	
$x$	$x^{dd*} = \frac{v^* + (1-\eta)u + (2-\eta)(s + A - v) - A^*}{(1-\eta)(3-\eta)}$
$y$	$y^{dd*} = \frac{v + (1-\eta)u + (2-\eta)(A^* - v^*) - s - A}{(1-\eta)(3-\eta)}$
$k$	$k^{dd*} = \frac{\eta}{(1-\eta)(3-\eta)} [v^* + (1-\eta)u + (2-\eta)(s + A - v) - A^*]$
$k^*$	$k^{*dd*} = \frac{\eta}{(1-\eta)(3-\eta)} [v + (1-\eta)u + (2-\eta)(A^* - v^*) - s - A]$

Also, the actual profit functions for both firms are:

$$\pi = x^2 - \frac{k^2}{2\eta} = \left(1 - \frac{\eta}{2}\right) x^{dd*2} \quad (6a)$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} = \left(1 - \frac{\eta}{2}\right) y^{dd*2} \quad (6b)$$

### B. Commitment, Delay Case

Suppose, in stage two, the home firm commits itself to invest, while the

foreign firm decides to defer its investment into the second period (4<sup>th</sup> stage). In period 2, the optimal choices for  $x$ ,  $y$  and  $k^*$  are the same as the first cost structure, and are found by solving equations (5b) and (3) simultaneously:

$$\begin{pmatrix} x^{cd*} \\ y^{cd*} \\ k^{cd*} \end{pmatrix} = \frac{1}{3-2\eta} \begin{pmatrix} v^* + (1-\eta)u + (2-\eta)(A+s+k-v) - A^* \\ 2A^* - A - s - k + u - 2v^* + v \\ \eta[2A^* - A - s - k + u - 2v^* + v] \end{pmatrix} \quad (7)$$

In (7), the values of  $x$ ,  $y$  and  $k^*$  depend on  $s$ ,  $k$ ,  $u$ ,  $v$  and  $v^*$ . In stage 3, the firms will know the rules given by (7) and each firm will know its own cost realization. Given this information, and its updated beliefs about the costs of firm 2, firm 1 has to decide its optimal investment level  $k^{cd*}$  by maximizing its expected profit<sup>45</sup> in the second period:

$$\begin{aligned} & \text{Max}_k \{E(\pi|v)\} \\ & \Leftrightarrow E \left\{ \text{Max}_k \left\{ \pi = (a-x-y+u+s)x - (c_0 - k + v)x - \frac{k^2}{2\eta} \right\} \middle| v \right\} \\ & \Leftrightarrow E \left\{ \pi_k + \pi_x x_k^{cd*} + \pi_y y_k^{cd*} \middle| v \right\} = 0 \\ & \Leftrightarrow E \left\{ \left( x - \frac{k}{\eta} \right) + (-x) \times \frac{-1}{3-2\eta} \middle| v \right\} = 0 \end{aligned}$$

(From F.O.C.,  $\pi_x = 0$ )

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<sup>45</sup> It is a conditional expectation of the profit because of the private information in stage three in this cost structure.



$$\Leftrightarrow k^{cd*} = \frac{2(2-\eta)}{3-2\eta} \eta E(x^{cd*} | v) \quad (8)$$

From the result we got in (7),  $E(x^{cd*} | v)$  can be calculated as:

$$\begin{aligned} E(x^{cd*} | v) &= \frac{1}{3-2\eta} E \left\{ v^* + (1-\eta)u + (2-\eta)(A+s+k-v) - A^* \mid v \right\} \\ &= \frac{1}{3-2\eta} [E(v^* | v) + (1-\eta)E(u | v) - (2-\eta)E(v | v) + (2-\eta)(A+s+k) - A^*] \\ &= \frac{1}{3-2\eta} \left[ \frac{V_c}{V_1} v - (2-\eta)v + (2-\eta)(A+s+k) - A^* \right] \quad (\text{cov}(u, v) = 0) \\ &= \left( \frac{V_c}{V_1} - 2 + \eta \right) \frac{v}{3-2\eta} + \frac{2-\eta}{3-2\eta} (A+s+k^{cd*}) - \frac{A^*}{3-2\eta} \quad (9)^{46} \end{aligned}$$

Finally, we can solve for  $k^{cd*}$  using equation (8) and (9):

$$\begin{aligned} k^{cd*} &= \frac{2(2-\eta)}{3-2\eta} \eta E(x^{cd*} | v) = \frac{2\eta(2-\eta)}{3-2\eta} \left[ \left( \frac{V_c}{V_1} - 2 + \eta \right) \frac{v}{3-2\eta} + \frac{2-\eta}{3-2\eta} (A+s+k^{cd*}) - \frac{A^*}{3-2\eta} \right] \\ \Leftrightarrow k^{cd*} &= \frac{2\eta(2-\eta) \left[ \left( \frac{V_c}{V_1} - 2 + \eta \right) v + (2-\eta)(A+s) - A^* \right]}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \quad (10) \end{aligned}$$

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<sup>46</sup> According to the assumptions,  $v$  and  $v^*$  are jointly normally distributed:  $\begin{pmatrix} v \\ v^* \end{pmatrix} : N \left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} V_1 & V_c \\ V_c & V_2 \end{pmatrix} \right)$ ,

therefore, the conditional distribution of  $v^*$  given  $v$  should be:  $v^* | v : N \left( \mu_{v^*} + \frac{\sigma_{v^*}}{\sigma_v} \rho (v - \mu_v), (1 - \rho^2) \sigma_{v^*}^2 \right)$ ,

which can be expressed as:  $v^* | v : N \left( \frac{V_c}{V_1} v, V_2 - \frac{V_c^2}{V_1} \right)$ .

Then, the optimal choices ( $x^{cd*}$ ,  $y^{cd*}$  and  $k^{*cd*}$ ) can be decided in terms of  $s$ ,  $u$ ,  $v$ ,  $v^*$  as well as variance variables ( $V_1$  and  $V_c$ ) when  $k^{cd*}$  is plugged in. (see Table 2)

Table 2

Optimal output and investment choices in commitment, delay case under both demand & cost uncertainties with private information

	$C, D^*$
$x$	$x^{cd*} = \frac{1}{3-2\eta} [v^* + (1-\eta)u - \frac{(2-\eta)[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_1}]v}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{(2-\eta)(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2}]$
$y$	$y^{cd*} = \frac{1}{3-2\eta} [u - 2v^* + \frac{[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_1}]v}{(3-2\eta)^2 - 2\eta(2-\eta)^2} - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + 2(1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2})A^*]$
$k$	$k^{cd*} = \frac{2\eta(2-\eta)[(\frac{V_c}{V_1} - 2 + \eta)v + (2-\eta)(A+s) - A^*]}{(3-2\eta)^2 - 2\eta(2-\eta)^2}$
$k^*$	$k^{*cd*} = \frac{\eta}{3-2\eta} [u - 2v^* + \frac{[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_1}]v}{(3-2\eta)^2 - 2\eta(2-\eta)^2} - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + 2(1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2})A^*]$

Compared with the situation where only public information is available, the home firm's capital decision also depends on its own cost realization when private cost information is also available. If the cost covariance is small (and positive) or negative relative to the home firm's cost variance, a larger cost

realization to the home firm leads to a smaller capital investment by itself. Intuitively, higher cost results in less willingness to invest. Otherwise, if the cost covariance is high enough<sup>47</sup>, higher cost realization increases home firm's optimal capital investment. In all, the private cost information (including both variance and covariance) greatly affects firms' optimal decisions on the level of the investment.

In this case, the actual profit functions for both firms are:

$$\begin{aligned}\pi &= x^2 - \frac{k^2}{2\eta} = x^2 - \left(\frac{1}{2\eta}\right) \left(\frac{2(2-\eta)}{3-2\eta} \eta E(x^{cd*} | v)\right)^2 \\ &= x^{cd*2} - 2\eta \left(\frac{2-\eta}{3-2\eta}\right)^2 \left(E(x^{cd*} | v)\right)^2\end{aligned}\quad (11a)^{48}$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} = \left(1 - \frac{\eta}{2}\right) y^{cd*2} \quad (11b)$$

### C. Delay, Commitment Case

When the home firm delays investment to the second period, and the foreign firm commits investment in the first period, the optimal choices ( $x^{dc*}$ ,  $y^{dc*}$ ,  $k^{dc*}$  and  $k^{*dc*}$ ) can be decided in terms of  $s$ ,  $u$ ,  $v$  and  $v^*$  as well as variance

<sup>47</sup> So that  $\left(\frac{V_c}{V_1} - 2 + \eta\right)$  is positive.

<sup>48</sup> The difference between home firm's actual and expected output is:  

$$x^{cd*} - E(x^{cd*} | v) = \frac{1}{3-2\eta} \left\{ v^* + (1-\eta)u - E\{v^* + (1-\eta)u | v\} \right\} = \frac{1}{3-2\eta} \left[ v^* - \frac{V_c}{V_1} v + (1-\eta)u \right].$$

variables ( $V_2$  and  $V_c$ ) by following a similar procedure as for the Commitment, Delay Case<sup>49</sup>. (See Table 3)

Table 3

Optimal output and investment choices in delay, commitment case under both demand & cost uncertainties with private information

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$D, C^*$
$x$
$x^{dc^*} = \frac{1}{3-2\eta} \left[ u - 2v + 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) (A+s) - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{[(3-2\eta)^2 - 2\eta(2-\eta)] \frac{V_c}{V_2} v^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$y$
$y^{dc^*} = \frac{1}{3-2\eta} \left[ v + (1-\eta)u - \frac{(2-\eta)[(3-2\eta)^2 - 2\eta(2-\eta)] \frac{V_c}{V_2} v^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} - \frac{(3-2\eta)^2 (A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{(2-\eta)(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$k$
$k^{dc^*} = \frac{\eta}{3-2\eta} \left[ u - 2v + 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) (A+s) - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{[(3-2\eta)^2 - 2\eta(2-\eta)] \frac{V_c}{V_2} v^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$k^*$
$k^{*dc^*} = \frac{2\eta(2-\eta) \left[ \left( \frac{V_c}{V_2} - 2 + \eta \right) v^* + (2-\eta)A^* - A - s \right]}{(3-2\eta)^2 - 2\eta(2-\eta)^2}$

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In this case, the actual profit functions for both firms are:

$$\pi = x^2 - \frac{k^2}{2\eta} = \left( 1 - \frac{\eta}{2} \right) x^{dc^* 2} \quad (12)$$

<sup>49</sup> See Appendix 1.

$$\begin{aligned}
\pi^* &= y^2 - \frac{k^{*2}}{2\eta} = y^2 - \left(\frac{1}{2\eta}\right) \left(\frac{2(2-\eta)}{3-2\eta} \eta E(y^{dc^*} | v^*)\right)^2 \\
&= y^{dc^*2} - 2\eta \left(\frac{2-\eta}{3-2\eta}\right)^2 \left(E(y^{dc^*} | v^*)\right)^2
\end{aligned} \tag{12b}$$

#### D. Commitment, Commitment Case

If both firms commit to invest in the second stage, they both have to choose their optimal outputs in the second period given the investment level they chose in stage three by maximizing their second period profits. (See equation (3))

Going back to stage 3, firms have to simultaneously decide optimal investment level  $(k^{cc^*}, k^{*cc^*})$ , given the rules governing second period outputs (equation 3) and their beliefs about the cost structure and investment level of the other firm. What is important here is that each firm only knows its own cost realization, which can be used to update their information on the distribution of the cost uncertainty and investment level for the other firm.

$$\begin{aligned}
& \text{Max}_k \{E(\pi|v)\} \\
& \Leftrightarrow E \left\{ \text{Max}_k \left\{ \pi = (a - x - y + u + s)x - (c_0 - k + v)x - \frac{k^2}{2\eta} \right\} \middle| v \right\} \\
& \Leftrightarrow E \left\{ \pi_k + \pi_x x_k^{cc^*} + \pi_y y_k^{cc^*} \middle| v \right\} = 0 \\
& \Leftrightarrow E \left\{ \left( x - \frac{k}{\eta} \right) + (-x) \times \left( -\frac{1}{3} \right) \middle| v \right\} = 0
\end{aligned}$$

(From F.O.C.,  $\pi_x = 0$ )

$$\Leftrightarrow k^{cc*} = \frac{4}{3}\eta E(x^{cc*} | v) \quad (13)$$

$$\text{Max}_{k^*} \{ E\pi^* | v^* \}$$

$$\Leftrightarrow E \left\{ \text{Max}_{k^*} \left\{ \pi^* = (a - x - y + u)y - (c_0^* - k^* + v^*)y - \frac{k^{*2}}{2\eta} \right\} | v^* \right\}$$

$$\Leftrightarrow E \left\{ \pi_{k^*}^* + \pi_x^* x_{k^*}^{cc*} + \pi_y^* y_{k^*}^{cc*} | v^* \right\} = 0$$

$$\Leftrightarrow E \left\{ \left( y - \frac{k^*}{\eta} \right) + (-y) \times \left( -\frac{1}{3} \right) \right\} = 0$$

(From F.O.C.,  $\pi_y^* = 0$ )

$$\Leftrightarrow k^{*cc*} = \frac{4}{3}\eta E(y^{cc*} | v^*) \quad (14)$$

Because for the home firm,  $v^*$  is not known when  $k$  is chosen, the optimal capital investment must be of form  $k = \alpha + \beta v$ , in a similar way, the optimal investment for the foreign firm should be of form  $k^* = \alpha^* + \beta^* v^*$ . Then, from (3) and the form we assumed for  $k$ :

$$E(x^{cc*} | v) = \frac{1}{3} E(2A - A^* + 2s + 2k - k^* + u - 2v + v^* | v)$$

$$\begin{aligned}
&= \frac{1}{3}[2A - A^* + 2s + 2k - E(\alpha^* + \beta^* v^* | v) + E(u|v) - 2E(v|v) + E(v^*|v)] \\
&= \frac{1}{3} \left\{ 2A - A^* + 2s + 2k - \alpha^* + \left[ \frac{(1-\beta^*)V_c}{V_1} - 2 \right] v^* \right\} \tag{15}
\end{aligned}$$

$$\begin{aligned}
E(y^{cc^*} | v^*) &= \frac{1}{3} E(2A^* - A - s + 2k^* - k + u - 2v^* + v | v^*) \\
&= \frac{1}{3} [2A^* - A - s + 2k^* - E(\alpha + \beta v | v^*) + E(u|v^*) - 2E(v^* | v^*) + E(v|v^*)] \\
&= \frac{1}{3} \left\{ 2A^* - A - s + 2k^* - \alpha + \left[ \frac{(1-\beta)V_c}{V_2} - 2 \right] v^* \right\} \tag{16}
\end{aligned}$$

Substitute (15) and (16) into (13) and (14), then solve them simultaneously together with the assumptions  $k = \alpha + \beta v$  and  $k^* = \alpha^* + \beta^* v^*$  to get the solution for  $k$  and  $k^*$ . Then,  $x^{cc^*}$  and  $y^{cc^*}$  will be solved automatically by equation (3) when we plug in  $k^{cc^*}$  and  $k^{*cc^*}$ . (See Table 4)

Table 4

Optimal output and investment choices in commitment, commitment case under both demand & cost uncertainties with private information

	$C, C^*$
$x$	$x^{cc^*} = \frac{6(3-2\eta)(A+s)-9A^*}{(3-4\eta)(9-4\eta)} + \frac{u}{3} + \frac{6[4\eta\rho\delta^{-1}-(9-8\eta)]v-3[4\eta\rho\delta-(9-8\eta)]v^*}{(9-8\eta)^2-16\eta^2\rho^2}$
$y$	$y^{cc^*} = \frac{6(3-2\eta)A^*-9(A+s)}{(3-4\eta)(9-4\eta)} + \frac{u}{3} + \frac{6[4\eta\rho\delta-(9-8\eta)]v^*-3[4\eta\rho\delta^{-1}-(9-8\eta)]v}{(9-8\eta)^2-16\eta^2\rho^2}$
$k$	$k^{cc^*} = \frac{4\eta[2(3-2\eta)(A+s)-3A^*]}{(3-4\eta)(9-4\eta)} + \frac{4\eta[9\rho\delta^{-1}-4\eta\rho^2-2(9-8\eta)]}{(9-8\eta)^2-16\eta^2\rho^2}v$
$k^*$	$k^{*cc^*} = \frac{4\eta[2(3-2\eta)A^*-3(A+s)]}{(3-4\eta)(9-4\eta)} + \frac{4\eta[9\rho\delta-4\eta\rho^2-2(9-8\eta)]}{(9-8\eta)^2-16\eta^2\rho^2}v^*$

With  $\rho \equiv \frac{V_c}{\sqrt{V_1}\sqrt{V_2}}$  and  $\delta \equiv \sqrt{\frac{V_1}{V_2}}$ .

In this case, the actual profit functions for both firms are:

$$\pi = x^2 - \frac{k^2}{2\eta} = x^2 - \left(\frac{1}{2\eta}\right) \left(\frac{4\eta}{3} E(x^{cc^*} | v)\right)^2 = x^{cc^*2} - \frac{8\eta}{9} \left(E(x^{cc^*} | v)\right)^2 \quad (17a)$$

$$\pi^* = y^2 - \frac{k^{*2}}{2\eta} = y^2 - \left(\frac{1}{2\eta}\right) \left(\frac{4\eta}{3} E(y^{cc^*} | v^*)\right)^2 = y^{cc^*2} - \frac{8\eta}{9} \left(E(y^{cc^*} | v^*)\right)^2 \quad (17b)$$



### 2.3 Optimal Expected Profits

In stage two, knowing only the distributional aspects of the cost uncertainties, the firms will decide simultaneously on the optimal investment timing which yields the highest expected profit, given their beliefs about the behavior of the other firm. So we take the unconditional expectations of the profits for both firms using the optimal choices above for each investment timing combination.

In Commitment, Commitment Case, the expected profit for the home firm is:

$$\begin{aligned}
 E\pi^{cc^*} &= E \left\{ (x^{cc^*})^2 - \frac{(k^{cc^*})^2}{2\eta} \right\} \\
 &= \text{var } x^{cc^*} + (Ex^{cc^*})^2 - \frac{1}{2\eta} [\text{var } k^{cc^*} + (Ek^{cc^*})^2]
 \end{aligned} \tag{18}^{50}$$

From Table 4 we can see:

$$Ex^{cc^*} = \frac{6(3-2\eta)(A+s) - 9A^*}{(3-4\eta)(9-4\eta)} \tag{19}^{51}$$

$$\text{Var}x^{cc^*} = \frac{\sigma^2}{9} + \frac{36V_1V_2^2[4\eta V_c - (9-8\eta)V_1]^2 + 9V_1^2V_2[4\eta V_c - (9-8\eta)V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2}$$

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<sup>50</sup> Refer to (4a).

<sup>51</sup> According to the assumptions, the unconditional mean of all the random variables are zero.

$$-\frac{36V_1V_2V_c[4\eta V_c - (9-8\eta)V_1][4\eta V_c - (9-8\eta)V_2]}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2} \quad (20)$$

$$Ek^{cc^*} = \frac{4\eta[2(3-2\eta)(A+s) - 3A^*]}{(3-4\eta)(9-4\eta)} \quad (21)$$

$$Vark^{cc^*} = \frac{16\eta^2V_1[9V_2V_c - 4\eta V_c^2 - 2(9-8\eta)V_1V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2} \quad (22)$$

So, the expected profit can be calculated from the five equations above:

$$\begin{aligned} E\pi^{cc^*} &= (9-8\eta) \left[ \frac{2(3-2\eta)(A+s) - 3A^*}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2}{9} \\ &+ \frac{36V_1V_2^2[4\eta V_c - (9-8\eta)V_1]^2 + 9V_1^2V_2[4\eta V_c - (9-8\eta)V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2} \\ &- \frac{36V_1V_2V_c[4\eta V_c - (9-8\eta)V_1][4\eta V_c - (9-8\eta)V_2] + 8\eta V_1[9V_2V_c - 4\eta V_c^2 - 2(9-8\eta)V_1V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2} \end{aligned}$$

(23)

Similarly, the expected profit for the foreign firm is derived as:

$$E\pi^{*cc^*} = E \left\{ (y^{cc^*})^2 - \frac{(k^{*cc^*})^2}{2\eta} \right\} = \text{var } y^{cc^*} + (Ey^{cc^*})^2 - \frac{1}{2\eta} [\text{var } k^{*cc^*} + (Ek^{*cc^*})^2]$$

$$\begin{aligned}
&= (9-8\eta) \left[ \frac{2(3-2\eta)A^* - 3(A+s)}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2}{9} \\
&+ \frac{36V_1^2V_2[4\eta V_c - (9-8\eta)V_2]^2 + 9V_1V_2^2[4\eta V_c - (9-8\eta)V_1]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2} \\
&- \frac{36V_1V_2V_c[4\eta V_c - (9-8\eta)V_2][4\eta V_c - (9-8\eta)V_1] + 8\eta V_2[9V_1V_c - 4\eta V_c^2 - 2(9-8\eta)V_1V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2}
\end{aligned}$$

(24)

Table 5 gives the maximized expected profits for all different investment timing combinations under demand and cost uncertainties with private information and correlation among cost shocks.

Table 5

Maximized expected profits for the different investment timing combinations under demand & cost uncertainties with private information and correlation among cost shocks

	$E\pi$
$C, C^*$	$(9-8\eta) \left[ \frac{2(3-2\eta)(A+s)-3A^*}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2}{9}$ $+ \frac{36V_1V_2^2[4\eta V_c - (9-8\eta)V_1]^2 + 9V_1^2V_2[4\eta V_c - (9-8\eta)V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2}$ $- \frac{36V_1V_2V_c[4\eta V_c - (9-8\eta)V_1][4\eta V_c - (9-8\eta)V_2] + 8\eta V_1[9V_2V_c - 4\eta V_c^2 - 2(9-8\eta)V_1V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2}$
$C, D^*$	$\frac{[(2-\eta)(A+s)-A^*]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{1}{(3-2\eta)^2} [(1-\eta)^2\sigma^2 + V_2]$ $+ \frac{(2-\eta)^2 \left\{ [(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_1}]^2 - 2\eta(3-2\eta)^2 \left( \frac{V_c}{V_1} - 2 + \eta \right)^2 \right\} V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2}$ $- \frac{2(2-\eta)[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_1}]V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2}$
$D, C^*$	$\frac{1-\eta}{(3-2\eta)^2} \left[ 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) (A+s) - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2$ $+ \frac{1-\eta}{(3-2\eta)^2} \left[ \sigma^2 + 4V_1 + \frac{[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_2}]^2 V_2}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} - \frac{4[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_2}]V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$D, D^*$	$\frac{(1-\eta)}{(1-\eta)^2(3-\eta)^2} \left\{ (1-\eta)^2\sigma^2 + (2-\eta)^2V_1 + V_2 - 2(2-\eta)V_c + [(2-\eta)(A+s)-A^*]^2 \right\}$

Table 5 (cont'd)

	$E\pi^*$
$C, C^*$	$(9-8\eta) \left[ \frac{2(3-2\eta)A^* - 3(A+s)}{(3-4\eta)(9-4\eta)} \right]^2 + \frac{\sigma^2}{9}$ $+ \frac{36V_1^2V_2[4\eta V_c - (9-8\eta)V_2]^2 + 9V_1V_2^2[4\eta V_c - (9-8\eta)V_1]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2}$ $- \frac{36V_1V_2V_c[4\eta V_c - (9-8\eta)V_2][4\eta V_c - (9-8\eta)V_1] + 8\eta V_2[9V_1V_c - 4\eta V_c^2 - 2(9-8\eta)V_1V_2]^2}{[(9-8\eta)^2V_1V_2 - 16\eta^2V_c^2]^2}$
$C, D^*$	$\frac{1-\frac{\eta}{2}}{(3-2\eta)^2} \left[ 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) A^* - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2$ $+ \frac{1-\frac{\eta}{2}}{(3-2\eta)^2} \left[ \sigma^2 + 4V_2 + \frac{[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_1}]^2 V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} - \frac{4[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_1}]V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$
$D, C^*$	$\frac{[(2-\eta)A^* - (A+s)]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{1}{(3-2\eta)^2} [(1-\eta)^2\sigma^2 + V_1$ $+ \frac{(2-\eta)^2 \left\{ [(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_2}]^2 - 2\eta(3-2\eta)^2 \left( \frac{V_c}{V_2} - 2 + \eta \right)^2 \right\} V_2}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2}$ $- \frac{2(2-\eta)[(3-2\eta)^2 - 2\eta(2-\eta)\frac{V_c}{V_2}]V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2}]$
$D, D^*$	$\frac{(1-\frac{\eta}{2})}{(1-\eta)^2(3-\eta)^2} \left\{ (1-\eta)^2\sigma^2 + V_1 + (2-\eta)^2V_2 - 2(2-\eta)V_c + [(2-\eta)A^* - (A+s)]^2 \right\}$

Compared with the situation in which the cost uncertainties are uncorrelated and only public information is available, under the assumption of private information and cost correlation the comparison of the maximized expected profits for both firms is more complicated because the profits are also affected by the correlation among the cost shocks.

In the first stage, for each given investment timing combination, a rent-shifting subsidy (set by the home government) is decided by maximizing the expected welfare of the home country:

$$\text{Max}\{EW\} = \text{Max}\{E\pi - sEx\}$$

The optimal rent-shifting subsidies for all possible investment timing combinations are the same as the first cost structure (See Table 9 in Chapter Two). Although the corresponding rent-shifting subsidy is the best choice for each investment timing combination, it is not always the best choice for the government since the home country may gain more by changing the subsidy so that the equilibrium investment timing combination is changed.

### **3. Optimal Trade Policy Analysis**

The optimal trade policy study in private information setting is similar to that in the scenario where only public information exists, that is, we explore the

equilibrium strategy for the government (and the optimal timing choices for the firms) by focusing on changing the variance (or covariance) of one uncertainty (or two uncertainties) at a time while fixing all the other variances (or covariance) at a certain level. Then, we compare different results and analyze the changes when the other variances (or covariance) are given different values. However, what is different in analyzing the optimal trade policy in this cost structure is that the covariance (or correlation) of the cost shocks are allowed to change, and the relationship of the correlation and the subsidy will be studied separately.<sup>52</sup>

Similar diagrams will be drawn as in Chapter One and the specification of the parameters is unchanged<sup>53</sup>. The figure of optimal subsidization and single variances is depicted in  $(\sigma^2, s)$ ,  $(V_1, s)$  and  $(V_2, s)$ , besides, the figure of optimal subsidy and the correlation of the cost shocks of the two firms is depicted in  $(\rho, s)$ <sup>54</sup>. The figure of corresponding optimal investment timing choice by both firms is depicted in  $(\sigma^2, t)$ ,  $(V_1, t)$ ,  $(V_2, t)$  and  $(\rho, t)$  where 1 represents “Commitment, Commitment” (both home firm and foreign firm Commit their investments); 2 represents “Delay, Commitment” (home firm delays and foreign firm commits); 3 represents “Commitment, Delay” (home firm commits and foreign firm delays) and 4 represents “Delay, Delay” (both home firm and foreign

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<sup>52</sup> Here, not only the variances of the uncertainties but also the covariance of the cost shocks and the choice of optimal subsidy will affect the equilibrium investment timing decisions of the firms.

<sup>53</sup> We are still going to use  $A = A^* = 1$  and  $\eta = 0.03$  in this simulation study on optimal trade policy.

<sup>54</sup> The reason we use correlation instead of covariance is that the correlation is a normalized coefficient, which completely characterizes the dependence structure in a multivariate normal distribution (that we use), although generally the information given by a correlation coefficient is not enough to define the dependence structure between random variables.

firm delay).

### 3.1 Optimal Subsidy and the Demand Variance

The optimal subsidy and the demand variance will be studied in the following sequence: Case one:  $V_1 = V_2$ . First, we suppose there is no correlation of the cost shocks ( $\rho = 0$ ). We then increase the level of the common cost variance to see the changing pattern of the optimal subsidy as the variance of the demand shock changes. Also, we compare the result in this information structure with that studied in the previous Chapter. Next, in each cost variance level, we increase the correlation between the cost uncertainties (positively and negatively) to see the change it made to both the optimal subsidy and firm's investment timing choices. In addition, cost asymmetry will also be studied in this case. Case two:  $V_1 \neq V_2$ . We first study the impact of the differences in cost variability under the assumption that cost shocks are not correlated ( $\rho = 0$ ), where both situations of  $V_1 > V_2$  and  $V_1 < V_2$  will be studied. The result will also be compared with the first cost structure. Second, the correlation is raised in each case where variance levels are different, and then the change will be explored before and after the correlation rises.

#### A. Case One: $V_1 = V_2$

First, assuming the variances of firms' cost shocks are equal and the



correlation between the two cost shocks is zero; we then increase the level of the cost variances from  $10^{-3}$ ,  $10^{-2}$  to  $10^{-1}$ , to study the impact on the optimal subsidy and firms' behaviors, These results are shown in fig. 1. As the level of the cost variances increases, both firms are more willing to delay, as is seen from the graph: the subsidy line and the investment timing line are both shifting down with the increasing common cost variances. The results look similar to those in the previous information structure; however, compared with the previous Chapter, for each level of cost variances, the demand variance levels where the government enforces foreign and home firm delay rise, and it seems like the graphs in the first cost structure moves upwards against the horizontal axis. It means the firms are more willing to commit and it is harder for the home government to enforce both firms delay. With private information revealed in stage 3, firms know more information about the cost uncertainties<sup>55</sup>, less uncertainties leads to less willingness to delay.

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<sup>55</sup> Firms at least learn their own cost shocks if  $\rho = 0$  in stage 3, besides, firms can also update their information on their rival's cost shock if  $\rho \neq 0$  under our assumptions.

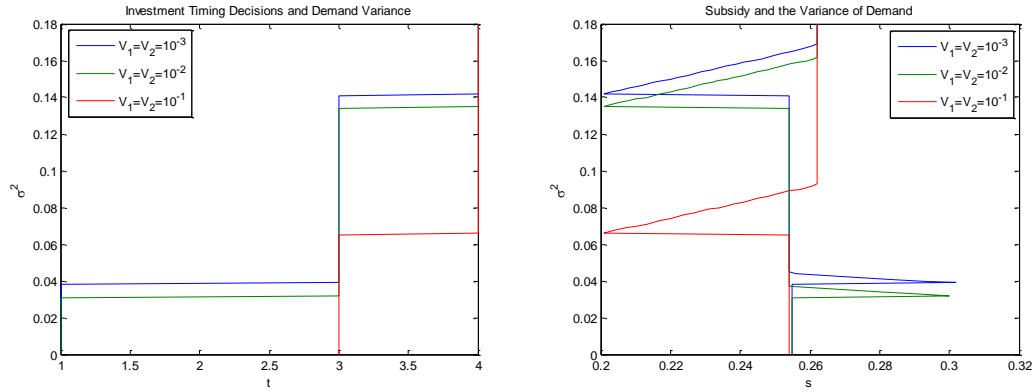
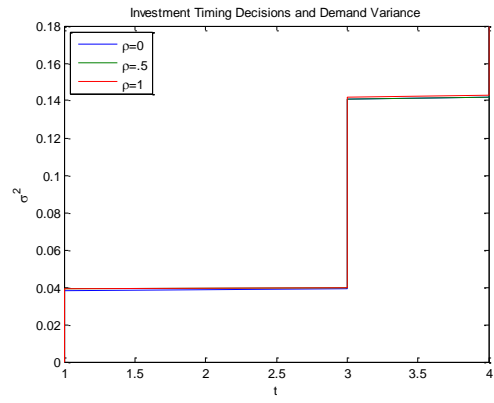
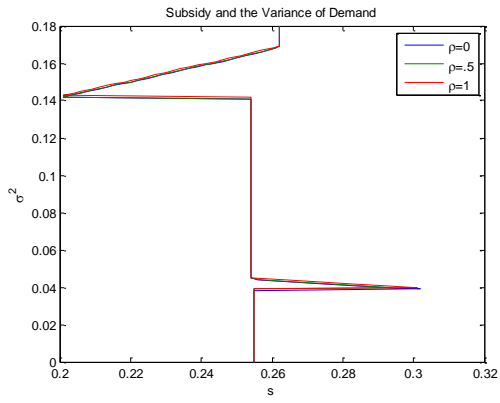


Fig. 1. Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $V_1$  and  $V_2$  increase from  $10^{-3}$ ,  $10^{-2}$  to  $10^{-1}$ . ( $\rho=0$ ;  $A=A^*=1$ ;  $\eta=0.03$ )

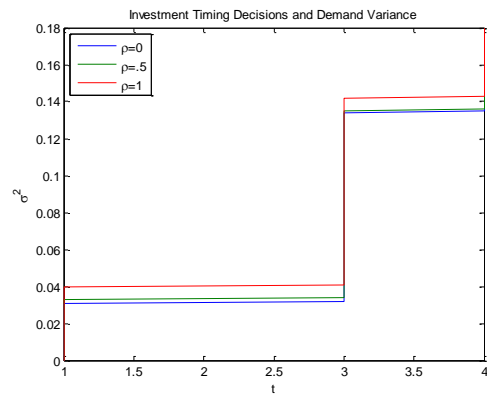
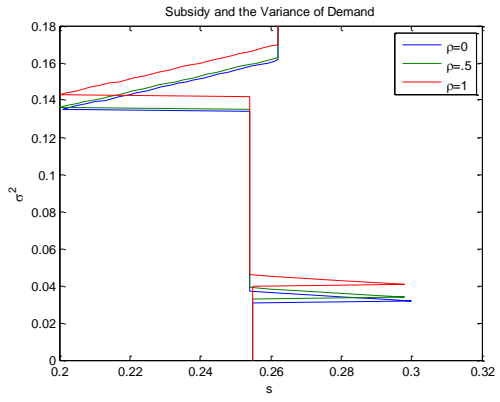
Next, in each cost variance level  $V_1=V_2=10^{-3}$ ,  $V_1=V_2=10^{-2}$  and  $V_1=V_2=10^{-1}$ , we increase the correlation between the cost uncertainties  $\rho$  positively from 0, 0.5 to 1<sup>56</sup>, the optimal subsidy and firms' investment timing choices are shown in figure 2.

<sup>56</sup> The conclusion will be the same if we increase  $\rho$  negatively from 0, -0.5 to -1. The only difference is that in negative case, there will be larger changes in optimal subsidy and firms' investment timing decisions than in the positive situation.

(a)



(b)



(c)

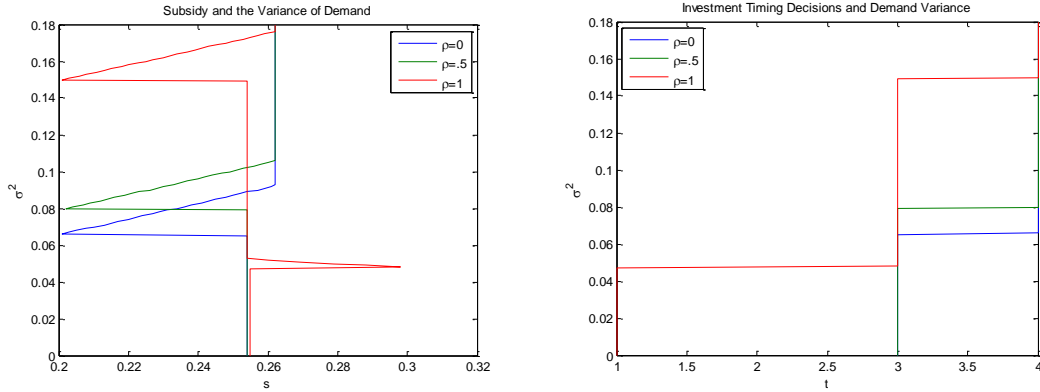


Fig. 2. (a) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = V_2 = 10^{-3}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ ) (b) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = V_2 = 10^{-2}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ ) (c) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = V_2 = 10^{-1}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

It can be seen from the graph above that at each cost variance level, the increase of the correlation between the cost shocks makes firms more willing to commit their investments.<sup>57</sup> For instance, in figure 2 (c), when  $\rho = 0$ , as  $\sigma^2$  increases from zero, the government starts to use  $s^{cd^*}$  and the firms choose “Commitment, Delay” in equilibrium. When  $\sigma^2$  approaches to 0.07, the government suddenly decreases its subsidy to a lower level which forces home

<sup>57</sup> The result can be seen more and more obviously from (a) to (c).

firm to delay. In the end, as  $\sigma^2$  continues to increase the government gradually increases its subsidy to  $s^{dd^*}$  and both firms delay their investments. When  $\rho$  increases by 0.5, the point where the government enforce home firm delay increases to 0.08, which means that the government is more willing to have home firm commit rather than delay. If the two cost shocks are fully correlated, equilibrium “Commitment, Commitment” emerges, where the foreign firm wants to commit in some range of demand variance; besides, the variance level where the government enforce home firm delay rise much further from the “no correlation” situation.

If there is cost asymmetry ( $A \neq A^*$  or  $c_0 \neq c_0^*$ ), and the home firm has a cost advantage ( $A > A^*$  or  $c_0 < c_0^*$ ), it is easier for the government to enforce foreign firm delay and harder for the government to enforce home firm delay. For instance, in the case where  $V_1 = V_2 = 10^{-2}$  ( $\rho = 0$ ), if we set  $A = 1.01$  and  $A^* = 0.99$ , the equilibrium subsidy and investment timing choices before and after the changes of  $A$  and  $A^*$  is shown in figure 3. Compared with the case where  $A = A^* = 1$ , the variance level where the government enforce the foreign firm delay drops and the point where it enforces home firm delay increases.

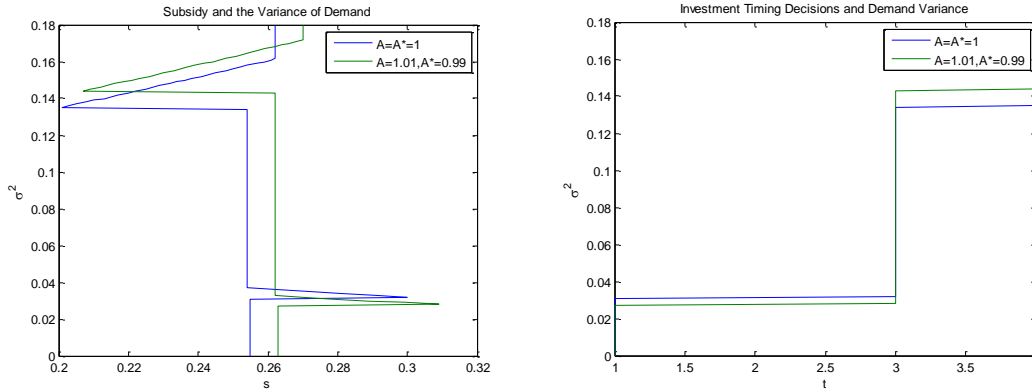


Fig. 3. Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $A = 1.01$  and  $A^* = 0.99$ . ( $V_1 = V_2 = 10^{-2}$ ;  $\rho = 0$ ;  $\eta = 0.03$ )

The result is opposite when the home firm has a cost disadvantage ( $A < A^*$  or  $c_0 > c_0^*$ ), it is harder for the government to enforce foreign firm delay and easier to enforce home firm delay. Again, if  $A = 1.01$  and  $A^* = 0.99$  ( $V_1 = V_2 = 10^{-2}$ ;  $\rho = 0$ ), the equilibrium subsidy and investment timing choices before and after the changes of  $A$  and  $A^*$  is shown in figure 4. Compared with the case where  $A = A^* = 1$ , the variance level where the government enforces the foreign firm delay rises and the point where it enforces home firm delay decreases.

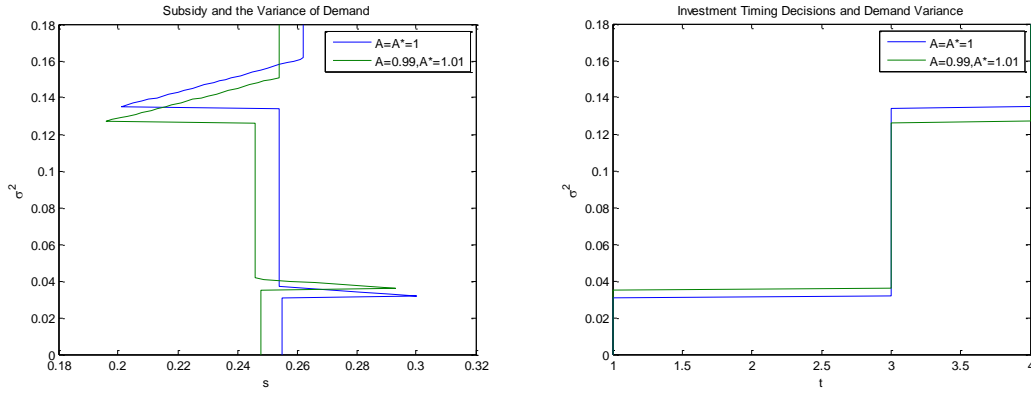


Fig. 4. Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $A = 0.99$  and  $A^* = 1.01$ . ( $V_1 = V_2 = 10^{-2}$  ;  $\rho = 0$  ;  $\eta = 0.03$ )

**B. Case Two:  $V_1 \neq V_2$**

Assuming the cost variances of the firms are different, first consider the case where the cost variance of the home firm is larger than that of the foreign firm ( $V_1 > V_2$ ). Assuming  $\rho = 0$ , we increase the difference of the cost variances of the two firms in steps ( $10^{-3}$ ,  $10^{-2}$  and  $10^{-1}$ ), and the results are shown in figure 5.

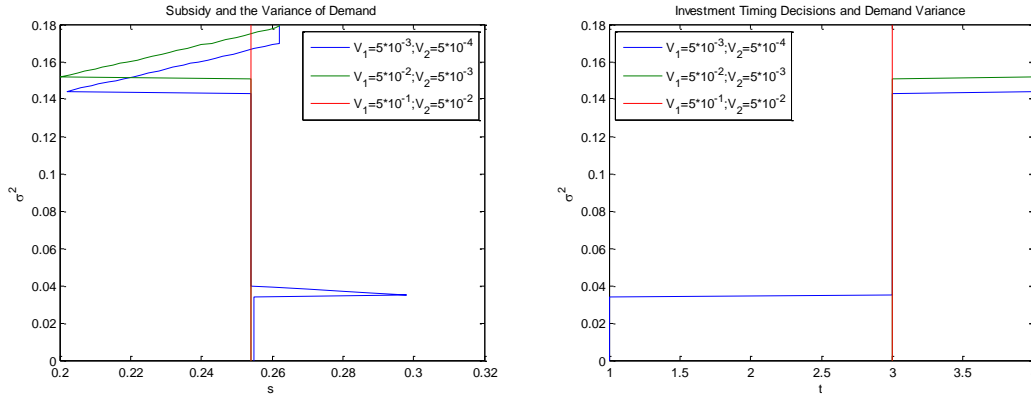


Fig. 5. Optimal subsidization and investment timing choice as  $\sigma^2$  changes in three cost variance levels:  $V_1 = 5 \times 10^{-3}$ ,  $V_2 = 5 \times 10^{-4}$ ;  $V_1 = 5 \times 10^{-2}$ ,  $V_2 = 5 \times 10^{-3}$  and  $V_1 = 5 \times 10^{-1}$ ,  $V_2 = 5 \times 10^{-2}$ . ( $\rho = 0$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

Compared with figure 1, in each cost variance level the increase of the difference of the firms' cost variances makes changes to the investment timing for both firms: the foreign firm starts to choose delay at a lower demand variance level and the home firm begins to delay at a higher variance level. It means that the government is more willing to enforce foreign firm delay and less willing to enforce home firm delay. This result is opposite to the first cost structure, which argues that it is easier for the government to enforce home firm flexibility if  $V_1 > V_2$  since the commitment has a lower value for the home firm than it has for the foreign firm. The reason for the difference is that in this cost structure, the cost shocks are revealed privately to each firm in stage 3, which provides (with each firm) information on its own cost shock and the updated (more accurate) distributional information on its rival's cost shock. This information helps firms



make better decisions on how much to invest than in the first cost structure, so there is information value to both firms in this cost structure. If  $V_1 > V_2$ , the information value to the home firm will be higher than to the foreign firm since home firm will benefit more from knowing its cost shock because of higher cost variance. Therefore, the home firm would be more willing to commit its investment so that it can get more information on the cost shocks of itself and the foreign firm.

Second, the result is opposite if the cost variance of the home firm is smaller than the foreign firm ( $V_1 < V_2$ )<sup>58</sup>, this can be seen in Fig. 6, which depicts the optimal subsidization and investment timing choice as  $\sigma^2$  changes when cost variance difference increases at three cost variance levels ( $10^{-3}$ ,  $10^{-2}$  and  $10^{-1}$ ) if  $V_1 < V_2$ . Compared to Fig. 1, the government will be more willing to enforce home firm delay and less willing to enforce foreign firm delay. What is more, we actually see a “delay deterrence”<sup>59</sup> by the home government in the case when  $V_1 = 5 \times 10^{-2}$ ,  $V_2 = 5 \times 10^{-1}$ . When the demand variance is less than about 0.13, the firms choose  $(D, C^*)$  and government uses rent-shifting subsidy  $s^{dc^*}$ . As demand variance continues to rise to the range above 0.13 and less than 0.14, it is optimal for the foreign firm to choose delay since the benefit of retaining flexibility for the future demand outweighs the benefit of making strategic

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<sup>58</sup> Here still suppose  $\rho = 0$ .

<sup>59</sup> It means that the government would like to enforce commitment (delay deterrence) to at least one firm in certain range of  $\sigma^2$ .

investment commitment. However, the home government would like the foreign firm to commit its investment for the welfare of the home country. The only way for the government to induce the foreign firm to maintain commitment is by setting a lower subsidy. However, the cost of deviating from the optimal rent-shifting subsidy for  $(D, C^*)$  goes up as demand variance increases. In the end, the government has to give up delay deterrence subsidy and chooses  $s^{dd^*}$ , and the equilibrium investment timing ends up to  $(D, D^*)$ .

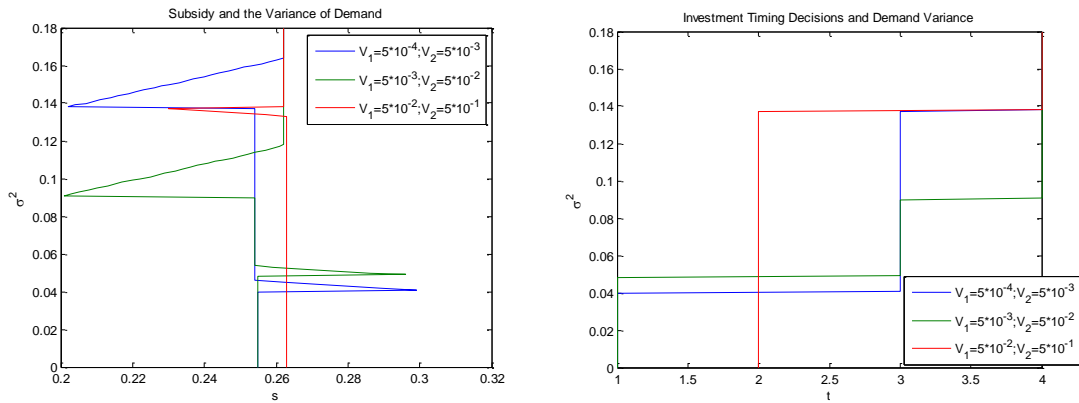


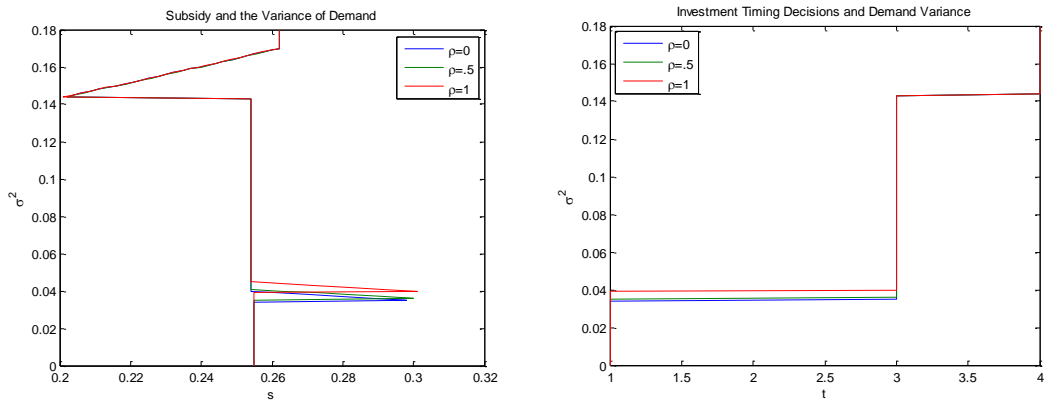
Fig. 6. Optimal subsidization and investment timing choice as  $\sigma^2$  changes when cost variance difference increases at three cost variance levels:  $V_1 = 5 \times 10^{-4}$ ,  $V_2 = 5 \times 10^{-3}$ ;  $V_1 = 5 \times 10^{-3}$ ,  $V_2 = 5 \times 10^{-2}$  and  $V_1 = 5 \times 10^{-2}$ ,  $V_2 = 5 \times 10^{-1}$ . ( $\rho = 0$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

Dewit and Leahy (2004) concludes that as uncertainty rises whenever the government wishes to manipulate investment timing, it always chooses its policy to deter investment commitment by the home or the foreign firm. However, after

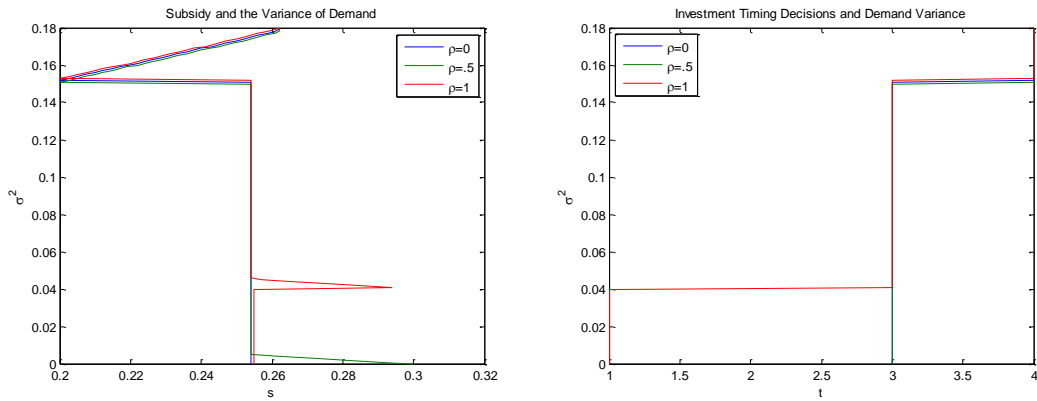
cost uncertainties and private information are added in, this conclusion is not always true. In this experiment we found that as demand uncertainty rises the government may choose its policy to induce investment commitment by the foreign firm when home firm's cost variance is smaller than foreign firm's cost variance.

Next, we allow the correlation coefficient  $\rho$  to be changed in addition to the change of the cost variance difference. Specifically, if  $V_1 > V_2$ , we increase  $\rho$  from 0 to 1 in each level of cost difference shown in figure 5, what we got is in figure 7.

(a)



(b)



(c)

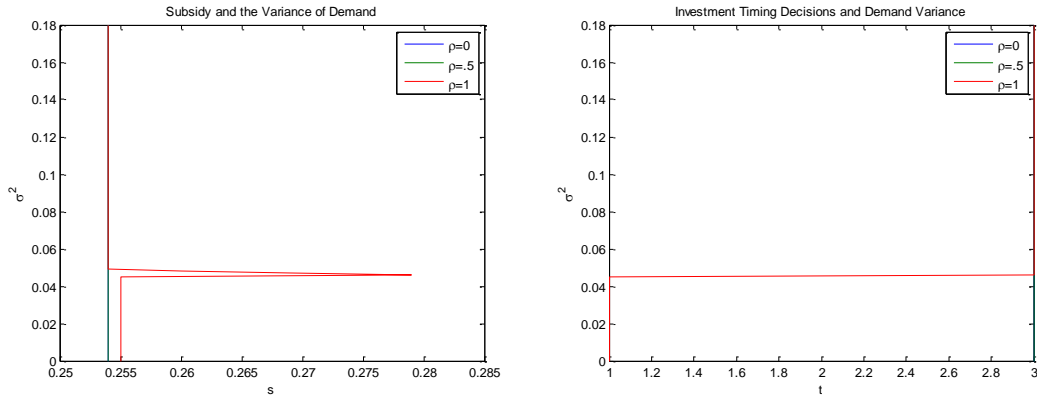


Fig. 7. (a) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = 5 \times 10^{-3}$ ,  $V_2 = 5 \times 10^{-4}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ ) (b) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = 5 \times 10^{-2}$ ,  $V_2 = 5 \times 10^{-3}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ ) (c) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = 5 \times 10^{-1}$ ,  $V_2 = 5 \times 10^{-2}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

From the graphs above, we can see that when  $V_1 > V_2$ , the foreign firm would like to commit more as the cost correlation increases, but there is little impact on the timing choice of the home firm. This can be seen easily from figure

7 (b) where as correlation increases the point where the foreign firm starts to delay rises from zero to 0.04, but there is almost no change on the variance level where the home firm starts to delay. Based on the assumptions we made previously, both the variances and covariance of the cost shocks are useful for the firm to infer its rival's cost information after the realization of its own cost shock. Specifically, for the home firm, the magnitude of the conditional mean of the foreign firm's cost is positively correlated with the covariance of the two cost shocks and negatively correlated to the home firm's own cost variance.<sup>60</sup> Furthermore, the conditional variance of the foreign firm's cost is positively correlated to the variances of the cost shocks for both firms and negatively correlated with the absolute value of the covariance of the two cost shocks. Therefore, the increase of the cost correlation given cost variances of both firms would increase the absolute value of the conditional mean of the foreign firm's cost and lower its conditional variance. It means that the higher the covariance, the more accurate the inference for foreign firm's conditional mean is. This is also true for the foreign firm, so as the cost correlation increases generally both firms would like to commit more in order to get more accurate cost information for the other firm. However, when  $V_1 > V_2$ , comparing to the foreign firm, the impact of the correlation on home firm's inference of the conditional mean and variance of foreign firm's cost shock is weakened by home firm's higher cost variance  $V_1$ . Hence, the impact of correlation increase on the foreign firm is larger than on the

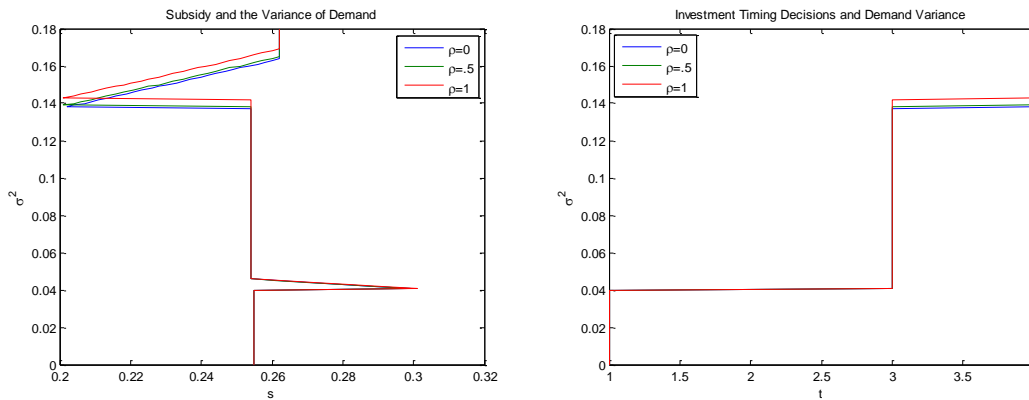
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<sup>60</sup> And vice versa.

home firm.

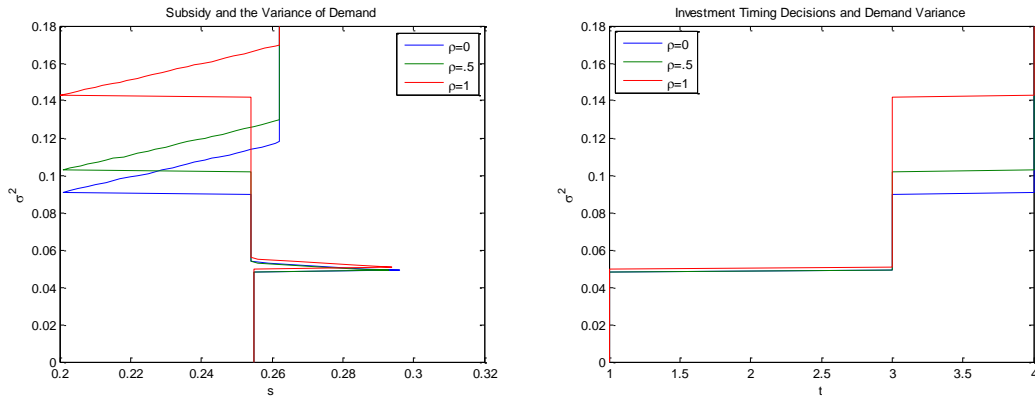
On the other hand, if  $V_1 < V_2$ , Fig. 8 depicts the optimal subsidy and investment timing choices when  $\rho$  is increased from 0 to 1 in each cost difference level. In contrast to the case where  $V_1 > V_2$ , it is easily seen that the home firm is more willing to make investment commitment as the cost correlation increases, whereas the impact of the correlation increase on the foreign firm is very small. Although the increase of the cost correlation generally leads to more investment commitments by both firms lower  $V_1$  magnifies the impact of the correlation increase on the home firm than on the foreign firm, so the home firm is more reactive to the change of the cost correlation than its rival.<sup>61</sup>

(a)



<sup>61</sup> Generally the increase of the cost correlation leads to more investment commitments by both firms, but it is not always true since the investment timing decisions also depend on other variances. Exceptions may exist for certain values of other cost or demand variances. Fig. 8 (c) is an example, as the correlation increases from 0 to .5, the foreign firm is actually more willing to delay rather than commit.

(b)



(c)

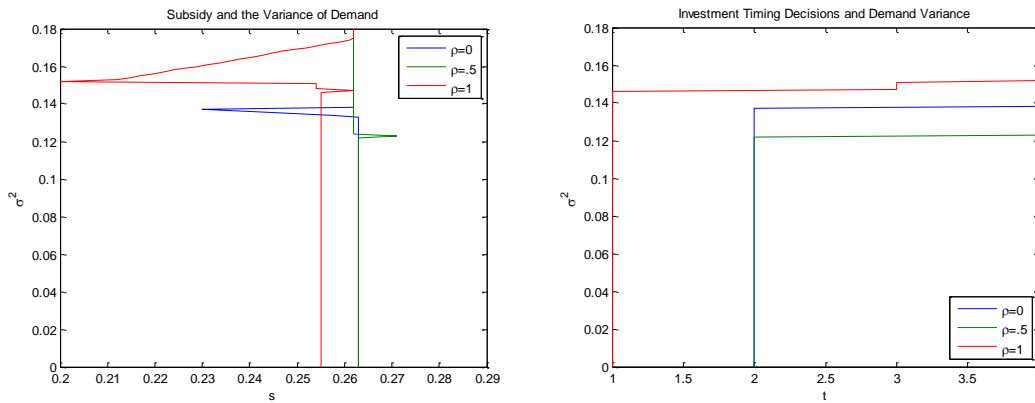


Fig. 8. (a) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = 5 \times 10^{-4}$ ,  $V_2 = 5 \times 10^{-3}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ ) (b) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = 5 \times 10^{-3}$ ,  $V_2 = 5 \times 10^{-2}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ ) (c) Optimal subsidization and investment timing choice as  $\sigma^2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $V_1 = 5 \times 10^{-2}$ ,  $V_2 = 5 \times 10^{-1}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

### 3.2 Optimal Subsidy and the Cost Variance of the Home Firm ( $V_1$ )

To explore the relationship between the optimal subsidy (and investment timing choices) and  $V_1$ , first of all, we study this relationship by setting different values for the demand variance from zero to 0.2 assuming  $\rho=0$  and  $V_2$  is very small; second, assuming  $\rho=0$  and  $\sigma^2=0$ ,  $V_2$  varies from  $10^{-3}$  to  $10^{-1}$ ; at last,  $\rho$  is changed from 0 to 1 given  $\sigma^2=0$  and small  $V_2$ .

Fig. 9 shows the relationship between subsidy (or investment timing) and  $V_1$  when demand variance changes. If demand variance is relatively small, as  $V_1$  increases the government will only enforce foreign firm delay by increasing the subsidy and never enforce home firm delay. Since the benefit of learning the realization of its own cost shock (by making commitment) increases, the home firm has more and more incentive to make investment commitment as  $V_1$  goes up. As  $\sigma^2$  rises, both firms are more and more willing to delay.



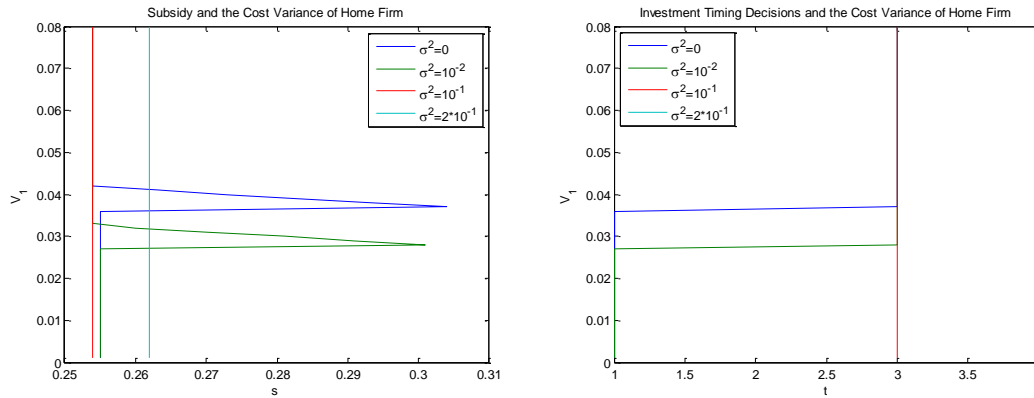


Fig. 9. Optimal subsidization and investment timing choice as  $V_1$  changes when  $\sigma^2$  increases from 0,  $10^{-2}$ ,  $10^{-1}$  to  $2 \times 10^{-1}$ . ( $V_2 = 10^{-3}$ ;  $\rho = 0$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

The relationship between subsidy (or investment timing) and  $V_1$  when  $V_2$  is changing is shown in Fig. 10. It is easily seen that as  $V_2$  increases, the foreign firm is more and more willing to commit instead of delay because getting its cost information (by making investment commitment) is more valuable when its cost variance is higher. This result is different from the result in the first cost structure where both firms would like to delay as  $V_2$  increases since there is information value in this cost structure, by making commitments the firms have opportunities to learn their real cost shocks and adjust the level of their investments.

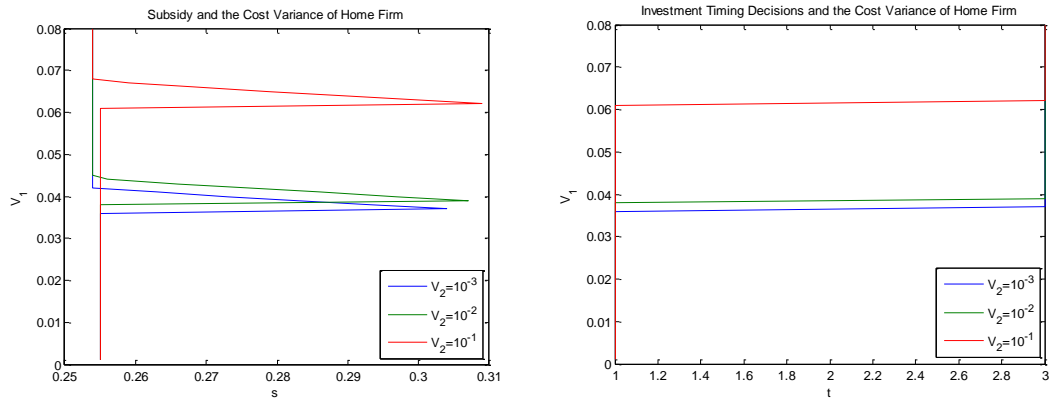


Fig. 10. Optimal subsidization and investment timing choice as  $V_1$  changes when  $V_2$  increases from  $10^{-3}$ ,  $10^{-2}$  to  $10^{-1}$ . ( $\sigma^2=0$  ;  $\rho=0$  ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

Fig. 11 depicts the relationship between subsidy (or investment timing) and  $V_1$  when  $\rho$  is increasing<sup>62</sup> assuming  $\sigma^2=0$  and  $V_2 = 10^{-3}$ . Similar to the case where  $V_1 > V_2$ , the increase of the cost correlation leads to more commitments by the foreign firm, since the foreign firm can get more accurate cost information about the home firm. But the correlation increase has no effect on home firm's timing choice, since the increase of the correlation further reinforce home firm's willingness to make commitments.

<sup>62</sup> Here  $\rho$  is only increased positively from 0 to 1, actually, the figure is very similar when  $\rho$  is increased negatively from 0 to -1.

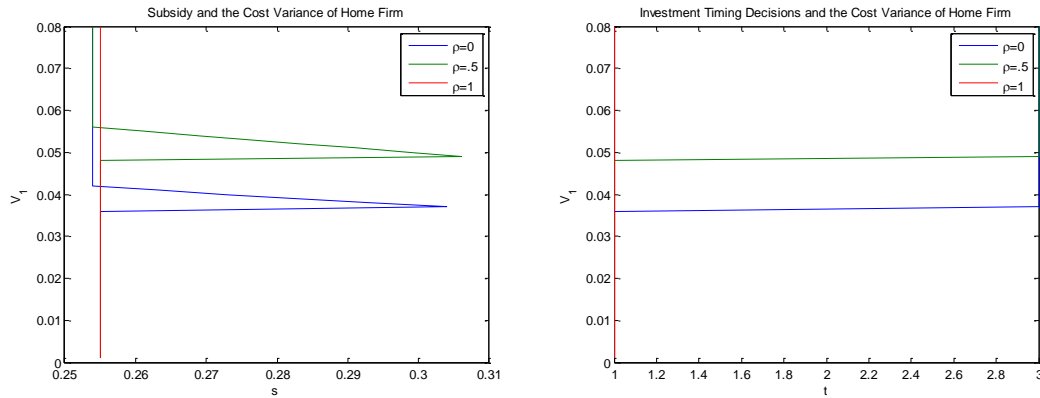


Fig. 11. Optimal subsidization and investment timing choice as  $V_1$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $\sigma^2=0$  ;  $V_2 = 10^{-3}$  ;  $A = A^* = 1$  ;  $\eta = 0.03$ )

### 3.3 Optimal Subsidy and the Cost Variance of the Foreign Firm ( $V_2$ )

The procedure of studying the relationship between the optimal subsidy (or investment timing) and  $V_2$  is the same as in the previous section. First, we study this relationship by varying demand variance from zero to 0.2, assuming  $\rho=0$  and  $V_1$  is small. Next, assuming  $\rho=0$  and  $\sigma^2=0$ ,  $V_1$  is increased from  $10^{-3}$  to  $10^{-1}$ . Lastly, we study the impact of raising  $\rho$  from 0 to 1 given  $\sigma^2=0$  and a small  $V_1$ .

The relationship between the subsidy (and investment timing) and  $V_2$  when demand variance changes is shown in Fig. 12. Given a small  $V_1$ , if demand variance is relatively low (for example: 0 and  $10^{-2}$  in Fig. 12), as  $V_2$  increases the equilibrium timing choices of the firms go from  $(C, C^*)$  to  $(D, C^*)$ . Although the benefit of retaining flexibility outweighs the strategic investment for the home

firm when  $V_2$  is high, the foreign firm would keep making commitment since it could benefit more by learning its real cost information (through making commitment). When demand variance is relatively high (set to be  $10^{-1}$  in Fig. 12), the investment timing line has an interesting backward shape: it goes from “4” to “2” (from  $(D, D^*)$  to  $(D, C^*)$ ) when  $V_2$  rises to around 0.22. Below this level, the timing line has the regular shape: it goes from “3” to “4” as  $V_2$  increases; however, it goes back to “2” when  $V_2$  is higher than this level. When  $V_2$  is very small, it is best for the home firm to commit and for the foreign firm to delay because the subsidy gives home firm an advantageous position to make investment commitment even if the demand variance is high, whereas the foreign firm have to choose delay due to the high demand variance. As  $V_2$  increased to about 0.04, the home government reduces the subsidy to a lower level, which enforces home firm delay, then the subsidy is increased gradually to  $s^{dd^*}$ . The benefit of flexibility dominates any strategic investment until  $V_2$  reaches a little over 0.2, where it is optimal for the foreign firm to choose commitment at  $s^{dd^*}$ , since the benefit of learning when  $V_2$  is high enough is more than the benefit of retaining flexibility for the high demand variance. But the home government would like the foreign firm to delay its investment so that it will not behave strategically. So the government gradually increases the subsidy (so called commitment deterrence subsidy) which forces the foreign firm to maintain delay. As  $V_2$  continues to rise the attraction of commitment for the foreign firm

increases due to greater benefit of learning by making commitment. However, commitment deterrence has to depart more from the optimal rent-shifting subsidy for  $(D, D^*)$  and will be increasingly costly. Finally, when  $V_2$  rises to 0.22 the government gives up commitment deterrence and accommodates the firms' investment timing choice using  $s^{dc^*}$ , and the equilibrium investment timing become  $(D, C^*)$ . When  $V_2$  is above 0.22, the home firm will continue to choose delay because of the high demand and cost variance of the foreign firm, but it is optimal for the foreign firm to make commitment as the loss of flexibility is dominated by the benefit of strategic investing and learning its own cost shock. Different from Dewit and Leahy (2004)<sup>63</sup>, although the government always wants to deter investment commitment by the home or the foreign firm, when the foreign firm's cost uncertainty is high enough (given a relatively high demand variance and a small cost variance for the home firm) the foreign firm may change its investment timing strategy from delay to commitment. If demand variance continues to rise, the government would only choose  $s^{dd^*}$  and both firms choose delay.

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<sup>63</sup> In Dewit and Leahy (2004), as demand variance increases the firms always change their investment timing strategies from commitment to delay and the government always wants to deter investment commitment by the home or the foreign firm.

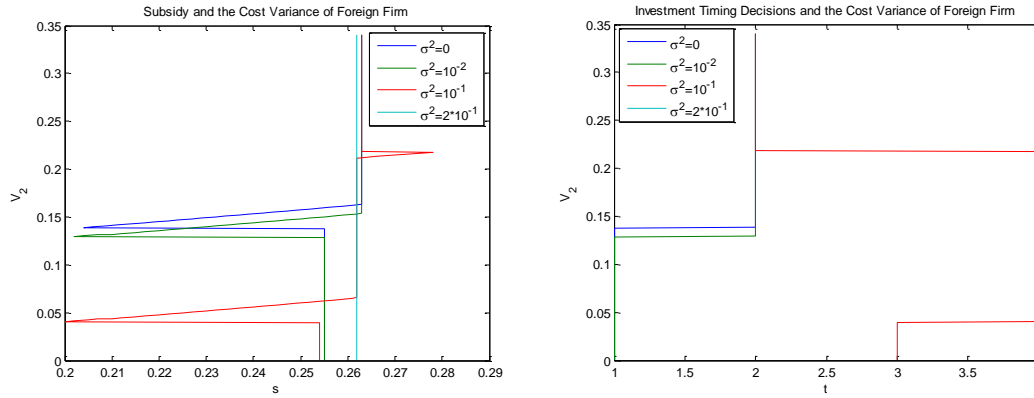


Fig. 12. Optimal subsidization and investment timing choice as  $V_2$  changes when  $\sigma^2$  increases from 0,  $10^{-2}$ ,  $10^{-1}$  to  $2 \times 10^{-1}$ . ( $V_1 = 10^{-3}$ ;  $\rho = 0$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

Fig. 13 shows the relationship between subsidy (and investment timing) and  $V_2$  when home firm's cost variance changes, assuming no correlation between the cost shocks and zero demand variance. It looks similar to Fig. 12 in the way in which the optimal investment timing choices are changing. For example, when  $V_1 = 10^{-1}$  the firms' investment timing choices move from  $(C, D^*)$ , to  $(D, D^*)$ , and then to  $(D, C^*)$  as  $V_2$  increases. The change for optimal subsidy looks similar to Fig. 12 too. When  $V_2$  is very small, firms' equilibrium investment timing choice is  $(C, D^*)$ , as  $V_2$  continues to rise to about 0.16, the home government sets a lower subsidy to enforce home firm delay. The maximum subsidy which can be used to enforce home firm delay increases until it reaches  $s^{dd^*}$  which accommodates firms' timing choices for flexibility. Just as in Fig. 12, when  $V_2$  increases to just over 0.2, the home government forces the foreign firm to

maintain delay by setting a higher commitment deterrence subsidy. The equilibrium investment timing ends up to  $(D, C^*)$  when  $V_2$  is above 0.25.

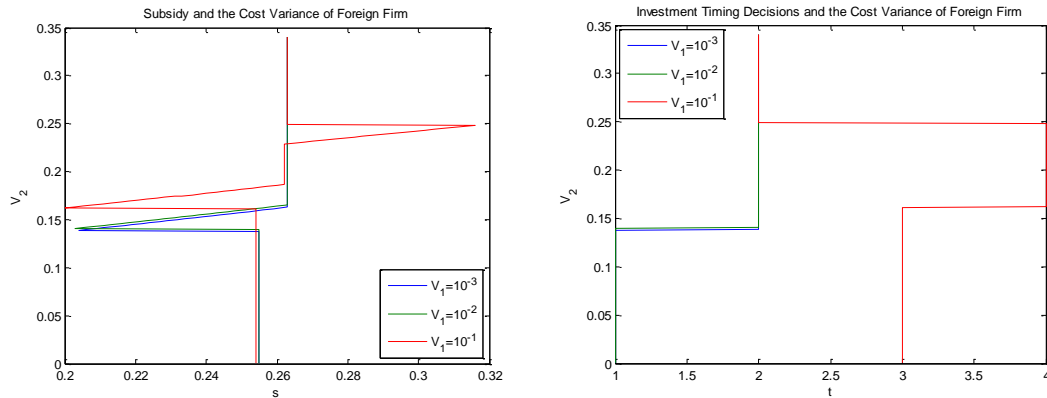


Fig. 13. Optimal subsidization and investment timing choice as  $V_2$  changes when  $V_1$  increases from  $10^{-3}$ ,  $10^{-2}$  to  $10^{-1}$ . ( $\sigma^2=0$ ;  $\rho=0$ ;  $A=A^*=1$ ;  $\eta=0.03$ )

This result is another example which shows that as cost variance increases, the firms do not always change their investment timing strategies from commitment to delay in the presence of cost uncertainties and private information. When the home firm's cost variance is relatively high and demand variance is small, the foreign firm may change its investment timing strategy from delay to commitment as its cost variance increases, even though the government wants to deter investment commitment by both firms.

Next, we allow the correlation to increase from 0 to 1 given  $\sigma^2=0$  and a

small  $V_1$ .<sup>64</sup> Fig. 14 shows the relationship among the optimal subsidy, investment timing and  $V_2$  as the correlation changes. If the correlation between the cost shocks is relatively small (less than 0.5), the equilibrium investment timing choice changes from  $(C, C^*)$  to  $(D, C^*)$  as foreign firm's cost variance increases. But if the cost shocks are fully correlated, both firms would only choose commitment. Therefore, as correlation increases the home firm is more and more willing to make commitment, although the foreign firm would always choose to commit. Thus, the increase of the correlation gives both firms more incentive to commit. Furthermore, with a small  $V_1$ , the benefit of the increased correlation on home firm's inference about the foreign firm's cost is greater than on the foreign firm. Hence the increase in the correlation has greater effect of encouraging home firm to make investment commitment.

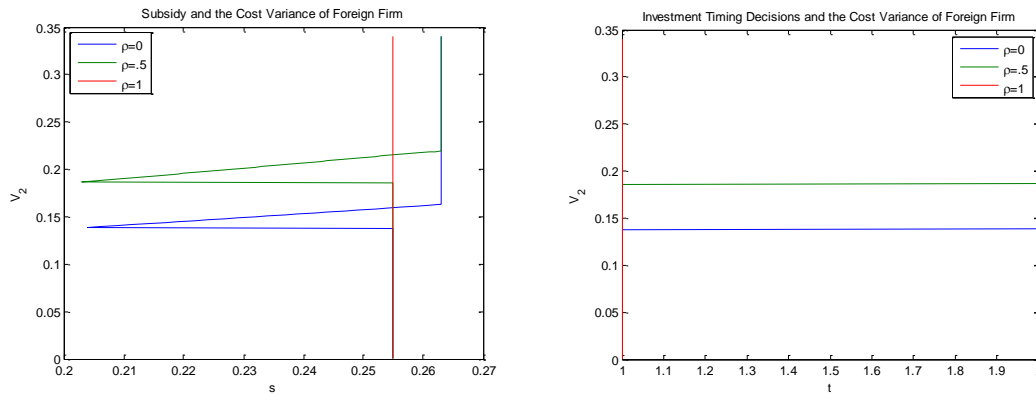


Fig. 14. Optimal subsidization and investment timing choice as  $V_2$  changes when  $\rho$  increases from 0, 0.5 to 1. ( $\sigma^2=0$ ;  $V_1 = 10^{-3}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

<sup>64</sup> The results are quantitatively the same if the correlation is negatively increased from 0 to -1.



### 3.4 Optimal Subsidy and the Correlation of the Cost Shocks ( $\rho$ )

Finally, we study the relationship between the correlation and the subsidy (or the investment timing) assuming all the other variances are fixed at a certain level. At first, suppose  $V_1 = V_2$ , we study the impact of the correlation at three different levels of the cost variances:  $10^{-3}$  to  $10^{-1}$ . The results are shown in Fig. 15. When cost variances are relatively low ( $10^{-3}$  or  $10^{-2}$  in the figure), the firms only choose  $(C, C^*)$ ; but when the cost variances increases to  $10^{-1}$ , as the correlation increases, the optimal timing choice goes from  $(C, D^*)$  to  $(C, C^*)$ . Meanwhile, the optimal subsidy starts at  $s^{cd^*}$ , when the correlation rises to about 0.65, the foreign firm would like to commit to take advantage of the better learning opportunity due to larger correlation. The home government can only prevent this by setting a higher subsidy, which maintains foreign firm delay. However, as the correlation increases, it becomes more and more costly to manipulate the subsidy. Finally the government abandons commitment deterrence by choosing  $s^{cc^*}$  when the correlation reaches a little over 0.7, and the equilibrium investment timing goes back to  $(C, C^*)$ .

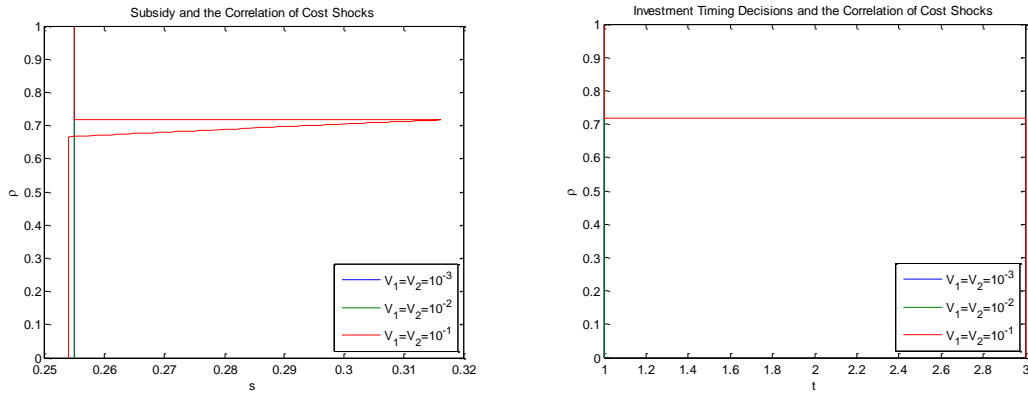


Fig. 15. Optimal subsidization and investment timing choice as  $\rho$  changes when the cost variances ( $V_1 = V_2$ ) increase from  $10^{-3}$  to  $10^{-1}$ . ( $\sigma^2=0$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

The increase in the difference between the two cost variances at each level does not change the relationship between the cost correlation and the subsidy (timing choices): the higher the cost correlation, the more willingness to commit by the firms. However, the increase in the difference of the cost variances makes at least one firm more willing to delay.

Next, suppose  $V_1$  and  $V_2$  are very small, demand variance is set to different levels from 0 to  $10^{-1}$ , the change of the optimal subsidy and investment timing choices are shown in Fig. 16. When demand variance is relatively small, the government chooses rent-shifting subsidy  $s^{cc^*}$  and both firms commit, because with small variances the benefit of taking first-mover advantage in order to strategically manipulate their rival excels the benefit of any other investment strategy no matter how correlated the cost shocks are. When demand variance is relatively high, the foreign firm chooses delay in order to

adjust their capital appropriately for the higher future uncertainty. But the demand variance is still not high enough for the home firm to abandon commitment. What's more, the change of the correlation between the cost shocks has little influence on the firms' timing choices.

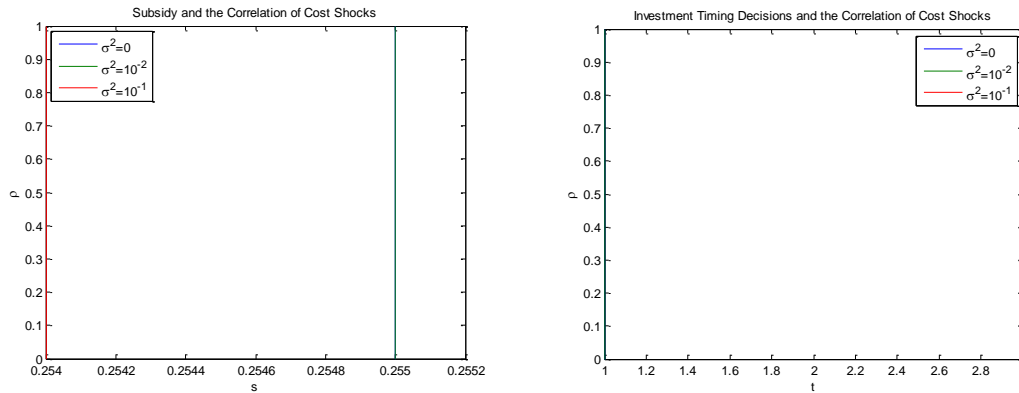


Fig. 16. Optimal subsidization and investment timing choice as  $\rho$  changes when  $\sigma^2$  increases from 0 to  $10^{-1}$ . ( $V_1 = V_2 = 10^{-3}$ ;  $A = A^* = 1$ ;  $\eta = 0.03$ )

#### 4. Conclusion

First, from the study of the relationship between the optimal subsidy and the demand variance we conclude the following: First of all, under zero correlation on the cost shocks, if  $V_1 = V_2$ , the increase of the level of the cost variances leads to more willingness to delay by both firms; but the increase of the correlation between the cost shocks makes firms more willing to commit their investments. In case there is cost asymmetry and the home firm has a cost advantage, it is

easier for the government to enforce foreign firm delay and harder to enforce home firm delay. The result is opposite if the foreign firm has a cost advantage. Second, if  $V_1 > V_2$ , the increase of the difference of the firms' cost variances makes the government more willing to enforce foreign firm delay and less willing to enforce home firm delay, this is due to the higher information value to the home firm than to the foreign firm in this structure. This result is different from the first cost structure, which argues that it is easier for the government to enforce home firm flexibility under  $V_1 > V_2$ .

On the contrary, if  $V_1 < V_2$ , the increase of the difference of the firms' cost variances makes the government more willing to enforce home firm delay and less willing to enforce foreign firm delay. A more interesting and important thing we found here is that when there is no correlation among cost shocks, as demand uncertainty rises the government may enforce foreign firm commitment by using "delay deterrence" subsidy when home firm's cost variance is smaller than foreign firm's cost variance. Dewit and Leahy (2004) argues that as demand uncertainty rises the government always wants to deter investment commitment by the home or the foreign firm; however, after cost uncertainties are added and assuming private information, this conclusion is not always true: under certain conditions on firms' cost uncertainty structures, the government may also deter investment delay by the foreign firm.

Next, we consider the effects of changing the correlation in the unequal cost shocks. When  $V_1 > V_2$  the foreign firm would like to commit more as the cost

correlation increases, but there is little impact on the timing choice of the home firm, because the impact of the correlation on home firm's inference of the conditional mean and variance of foreign firm's cost shock is weakened by home firm's higher cost variance  $V_1$ . The result is opposite if  $V_1 < V_2$  because of symmetry.

To explore the relationship between the optimal subsidy (and investment timing choices) and the cost variance of the home firm, first, we increase the demand variance assuming small  $\rho$  and  $V_2$ . It is found that under small demand variance, as  $V_1$  increases the government will only enforce foreign firm delay and never enforce home firm delay. As  $V_1$  increases the home firm benefits more from learning the realization of its own cost shock through making commitment. However, as  $\sigma^2$  rises, both firms are more and more willing to delay. Next,  $V_2$  is increased assuming no correlation and demand variance. As  $V_2$  increases, the foreign firm is more and more willing to commit because getting its cost information (by making investment commitment) is more valuable when its cost variance is higher. In the end, the cost correlation is increased with the result of more commitments for the foreign firm but no effect on home firm's timing choice.

The analysis of the relationship between the optimal subsidy (or investment timing) and  $V_2$  is made in three aspects. Firstly, demand variance is set at different levels assuming  $\rho = 0$  and a small  $V_1$ , and it is interestingly found that

different from Dewit and Leahy (2004), when foreign firm's cost uncertainty is high enough (given a relatively high demand variance) the foreign firm may change its investment timing from delay to commitment although the government always wants to deter investment commitment by both firms. Secondly, we change home firm's cost variance assuming no cost correlation and zero demand variance. It is found that the foreign firm may also change its investment timing strategy from delay to commitment as  $V_2$  rises if the home firm's cost variance is relatively high and demand variance is small. At last, the increase of the correlation between the cost shocks makes the home firm more willing to commit, whereas it has little impact on foreign firm's timing choice.

Finally, we investigate the relationship of the correlation and the subsidy (or the investment timing). At first, suppose  $V_1 = V_2$ , as expected, the increase of the correlation makes at least one firm more willing to commit; the increase of the level of the cost variances leads to more willingness to delay by at least one firm; when cost variances are relatively high, as the correlation increases, the foreign firm may change its investment timing from delay to commitment. Next, the increase of the difference of the two cost variances does not change the relationship between the cost correlation and the subsidy (or timing choices): the higher the cost correlation, the more willingness to commit by the firms. However, the increase of the difference of the cost variances makes at least one firm more willing to delay. In the end, the increase of the demand variance gives foreign firm more incentive to delay.

In this paper, time consistency problem is ignored; what is more, to make things simple, there is no signaling in this four stage game. These problems may need further study.

## APPENDIX B

### 1. Decision on the optimal investment level by the foreign firm in Delay, Commitment Case

In Delay, Commitment Case, in period 2,  $u$ ,  $v$  and  $v^*$  are known to both firms, and  $k^*$  (also  $s$ ) is exogenous. Thus, we solve equation (5a) and (3) at the same time and got:

$$\begin{pmatrix} x^{dc*} \\ y^{dc*} \\ k^{dc*} \end{pmatrix} = \frac{1}{3-2\eta} \begin{pmatrix} 2A - A^* + 2s - k^* + u - 2v + v^* \\ v + (1-\eta)u + (2-\eta)(A^* + k^* - v^*) - A - s \\ \eta[2A - A^* + 2s - k^* + u - 2v + v^*] \end{pmatrix} \quad (25)$$

where the values of  $x$ ,  $y$  and  $k$  will depend on  $s$ ,  $k^*$ ,  $u$ ,  $v$  and  $v^*$ . Going back to stage 3, observing  $v^*$  firm 2 has to decide optimal investment level  $k^{*dc*}$  by maximizing its expected profit in the second period:

$$\begin{aligned} & \text{Max}_{k^*} \{ E(\pi^* | v^*) \} \\ \Leftrightarrow & E \left\{ \text{Max}_{k^*} \left\{ \pi^* = (a - x - y + u)y - (c_0^* - k^* + v^*)y - \frac{k^{*2}}{2\eta} \right\} \middle| v^* \right\} \\ \Leftrightarrow & E \left\{ \pi_{k^*}^* + \pi_x^* x_{k^*}^{dc*} + \pi_y^* y_{k^*}^{dc*} \middle| v^* \right\} = 0 \end{aligned}$$



$$\Leftrightarrow E \left\{ \left( y - \frac{k}{\eta} \right) + (-y) \times \frac{-1}{3-2\eta} \middle| v^* \right\} = 0$$

(From F.O.C.,  $\pi_y^* = 0$ )

$$\Leftrightarrow k^{*dc^*} = \frac{2(2-\eta)}{3-2\eta} \eta E(y^{dc^*} | v^*) \quad (26)$$

From the result we got in (25),  $E(y^{dc^*} | v^*)$  can be calculated as:

$$\begin{aligned} E(y^{dc^*} | v^*) &= \frac{1}{3-2\eta} E \left\{ v + (1-\eta)u + (2-\eta)(A^* + k^* - v^*) - A - s \middle| v^* \right\} \\ &= \frac{1}{3-2\eta} [E(v | v^*) + (1-\eta)E(u | v^*) - (2-\eta)E(v^* | v^*) + (2-\eta)(A^* + k^*) - A - s] \\ &= \frac{1}{3-2\eta} \left[ \frac{V_c}{V_2} v^* - (2-\eta)v^* + (2-\eta)(A^* + k^*) - A - s \right]^{65} \quad (\text{cov}(u, v^*) = 0) \\ &= \left( \frac{V_c}{V_2} - 2 + \eta \right) \frac{v^*}{3-2\eta} + \frac{2-\eta}{3-2\eta} (A^* + k^{*dc^*}) - \frac{A+s}{3-2\eta} \quad (27) \end{aligned}$$

Finally, we can solve  $k^{*dc^*}$  by equation (26) and (27):

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<sup>65</sup> Since  $v$  and  $v^*$  are jointly normally distributed:  $\begin{pmatrix} v \\ v^* \end{pmatrix} : N \left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} V_1 & V_c \\ V_c & V_2 \end{pmatrix} \right)$ , the conditional distribution of

$v$  given  $v^*$  should be :  $v | v^* : N \left( \mu_v + \frac{\sigma_v}{\sigma_{v^*}} \rho (v^* - \mu_{v^*}), (1-\rho^2) \sigma_v^2 \right)$ , which can be expressed as:

$$v | v^* : N \left( \frac{V_c}{V_2} v^*, V_1 - \frac{V_c^2}{V_2} \right).$$

$$k^{*dc*} = \frac{2(2-\eta)}{3-2\eta} \eta E(y^{dc*} | v^*) = \frac{2\eta(2-\eta)}{3-2\eta} \left[ \left( \frac{V_c}{V_2} - 2 + \eta \right) \frac{v^*}{3-2\eta} + \frac{2-\eta}{3-2\eta} (A^* + k^{*dc*}) - \frac{A+s}{3-2\eta} \right]$$

$$\Leftrightarrow k^{*dc*} = \frac{2\eta(2-\eta) \left[ \left( \frac{V_c}{V_2} - 2 + \eta \right) v^* + (2-\eta)A^* - A - s \right]}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \quad (28)$$

Then, the optimal choices ( $x^{dc*}$ ,  $y^{dc*}$  and  $k^{dc*}$ ) can be decided in terms of  $s$ ,  $u$ ,  $v$ ,  $v^*$  as well as variance variables ( $V_2$  and  $V_c$ ) when  $k^{*dc*}$  is plugged in.

## 2. Maximized expected profits for both firms in Delay, Delay Case

In Delay, Delay Case, the maximized expected profit for the home firm can be calculated as:

$$E\pi^{dd*} = E \left\{ (x^{dd*})^2 - \frac{(k^{dd*})^2}{2\eta} \right\} = \text{var } x^{dd*} + (Ex^{dd*})^2 - \frac{1}{2\eta} [\text{var } k^{dd*} + (Ek^{dd*})^2] \quad (29)$$

Where according to Table 1:

$$Ex^{dd*} = \frac{(2-\eta)(A+s) - A^*}{(1-\eta)(3-\eta)}$$

$$\text{var } x^{dd*} = \frac{(1-\eta)^2 \sigma^2 + (2-\eta)^2 V_1 + V_2 - 2(2-\eta)V_c}{(1-\eta)^2 (3-\eta)^2}$$

$$Ek^{dd*} = \frac{\eta[(2-\eta)(A+s) - A^*]}{(1-\eta)(3-\eta)}$$

$$\text{var } k^{dd*} = \frac{\eta^2[(1-\eta)^2\sigma^2 + (2-\eta)^2V_1 + V_2 - 2(2-\eta)V_c]}{(1-\eta)^2(3-\eta)^2}$$

Therefore, it is easily seen that:

$$E\pi^{dd*} = \frac{(1-\frac{\eta}{2})}{(1-\eta)^2(3-\eta)^2} \left\{ (1-\eta)^2\sigma^2 + (2-\eta)^2V_1 + V_2 - 2(2-\eta)V_c + [(2-\eta)(A+s) - A^*]^2 \right\}$$

(30)

Similarly, the maximized expected profit for the foreign firm is:

$$E\pi^{*dd*} = \frac{(1-\frac{\eta}{2})}{(1-\eta)^2(3-\eta)^2} \left\{ (1-\eta)^2\sigma^2 + V_1 + (2-\eta)^2V_2 - 2(2-\eta)V_c + [(2-\eta)A^* - (A+s)]^2 \right\}$$

(31)

### 3. Maximized expected profits for both firms in Commitment, Delay Case

In Commitment, Delay Case, the maximized expected profit for the home firm is also:

$$E\pi^{cd*} = E \left\{ (x^{cd*})^2 - \frac{(k^{cd*})^2}{2\eta} \right\} = \text{var } x^{cd*} + (Ex^{cd*})^2 - \frac{1}{2\eta} [\text{var } k^{cd*} + (Ek^{cd*})^2] \quad (32)$$

Where from table 2:

$$Ex^{cd*} = (3-2\eta) \left[ \frac{(2-\eta)(A+s) - A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$$

$$\text{var } x^{cd*} = \frac{1}{(3-2\eta)^2} \left[ (1-\eta)^2 \sigma^2 + V_2 + \frac{(2-\eta)^2 [(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}]^2 V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} \right. \\ \left. - \frac{2(2-\eta) [(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}] V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$$

$$Ek^{cd*} = \frac{2\eta(2-\eta) [(2-\eta)(A+s) - A^*]}{(3-2\eta)^2 - 2\eta(2-\eta)^2}$$

$$\text{var } k^{cd*} = \frac{4\eta^2 (2-\eta)^2 \left( \frac{V_c}{V_1} - 2 + \eta \right)^2 V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2}$$

Then, the maximized expected profit for the home firm should be:

$$E\pi^{cd*} = \frac{[(2-\eta)(A+s) - A^*]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{1}{(3-2\eta)^2} \left[ (1-\eta)^2 \sigma^2 + V_2 \right. \\ \left. + \frac{(2-\eta)^2 \left\{ [(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}]^2 - 2\eta(3-2\eta)^2 \left( \frac{V_c}{V_1} - 2 + \eta \right)^2 \right\} V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} \right. \\ \left. - \frac{2(2-\eta) [(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}] V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right] \quad (33)$$

Similarly, the maximized expected profit for the foreign firm is:

$$E\pi^{*cd^*} = E \left\{ (y^{cd^*})^2 - \frac{(k^{*cd^*})^2}{2\eta} \right\} = \text{var } y^{cd^*} + (Ey^{cd^*})^2 - \frac{1}{2\eta} [\text{var } k^{*cd^*} + (Ek^{*cd^*})^2] \quad (34)$$

From Table 2:

$$Ey^{cd^*} = \frac{1}{3-2\eta} \left[ 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) A^* - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$$

$$\text{var } y^{cd^*} = \frac{1}{(3-2\eta)^2} \left[ \sigma^2 + 4V_2 + \frac{[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}]^2 V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} - \frac{4[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}] V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$$

$$Ek^{*cd^*} = \frac{\eta}{3-2\eta} \left[ 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) A^* - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$$

$$\text{var } k^{*cd^*} = \frac{\eta^2}{(3-2\eta)^2} \left[ \sigma^2 + 4V_2 + \frac{[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}]^2 V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} - \frac{4[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}] V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]$$

Therefore:

$$E\pi^{*cd^*} = \frac{1-\eta}{(3-2\eta)^2} \left[ 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) A^* - \frac{(3-2\eta)^2(A+s)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2$$

$$+ \frac{1-\eta}{(3-2\eta)^2} \left[ \sigma^2 + 4V_2 + \frac{[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}]^2 V_1}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} - \frac{4[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_1}] V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right] \quad (35)$$

#### 4. Maximized expected profits for both firms in Delay, Commitment Case

Due to the symmetry, the maximized expected profits for the firms in Delay, Commitment Case could be derived easily from the results in Commitment, Delay Case.

$$\begin{aligned}
 E\pi^{dc*} &= \frac{1-\eta}{(3-2\eta)^2} \left[ 2 \left( 1 + \frac{\eta(2-\eta)}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right) (A+s) - \frac{(3-2\eta)^2 A^*}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right]^2 \\
 &+ \frac{1-\eta}{(3-2\eta)^2} \left[ \sigma^2 + 4V_1 + \frac{[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_2}]^2 V_2}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} - \frac{4[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_2}] V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \right] \quad (36)
 \end{aligned}$$

$$\begin{aligned}
 E\pi^{*dc*} &= \frac{[(2-\eta)A^* - (A+s)]^2}{(3-2\eta)^2 - 2\eta(2-\eta)^2} + \frac{1}{(3-2\eta)^2} [(1-\eta)^2 \sigma^2 + V_1 \\
 &+ \frac{(2-\eta)^2 \left\{ [(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_2}]^2 - 2\eta(3-2\eta)^2 \left( \frac{V_c}{V_2} - 2 + \eta \right)^2 \right\} V_2}{[(3-2\eta)^2 - 2\eta(2-\eta)^2]^2} \\
 &- \frac{2(2-\eta)[(3-2\eta)^2 - 2\eta(2-\eta) \frac{V_c}{V_2}] V_c}{(3-2\eta)^2 - 2\eta(2-\eta)^2} \quad (37)
 \end{aligned}$$

## CHAPTER 4

### ROBUST FDI DETERMINANTS WITH ENDOGENOUS EXCHANGE RATE IN THE PRESENCE OF MODEL UNCERTAINTY AND SELECTION BIAS

#### 1. Relevance of the Topic

As an increasingly important source of cross-border capital reallocation over the past two decades, foreign direct investment (FDI) has become more important than trade and presently constitutes the single largest source of capital flows<sup>66</sup> (Abbott and De Vita, 2011). From 1990 to 2011, the ratio of global FDI inflows to GDP increased 135 percent and sales of foreign affiliates of multinational firms jumped from \$76,258 million to \$242,027 million in real terms (UNCTAD World Investment Report, 2012). FDI flows to developing countries rose from an annual average of \$17 billion over 1980–85 to an annual average of \$242 billion over 2000–05, reaching \$621 billion in 2008 (Abbott et al., 2012). Since 1995, developing countries continued to account for nearly half of global FDI as their inflows reached a new record high of \$684 billion in 2011 (UNCTAD World Investment Report, 2012). The FDI outflow of the largest developed countries (G-20) ran up to more than \$1 trillion in 2011 and more than a third of that amount was from the United States (Jeanneret, 2013).

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<sup>66</sup> Financial flow is defined as any and all of the transactions in the financial (capital) account of the balance of payments, most importantly international borrowing and lending and acquisition across borders of financial and real assets (Deardorff's Glossary of International Economics). Capital account is composed of foreign direct investment, portfolio investment, other investment and reserve account. So, FDI flows are part of the financial flows.

### *1.1 Debates on the Relationship between FDI and the Exchange Rate*<sup>67</sup>

Over the past two decades, the growth in FDI has stimulated significant attempts at developing theories that explain the determinants of FDI. Bergstrand and Egger (2007) suggest a formal N-country theoretical rationale for estimating gravity equations of FDI flows and foreign affiliate sales. The standard gravity variables include “mass” variables (the source and host population sizes) and “distance” variable (the physical distance between the source and host countries). Along with the typical gravity variables, common border, colony relationship and common language are often added into the gravity equation to capture the impact of geographic and historical conditions on bilateral FDI decisions. Real gross domestic product per capita, which is a measure of capital abundance, is put forward by the factor endowment argument of FDI. It is found that Capital-abundant economies (with a high capital-labor ratio) conduct more outward FDI than labor-abundant countries (Egger and Pfaffermayr, 2004). GDP growth rate, which signals higher returns, is shown to be positively related to the presence of foreign firms (Lim, 2001). However, real GDP per capita and GDP growth rate are excluded in this paper because of their well suspected endogeneity (Russ, 2007). Another hypothesis between FDI and trade protection was proposed by trade economists: higher trade protection make firms more likely to substitute foreign affiliate production for exports to avoid the costs of

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<sup>67</sup> Here the debates focus on theories investigating the effects of the volatility and the level of the exchange rate on FDI. However, it is worth notice that the impact of exchange rate regime combinations (under different policy frameworks) upon bilateral foreign direct investment flows has been investigated in recent literature (Abbott et al., 2011, 2012), and the FDI-inducing properties of the various exchange rate regimes have been found.



trade production. This so called tariff-jumping FDI is not considered in this paper since the support for tariff-jumping FDI is mixed, besides, FDI and trade protection may be endogenous (Blonigen, 2005). Other important FDI determinants included in this paper such as education difference, market potential, productivity, corporate tax, tax treaty, RTAs, economic risk, financial risk and political risk are explained in section three.

Another branch of the literature is concerned with the relationship between the exchange rate and FDI. However, there is no consensus about the nature of the relationship in theoretical and empirical models treating exchange rate fluctuations as exogenous. Those models that are based on partial equilibrium analysis are divided as to whether exchange rate uncertainty promotes or depresses FDI. There are numerous theoretical models which show that exchange rate uncertainty promotes FDI. First, the arguments based on the risk-taking characteristics of producers, which assert that if there is risk aversion among producers, exchange rate volatility may expand the share of investment activity located on foreign soil, and the FDI share increases as the correlation between exchange rate and real demand shocks rises. This result holds because by increasing the share of foreign FDI, the producers minimize the variance of expected profits and increase expected utility (Goldberg and Kolstad, 1995). Second, there is the production flexibility approach, which shows that exchange-rate volatility increases the value of having plants in both countries, so that the multinational firm could decide at any time whether it is better to export

from home or to produce in its foreign facility, depending on where the value of the local currency makes input costs cheapest (Sung and Lapan, 2000). Third, the financial flexibility argument developed by Itagaki (1981), which posits that an increase in exchange-rate uncertainty could cause a firm to invest abroad as a way of hedging against a short position in its balance sheet. Specifically, if a firm's home currency depreciates, the value of its domestic assets decreases relative to its foreign liabilities. However, investing abroad could offset the loss due to the increased value of the firm's foreign assets and revenues.

Other theoretical models predict that exchange-rate uncertainty would discourage FDI. One line of research originates in the real option approach of FDI (Dixit and Pindyck, 1994), declaring that exchange rate fluctuations raise the option value of waiting due to the increased uncertainties on the payoff abroad and the cost of the investment. This theory is based on an important characteristic of investment decisions: irreversibility due to the sunk cost<sup>68</sup>. The other line of research assumes firms are risk averse. These papers demonstrate that exchange-rate uncertainty may reduce the certainty-equivalence value of expected profits from foreign production, if the loss of the repatriated profits due to host country depreciation is not offset by the increase in host country demand or reduction in host country input costs (Goldberg and Kolstad, 1995).

In contrast with the theoretical predictions obtained from existing real options models, Jeanneret (2013) highlights the key role of firm heterogeneity in

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<sup>68</sup> Dixit and Pindyck (1994) assume the uncertain output price  $P$  (or a demand shift variable, here we refer to exchange rate) for a firm follows the geometric Brownian motion:  $\frac{dP}{P} = \alpha_P dt + \sigma_P dz_P$  where  $E[dz_P^2] = dt$ .

a U-shaped relationship between exchange rate uncertainty and aggregate investment. This non-monotonicity emerges because firms are heterogeneous in productivity and have different incentives to invest under different time and conditions: the least productive firms prefer to invest overseas when exchange rate volatility is low and otherwise export, whereas the most productive firms choose to invest overseas when volatility is high. Eventually, the aggregation over heterogeneous firms produces a U-shaped relationship between uncertainty and aggregate investment<sup>69</sup>.

Empirical models treating exchange rate fluctuations as exogenous also generate conflicts on the relationship between exchange rates and FDI. Udomkerdmongkol, Morrissey, and Görg (2009) employ annual panel data and the fixed effects model with first-order autocorrelation disturbances estimation to explore the effect of exchange rates on US foreign direct investment in 16 emerging market countries from 1990 to 2002. The result reveals three distinct effects: local currency devaluation promotes inward FDI; expectations of local currency depreciation (appreciation) postpones (brings forward) FDI; and

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<sup>69</sup> Jeanneret (2013) explained the intuition behind the U-shaped relations. For the firms with low levels of productivity, investing abroad is more likely to be profitable since they could build more efficient production lines abroad. What is more, when exchange rate volatility is low, there is no incentive for them to wait as the payoff of the foreign project will not change much in the future. However, greater exchange rate volatility increases the value to waiting because the opportunity cost for the investment is higher. Firms need to wait for a more favorable exchange rate which lowers the cost of a new investment. Hence, for those firms, the probability of investing abroad (expected level of FDI) decreases with uncertainty. On the contrary, the firms with high levels of productivity find it more profitable to export their cost-efficient products than to invest abroad under low exchange rate uncertainty. As exchange rate volatility rises, the level of the exchange rate could be such that relocating production may foster these firms' profits through enhanced productivity. Therefore, for high-productivity firms, the probability of investing abroad increases with exchange rate uncertainty. Since the effect of exchange rate volatility on FDI is mostly driven by low-productivity firms when exchange rate volatility is low and by high-productivity firms when exchange rate volatility is high, the aggregation of firms with heterogeneous levels of productivity finally creates a U-shaped relationship between exchange rate volatility and FDI.

exchange rate volatility discourages FDI inflows. Cavallaria and d'Addona (2013) also find a strong negative relationship between exchange rate volatility and bilateral FDI flows among 24 OECD countries over the period 1985–2007.<sup>70</sup> However, the exchange rate volatility matters in particular for the decision whether to invest in a foreign country. Meanwhile, there are papers that find opposite results; Goldberg and Kolstad (1995) find that exchange rate volatility stimulates the share of U.S. investment capacity to Canada, Japan and the United Kingdom in accord with the early horizontal FDI theory. But they find no statistical evidence of the relationship between the level of the exchange rate and FDI<sup>71</sup>. Zhang (2004) supports their results, finding a positive and significant relationship between exchange rate volatility and FDI flowing into the European Union (EU) from both inside and outside the EU. Using data of Japanese industry-level foreign direct investment to five Asian countries, Dennis et al. (2008) find evidence that the impact of exchange rates on FDI reflects heterogeneity across different types of FDI, which addresses the major conflicts in the previous literature on exchange rates and FDI<sup>72</sup>.

Buch and Kleinert (2008) argue that exchange rates could affect FDI decisions for two main reasons. On the one hand, frictions on capital markets can

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<sup>70</sup> Cavallaria and d'Addona (2013) point out that the rise in exchange rate volatility strongly deters foreign investments only when selection bias is properly accounted for.

<sup>71</sup> If purchasing power parity (PPP) always holds, there should be no relationship between FDI and exchange rates, because the changes of the exchange rates offset differences in relative inflation, keeping earnings, as measured in the home currency, constant (Dewenter, 1995).

<sup>72</sup> Taylor (2008) assessed the changes in FDI flows between the major economies in the first five years of economic and monetary union (EMU) of the European Union, and found that the euro was only a subsidiary cause for the massive but short-lived wave of FDI to the Eurozone after EMU. Intra-zone FDI turns out to be weaker after EMU, both in relation to previous trends and as a share of major economies' global FDI flows. On this evidence, intra-zone investment did not respond to the elimination of exchange-rate uncertainty. However, the euro appears to attract modest inflows from outside the zone.

affect FDI through a wealth effect, specifically, FDI of sectors (or firms) that face greater credit market restrictions responds more to exchange rate changes. On the other hand, goods market frictions can be another source of the effects of exchange rate changes on FDI. A home currency appreciation increases the profits generated from the home market in terms of the foreign currency, which enables a home firm to bid a higher price (increase FDI) for firm-specific assets on international markets. The impact of the home appreciation is greater if home firms sell higher share of their outputs on the home market and use lower share of the domestic inputs. However, their results suggest that the effect of exchange rate changes on FDI will be weakened as the integration of goods markets develops.

### *1.2 Endogenous Exchange Rate and FDI in General Equilibrium Model*

The conflicting results generated from the previous studies of exchange rate variability and multinational firms are based on partial equilibrium models that treat the exchange rate as exogenous. Those studies make partial equilibrium predictions of FDI by modeling firm-level decisions and examine how exogenous factors, such as taxes and exchange rates, affect these firm-level decisions (Blonigen, 2005). The chief objection to the previous literature based on partial equilibrium and firm-level decisions is its ignorance of the connections of FDI behavior with the underlying fundamental macroeconomic variables and trade flows. A recent body of literature has begun to model FDI decisions in a

general equilibrium framework and to analyze how fundamental country-level factors affect aggregate country-level FDI behavior.

Russ (2007) points out that when the exchange rate and consumer demand in the host country are jointly determined by underlying macroeconomic variables (such as money supply and interest rate), regressions of FDI flows on both exchange rate levels and volatility are subject to bias. The reasoning behind this is: because of the rigidity of prices<sup>73</sup> monetary shocks not only affect realizations of the exchange rate but also the demand for consumption goods in the host country. Furthermore, the exchange rate covaries negatively with the demand for goods when monetary shocks happen<sup>74</sup>. A two-country open-economy macroeconomic model is set up to connect both demand and the exchange rate to fluctuations in a common underlying variable: money. It is shown that the relative difficulty that foreign-owned firms face when entering the Home market would be determined by the uncertainties of money-supply growth rate and the relative sunk cost:

$$\gamma = \frac{\hat{\varphi}_F(t)}{\hat{\varphi}_H(t)} = \left[ \left( \frac{1+\psi}{1+\psi^*} \right) \left( \frac{f_{MNE}}{f} \right) \right]^{\left( \frac{1}{\mu-1} \right)} e^{\left( \frac{1}{\mu-1} \right) (\sigma_{m^*}^2 - \sigma_m^2)}, \quad (1)$$

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<sup>73</sup> Russ (2007) depicts the sticky-price mechanism in its firm's maximization problem: At period t-1, a particular firm, Given its knowledge of a permanent idiosyncratic productivity index and its expectations of economic conditions in the next period, decide whether it will produce domestically or abroad in the following period and set the price for its unique good in period t if it chooses to invest. On that basis, the general equilibrium price a firm will set depends on the firm's productivity index and the expectation of the money supply in period t. So the rigidity of prices comes from the fact that the pricing rule does not depend on the real monetary shocks.

<sup>74</sup> Due to the sticky-price mechanism a positive shock to the home money supply weakens the value of the home currency but simultaneously increases home country's real income, and therefore boosts sales by both domestically owned firms and multinationals operating in the home market.

In (1)  $\gamma$  is defined as the ratio of the productivity levels of the least productive Foreign and Home firms. The  $\hat{\varphi}_F(t)$  is the foreign firms' threshold productivity level, which means that only the foreign firms with higher productivity levels than the threshold productivity level can cover their fixed costs and enter the home market. Likewise,  $\hat{\varphi}_H(t)$  is the threshold productivity level for the home firms. The  $f_{MNE}$  and  $f$  are fixed overhead costs or sunk costs to invest in the home country for multinational enterprises and Home-owned firms, respectively;  $\sigma_{m^*}^2$  and  $\sigma_m^2$  are the variances of the growth rates of the foreign and home money supplies, respectively. It is assumed that the growth rate of the home money supply (the same for foreign money supply) has a lognormal distribution defined by

$$\frac{M_t}{M_{t-1}} = (1 + \psi)e^{v_t}, \quad (2)$$

where  $\psi$  is a constant and the  $v_t$ 's are i.i.d. random variables with a normal distribution of mean  $-\frac{1}{2}\sigma_m^2$  and variance  $\sigma_m^2$ . The  $\mu$  is the elasticity of substitution in the utility function with constant elasticity of substitution (CES).

Besides, the change of FDI flows with exchange-rate volatility differs depending on whether the volatility comes from a firm's native or host country. This model has extremely important contributions in that it is the first to analyze FDI in an open-economy macroeconomic model with sunk cost where exchange

rates and local demand are jointly determined. Besides, the model assumes heterogeneity in productivity across firms to explain why exchange rate uncertainty together with the sunk cost deters entry by the lower productivity firms into the foreign market. It coincides with the fact that larger firms with higher productivities are not easily driven out of the foreign market in uncertain macroeconomic conditions (Melitz (2002, 2003)).

With the same assumption of nominal rigidity and endogenous entry by national and multinational firms as that of Russ (2007), Cavallari (2010) uses a dynamic stochastic general equilibrium (DSGE) model with both exports and foreign direct investments to show that the decision whether to engage in start-up investments as well as the choice of whether to invest at home or abroad depend on various dimensions of monetary policy and world-wide productivity conditions. The equilibrium dynamics of foreign start-up investments in the home country is derived as:

$$n_{MNT}^* = \frac{1}{(1+\rho)} \left[ \left(1 + \left(1 + \frac{1}{2\rho}\right) a_1\right) a_t - \left(1 + \frac{1}{2\rho}\right) [a_1 a_t^* + (1 - a_0)(m_t - m_t^*)] + \chi^{MN} \right], \quad (3)$$

where  $n_{MNT}^* = \log N_{MNT}^* - \log N_{MNT-1}^*$  is the log deviation of the total quantity of the foreign investments (new foreign investments) in the home country in year t.  $a_t = \log A_t$  and  $a_t^* = \log A_t^*$  are the log of the productivity shocks for the home and foreign country in year t, respectively. Similarly,  $m_t = \log \mu_t$  and  $m_t^* = \log \mu_t^*$  are the log of money supplies for home and foreign country in year t, respectively.



$m_t$ ,  $m_t^*$ ,  $a_t$  and  $a_t^*$  are random variables which are assumed jointly normally distributed and symmetric across countries with variances  $\sigma_m^2$  and  $\sigma_a^2$ .  $\rho$  is a constant which measures the concavity of the cost function.  $a_0$  and  $a_1$  are constants defined as the functions determined by the parameters in the model including the discount factor, elasticity of substitution and exchange rate pass-through<sup>75</sup>. At last,  $\chi^{MN}$  is a constant entirely determined by uncertainties:

$$\chi^{MN} = \chi^D - \left(1 + \frac{1}{\rho}\right) a_2 (\sigma_{am} - \sigma_{a^*m^*}) \quad (4a)$$

$$\chi^D = \frac{\phi-1}{2} \left[ \begin{aligned} &\sigma_m^2 - \sigma_a^2 + \left(1 + \frac{1}{\rho(\phi-1)}\right) a_2 (\sigma_{am} - \sigma_{a^*m^*}) + \frac{(\eta^2-1)}{2} (a_0^2 \sigma_m^2 + a_1^2 \sigma_a^2) \\ &- (2\eta - 1)(a_0 \sigma_m^2 + a_1 \sigma_a^2) + \eta(a_0 \sigma_{am} + a_1 \sigma_a^2) \end{aligned} \right] \quad (4b)$$

where  $\sigma_{am}$  and  $\sigma_{a^*m^*}$  are the covariance of the productivity shocks and the monetary shocks in home and foreign country, respectively,  $\eta$  is the elasticity of exchange rate pass-through,  $\phi$  is the elasticity of substitution in consumption.  $a_0$ ,  $a_1$  and  $a_2$  are constants.

Eq. (3) shows that current monetary policy shocks can affect the attractiveness of investing in the home country as compared with overseas. A domestic monetary expansion is found to discourage foreign investments when exchange rate pass-through is not complete since the depreciation of the home

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<sup>75</sup> Exchange rate pass-through, taken as given by firms active in foreign markets, is defined in Cavallari (2010) as a constant elasticity  $\eta$ , at which firms let the final prices of their products (in their own currency) vary with the exchange rate.  $\eta = 0$  corresponds to local currency pricing, a situation where prices are pre-determined in the consumers' currency and do not respond to movements in the exchange rate, whereas  $\eta = 1$  corresponds to producers' currency pricing. In this setting, exchange rate pass-through is incomplete if  $\eta \neq 1$ .

currency reduces the prospective profits of the overseas affiliate more than reducing the entry costs in foreign currency. On the contrary, monetary expansion originating from the foreign country would boost foreign investment into the home country for the same reasoning. Furthermore, Eq. (4) shows that an increase in the degree of monetary stabilization improves trend investments in all sectors; foreign direct investments might be discouraged by exchange rate fluctuations because the value of the multinational firms' foreign assets is reduced. This is the way for foreign firms to minimize the macroeconomic risks related to pre-determined prices under a counter-cyclical monetary policy.

There are several differences between Cavallari (2010) and Russ (2007). For one, Russ (2007) assumes heterogeneous productivity across firms whereas Cavallari (2010) assumes firms are homogeneous except that they produce different product varieties. In addition, Cavallari (2010) incorporates the export sector into the investment model, whereas Russ (2007) assumes no trade in goods. Moreover, Russ (2007) shows that FDI responds to monetary volatility from the firm's native or host country, whereas in Cavallari (2010)'s framework, current monetary policy shocks can affect nominal marginal costs, which influence firms' investment decisions. This implies that current monetary shocks would also play a role in re-directing investments across countries, besides the various dimensions of monetary uncertainty.

### *1.3 Model Uncertainty and Selection Bias*

Theories explaining the incentives of FDI go back as early as horizontal FDI, which explains cross-country penetration of multinational corporations as a substitute for trade when there are significant trade barriers (such as transport costs or tariffs), and vertical FDI, which assumes the investment occurs to take advantage of lower factor prices in the host country. These two incentives are unified into the knowledge-capital model of FDI. New trade theories are developed to provide more patterns for FDI, which includes export platform FDI<sup>76</sup> and vertical interaction FDI. The former suggests that the main purpose for firms to invest and produce in the host country is to use the country as an export platform and export their goods to neighboring countries. Similarly, the latter is undertaken when subsidiaries in host countries do not serve the local market, but instead ship intermediate goods back and forth for processing and export finished products back to the parent. Unfortunately, those theories of FDI have only got mixed supports from the vast majority of empirical studies<sup>77</sup>. Although the literature on the determinants of FDI is quite substantial, the literature based on partial equilibrium and firm-level decisions is still too young that there are few definitive conclusions. It also has been found that most of the empirical determinants of cross-country FDI are fairly fragile<sup>78</sup> statistically (Blonigen, 2005). Because of the model uncertainty in FDI theories, an individual empirical

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<sup>76</sup> The theory of export platform FDI addresses the importance of regional trade agreements in driving the FDI.

<sup>77</sup> Bergstrand and Egger (2007) find conditional evidence for effects of RTAs on FDI flows; similarly, Baltagi et al. (2007) only finds weak support for export platform FDI and vertical interaction FDI theory.

<sup>78</sup> The fragility of the results comes from the arguably theoretical hypotheses or model uncertainty.

approach that contains only limited subsets of the FDI determinants would cause ambiguous and often contradictory results. Even, if model uncertainty is not taken into account in the estimation process, the statistically significant FDI determinants will be doubted<sup>79</sup> for their level of significance when alternative specifications are considered (Eicher, Helfman and Lenkoski, 2012). Without a full account of model uncertainty conventional sensitivity analyses overstates the significance levels and confidence intervals in a statistical analysis. The Bayesian Model Averaging (BMA) methodology is developed to address the problem of model uncertainty in the estimation procedure. Therefore, the BMA methodology is used to handle the large set of potential determinants proposed by various FDI theories<sup>80</sup>.

It is commonly found that a large number of FDI data are missing<sup>81</sup>. Heckman (1979) puts forward the problem of sample selection bias from using nonrandomly selected samples with missing data. A usual procedure for computing standard errors for least squares coefficients will understate the true standard deviations and overstate the true significance levels. Consequently, a two-step consistent estimation method is developed to correct the selection bias, which is treated as a specification error. The large amount of missing data in FDI flows between country pairs could be explained by three reasons: lack of

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<sup>79</sup> It means the results will not be robust when alternative specifications are used.

<sup>80</sup> Blonigen and Piger (2011) use Bayesian statistical techniques to deal with model uncertainty on FDI activities in a cross section. Bayesian method was used to select the variables (from a large set of candidates) that are most likely to be the determinants of FDI. Their results found that many covariates found significant by previous studies are not robust.

<sup>81</sup> Razin et al. (2008) finds around 62 percent host-source pairs of FDI flows are not observable in their data. Eicher, Helfman and Lenkoski (2012) also find large sections of missing data in their comprehensive global dataset.

incentives to invest (even if there were no fixed costs); setup costs, which prevent FDI from taking place; and measurement errors<sup>82</sup>. Therefore, the Heckman selection method is adopted in the FDI analyses to solve the selection bias problem due to the missing data. This method jointly estimates the maximum likelihood of the selection equation and the magnitude of the FDI flow (flow equation). Furthermore, this estimation method accommodates both measurement errors and a possible existence of setup costs (Razin, Rubinstein and Sadka, 2004; Razin, Sadka and Tong, 2008). The two equations (selection and flow equations) make it possible to analyze the determinants of the intensive and extensive margins of FDI (“the volume of investment flows” and “the decision whether to invest”, respectively) separately. Razin, Sadka and Tong (2008) address the importance of fixed costs as sizeable threshold barriers to FDI and explain two different decision mechanisms behind the two-part investment decisions: the standard marginal productivity condition that determines how much to invest, and the total profitability condition that decides whether to invest.

Finally, Eicher et al. (2012) combine the BMA and the Heckman selection method and introduce HeckitBMA to address both model uncertainty and selection bias problems in FDI analyses. Their FDI flow equation is based on the gravity equations for FDI:

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<sup>82</sup> Refer to Eicher, Helfman and Lenkoski (2012). The missing data do not necessarily mean the true entry is absolute “zero” since there is also a possibility of measurement errors.

$$Y_{ijt} = \alpha_0 + \alpha_t + \beta_1 \log GDP_{it} + \beta_2 \log GDP_{jt} + \beta_3 \log D_{ij} + \beta_4 X_{ijt} + \varepsilon_{ijt} \quad (5)$$

where  $Y_{ijt}$  represents the log of FDI from source country  $i$  to host country  $j$  at time  $t$ ,  $GDP_{it}$  and  $GDP_{jt}$  are GDPs for country  $i$  and  $j$ , respectively,  $D_{ij}$  is the bilateral distance between country  $i$  and country  $j$ .  $X_{ijt}$  is a  $K \times 1$  vector of other covariates that represents alternative FDI theories.  $\alpha_t$  is the time fixed effect,  $\alpha_0$  is the intercept and  $\varepsilon_{ijt}$  is the error term. A large panel including 46 countries from 1988 to 2000 and a comprehensive set of FDI determinants (55 regressors proposed by previous theories) is constructed in their dataset. It is shown from the data that the impact of model uncertainty and selection bias on FDI estimates is substantial; therefore applying HeckitBMA methodology to correct both model uncertainty and selection bias problems in FDI analysis is necessary. Their results showed mixed support for horizontal or export platform FDI theories. Trade agreements and currency unions do not encourage FDI except in specific instances (e.g., dollarization and APEC membership). Market potential exerts a decisive negative effect on the extensive margin of FDI: a host's proximity to large markets results in less new FDI inflows. This is contrary to the predictions of export platform FDI theories. Vertical FDI theories are not strongly supported since FDI is also affected by higher levels of development. Contrary to the knowledge-capital model they find no evidence that educational differences have strong effects on either margin of FDI. However, productivity is found to be a vital determinant to the extensive margin of FDI, besides, corporate taxes in source

and host countries affect both margins of FDI although bilateral tax treaties did not show much impact on FDI.

## 2. Empirical Methodology

### 2.1 The Empirical model

Inspired by Russ (2007), an empirical model based on FDI decisions in a general equilibrium framework with endogenous exchange rate is set up in Eq. (6). Built on the theoretical predictions on the dynamics of foreign start-up investments in the home country in Cavallari (2010), this model treats country productivity levels and money supplies as exogenous variables affecting the bilateral FDI flows. In addition, the typical gravity variables and other covariates representing alternative FDI theories are added into the regression as in Eicher et al. (2012). Besides, HeckitBMA methodology suggested in Eicher et al. (2012) is applied to address both model uncertainty and selection bias problems. However, Eicher et al. (2012) leaves endogeneity unsolved and includes some covariates which have long been suspected to be endogenous. Therefore, variables such as exchange rate, real GDP, real per capita GDP and GDP growth rate have been excluded in this model.

$$Y_{ijt} = \alpha_0 + \alpha_t + \beta_1 \log A_{it} + \beta_2 \log A_{jt} + \beta_3 \log M_{it} + \beta_4 \log M_{jt} + \beta_5 \log POP_{it} \\ + \beta_6 \log POP_{jt} + \beta_7 \log DIST_{ij} + \beta_8 X_{ijt} + \varepsilon_{ijt}, \quad (6)$$

where the subscripts  $i$  and  $j$  denote the source and the host country of the FDI, and  $t$  denotes the year.

The dependent variable,  $Y_{ijt}$ , is the log of FDI<sup>83</sup> from country  $i$  to  $j$  in year  $t$ ,  $A_{it}$  is labor productivity in country  $i$  at year  $t$ ,  $A_{jt}$  is labor productivity in country  $j$  at year  $t$ <sup>84</sup>,  $M_{it}$  and  $M_{jt}$  are money supplies for country  $i$  and country  $j$  at year  $t$ , respectively,  $POP_{it}$  and  $POP_{jt}$  are standard “mass” variables: the source and host country population sizes,  $DIST_{ij}$  is the physical distance between the source and host countries,  $X_{ijt}$  is a  $K \times 1$  vector of other covariates that represents alternative FDI theories,  $\beta_8$  is a  $1 \times K$  vector of parameters for  $X_{ijt}$  whereas  $\beta_1, \beta_2, \dots, \beta_7$  are scalar parameters.  $\alpha_0$  is the intercept and  $\alpha_t$  is the time fixed effect, which is standard to avoid bias caused by aggregate global shocks and possible correlations<sup>85</sup>.  $\varepsilon_{ijt}$  is the error term.

## 2.2 The HeckitBMA Approach

The HeckitBMA methodology developed by Eicher et al. (2012) is a nested BMA approach based on the Heckman selection framework:

$$Z = \theta'W + \varepsilon,$$

$$Y = \beta'X + \eta \text{ (if } Z > 0), \tag{7}$$

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<sup>83</sup> It is routine to use log transformation in FDI analyses and forecasting since the log transformation stabilizes the variance of the underlying time series. To deal with the “0” FDI observations, we have to transform the data so that the log function could be used, see section 4 for details.

<sup>84</sup> The amount of country  $i$  investments in country  $j$  might also depend on productivities in other countries; however, to simplify the problem, we only focus on the two country model to explain the bilateral FDI.

<sup>85</sup> For example, using US CPI to deflate FDI flows could introduce correlation between FDI flows.



where  $Y$  is the dependent variable,  $X$  is a set of explanatory variables, and  $Z$  is an unobserved factor indicating whether  $Y$  is observed or not.  $Z$  depends on some variables  $W$ , which may share some common variables with  $X$ <sup>86</sup>. The joint distribution of the error terms of (7) is

$$\begin{pmatrix} \eta \\ \varepsilon \end{pmatrix} \sim N \left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{\varepsilon}^2 & \sigma_{\eta\varepsilon} \\ \sigma_{\eta\varepsilon} & \sigma_{\varepsilon}^2 \end{pmatrix} \right) \quad (8)$$

If  $\sigma_{\eta\varepsilon} \neq 0$ , selection bias exists, and the usual OLS estimates of  $\beta$  in the second equation of (7) will be biased. To address this problem, Heckman (1979) suggests first fitting a probit regression on  $Z$ , and then computing the Inverse Mills Ratio,  $\hat{\lambda} = \phi[\tilde{Z}]/\Phi[\tilde{Z}]$ , which is the ratio of the probability density function of the first-stage fitted value ( $\tilde{Z} = \hat{\theta}'W$ ) over its cumulative distribution function. After that, the computed Inverse Mills Ratio is added into the second-stage regression as an additional covariate, which generates a consistent estimate of  $\beta$ . A statistically significant coefficient on the Inverse Mills Ratio indicates the presence of selection bias.

HeckitBMA addresses model uncertainty in both stages of the Heckman selection framework and applies BMA to form the weighted averaged estimates for each stage. Specifically, in stage 1, let  $Z = \alpha + \sum_{i=1}^p \theta_i W_i^* + \varepsilon$ , where  $W_1^*$ ,

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<sup>86</sup> In FDI studies, the first equation is used as the FDI participation equation which explains the decision to invest and the second equation is used as the FDI flow equation which explains the change of the quantity of FDI flows (Razin et al., 2008, 2004).

$W_2^*, \dots, W_p^*$  is a subset of  $\{W_1, W_2, \dots, W_n\}$ . The suggested underlying models that contain the  $W^*$ 's are  $\{M_1, \dots, M_S\}$ . The posterior distribution of  $\theta$  (the vector parameter with elements  $\theta_1, \theta_2, \dots, \theta_p$ ) given data  $D$  is the weighted average of the posterior distributions under the suggested models. Note that

$$pr(\theta|D) = \sum_{s=1}^S pr(\theta|M_s, D)\pi_s, \quad (9)$$

where  $pr(\theta|M_s, D)$  is the posterior distribution of  $\theta$  given model  $M_s$ , and  $\pi_s$  is the posterior probability of model  $M_s$  given the data. The posterior model probability,  $\pi_s$ , is given by

$$\pi_s = pr(M_s|D) \propto pr(D|M_s)pr(M_s), \quad (10)$$

$$\text{where } pr(D|M_s) = \int pr(D|\theta_s, M_s) pr(\theta_s|M_s) d\theta_s. \quad (11)$$

Here the constant of proportionality in (10) is chosen so that the posterior model probabilities add up to one. In equations (10) and (11),  $pr(M_s)$  and  $pr(\theta_s|M_s)$  are prior probabilities of model  $M_s$  and parameter  $\theta_s$  given  $M_s$ , respectively, and  $pr(D|M_s)$  is calculated as the integrated likelihood of model  $M_s$  over parameter  $\theta_s$ .

Based on the posterior distributions of the parameters obtained above, the estimated posterior means and variances of the BMA parameters are

$$\hat{\theta}^{BMA} = \sum_{s=1}^S \pi_s \hat{\theta}_s \quad (12)$$

$$\begin{aligned} (\hat{\sigma}^{BMA})^2 &= \widehat{Var}(\theta^{BMA}|D) = \widehat{E}(\theta^{BMA}|D)^2 - [\widehat{E}(\theta^{BMA}|D)]^2 \\ &= \sum_{s=1}^S \widehat{E}(\theta^{BMA}|D, M_s)^2 \pi_s - [\widehat{E}(\theta^{BMA}|D)]^2 \\ &= \sum_{s=1}^S \left[ \widehat{Var}(\theta^{BMA}|D, M_s) + (\hat{\theta}_s)^2 \right] \pi_s - [\widehat{E}(\theta^{BMA}|D)]^2 \end{aligned} \quad (13)$$

In the end, in order to measure the importance of a variable, the inclusion probability of this particular variable is defined as the sum of the posterior probabilities of the suggested models that contain this variable. The inclusion probability for variable  $W_k$  is written as

$$\mu^{BMA}(\theta_{W_k}) = pr(\hat{\theta}_{W_k} \neq 0|D) = \sum_{s \in U_k} \pi_s, \quad (14)$$

where  $U_k$  is the set of models that contain variable  $W_k$ . The higher the inclusion probability is, the more effective the variable. Following Eicher, Helfman and Lenkoski (2012), we consider a variable effective if its inclusion probability exceeds 50%.

First-stage estimation using the BMA approach derives the posterior model probability  $\pi_s$  and the fitted values  $\tilde{Z}_s$ <sup>87</sup> for each model, which could then be used to get the weighted average BMA estimate  $\tilde{Z}^{BMA}$

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<sup>87</sup>  $\tilde{Z}_s$  is calculated by the fitted first-stage coefficients for model  $M_s$ .

$$\tilde{Z}^{BMA} = \sum_{s=1}^S \pi_s \tilde{Z}_s. \quad (15)$$

Therefore, a “BMA version” of the Inverse Mills Ratio could be obtained by:

$$\hat{\lambda}^{BMA} = \phi[\tilde{Z}^{BMA}] / \Phi[\tilde{Z}^{BMA}].$$

In stage 2, the BMA approach is used again in a linear regression for only the observed  $Y$ 's on  $X$ 's and the Inverse Mills Ratio  $\hat{\lambda}^{BMA}$  derived from the first stage. Let  $L = \{L_1, \dots, L_N\}$  be the set of potential second-stage models. As in the first stage, the second-stage posterior model probabilities  $v_n = pr(L_n|D)$  and the posterior distribution of  $\beta_n$  for each model  $L_n \in L$  could be used to compute the second-stage posterior mean and variance:

$$\hat{\beta}^{HeckitBMA} = \sum_{n=1}^N v_n \hat{\beta}_n, \quad (16)$$

$$\begin{aligned} (\hat{\sigma}^{HeckitBMA})^2 &= \sum_{n=1}^N \left[ \widehat{Var}(\beta^{HeckitBMA} | D, L_n, \hat{\lambda}^{BMA}) + (\hat{\beta}_n)^2 \right] v_n \\ &\quad - \left[ \hat{E}(\beta^{HeckitBMA} | D, \hat{\lambda}^{BMA}) \right]^2. \end{aligned} \quad (17)$$

The HeckitBMA estimate is the weighted average of the second-stage estimates from models  $L_n$ 's that include  $\hat{\lambda}^{BMA}$  as an additional covariate. Finally, as in the first stage, the inclusion probability is calculated as:

$$\mu^{HeckitBMA}(\beta_{X_k}) = pr(\hat{\beta}_{X_k} \neq 0 | D) = \sum_{n \in Q_k} v_j, \quad (18)$$

where  $Q_k$  is the set of models that contain variable  $X_k$ . The HeckitBMA inclusion probability is different from the inclusion probability in the conventional BMA methodology in that it is based on information that also accounts for selection bias.

### 3. The Candidate Regressors

The candidate regressors in (6) are summarized in Table 1. Cavallari (2010) argues that the equilibrium dynamics of the start-up foreign investments is determined by source and host country productivity levels and current monetary shocks. It is found that a rise in home productivity reduces entry costs in home markets, which encourages foreign investments at home; whereas a rise in source country productivity will induce foreign firms to opt in favor of exports rather than direct investments, which depresses FDI at home<sup>88</sup>. What is more important, current monetary shocks can play a role in redirecting investments across countries: a home monetary expansion will discourage foreign investments when exchange rate pass through is not complete, whereas a monetary easing from the source country will boost FDI and crowd out domestic investments.

The source and host population sizes are the standard “mass” variables in the gravity equation of FDI, which also includes Distance. Geography/history

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<sup>88</sup> Razin et al. (2008) show that a positive productivity shock tends to increase FDI flow to the host country through the marginal profitability effect, however, it may also reduce the likelihood of new FDI from the source country through a total profitability effect due to the increases of the variable and setup costs.

variables, Language and Border are commonly used to capture country-pair specific effects that might affect FDI. Greater education differences between source and host countries, according to the knowledge-capital model, would promote larger vertical FDI flows into the host country<sup>89</sup>.

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<sup>89</sup> The previous FDI theories and empirical studies suggested a large set of candidate FDI determinants, which associate with different types of FDI theories. For example: trade agreements and the measure of market potential represent the horizontal or export platform FDI theories, and education differences represent the vertical FDI theories.

**Table 1** Discriptions of the candidate FDI determinants

	Variable name	Variable description <sup>e</sup>
Gravity	DIST <sub>ij</sub>	Natural log of bilateral distance
	POPI	Natural log of source population size
	POP <sub>j</sub>	Natural log of host population size
Geography/history	BORDER <sub>ij</sub>	=1 If pair share a common border
	COM_LANG <sub>ij</sub>	=1 If pair share common language
Factor endowment	EDU_DIFF <sub>ij</sub>	Source minus host education level
Productivity and growth	PRODUCTIVITY <sub>i</sub>	Source productivity (real GDP per worker)
	PRODUCTIVITY <sub>j</sub>	Host productivity (real GDP per worker)
	MRKT_POTENTIAL <sub>j</sub>	Sum of host's distance-weighted GDP to all other countries
Fiscal/monetary policy	M <sub>i</sub>	Source money supply
	M <sub>j</sub>	Host money supply
	TAX <sub>i</sub>	Source corporate effective tax rate
	TAX <sub>j</sub>	Host corporate effective tax rate
RTAs/CUs/investment <sup>a</sup>	INVEST_TREATY <sub>ij</sub>	=1 If both countries are in an investment treaty
	Bi_RT <sub>Aij</sub>	=1 if both countries are in the bilateral RTA
	NAFTA <sub>ij</sub>	=1 if both countries are in NAFTA
	APEC <sub>ij</sub>	=1 if both countries are in APEC
Economic risk <sup>b</sup>	ECON_RISK <sub>i</sub>	Source Economic risk
	ECON_RISK <sub>j</sub>	Host Economic risk
Financial risk <sup>c</sup>	FIN_RISK <sub>i</sub>	Source financial risk
	FIN_RISK <sub>j</sub>	Host financial risk
Political risk	BUREAU <sub>i</sub>	Source bureaucratic quality
	BUREAU <sub>j</sub>	Host bureaucratic quality
	CORRUPT <sub>i</sub>	Source corruption
	CORRUPT <sub>j</sub>	Host corruption
	DEMOCRATIC <sub>i</sub>	Source democratic accountability
	DEMOCRATIC <sub>j</sub>	Host democratic accountability
	ETHNIC_TENSION <sub>i</sub>	Source ethnic tentions
	ETHNIC_TENSION <sub>j</sub>	Host ethnic tentions
	EXTERN_CONFLICT <sub>i</sub>	Source external conflict
	EXTERN_CONFLICT <sub>j</sub>	Host external conflict
	GOV_STABILITY <sub>i</sub>	Source government stability
	GOV_STABILITY <sub>j</sub>	Host government stability
	INTERN_CONFLICT <sub>i</sub>	Source internal conflict
	INTERN_CONFLICT <sub>j</sub>	Host internal conflict
	INV_PROFILE <sub>i</sub>	Source investment profile <sup>d</sup>
	INV_PROFILE <sub>j</sub>	Host investment profile
	LAW_ORDER <sub>i</sub>	Source law and order
	LAW_ORDER <sub>j</sub>	Host law and order
	MILITARY <sub>i</sub>	Source military in politics
MILITARY <sub>j</sub>	Host military in politics	
RELIGIOUS_TENSION <sub>i</sub>	Source religion in politics	
RELIGIOUS_TENSION <sub>j</sub>	Host religion in politics	
SOCIO_ECON <sub>i</sub>	Source socioeconomic conditions	
SOCIO_ECON <sub>j</sub>	Host socioeconomic conditions	

**Notes:**

a. RTAs means regional trade agreements, which includes bilateral RTAs, North America Free Trade Agreement (NAFTA) and Asia-Pacific Economic Community (APEC) in this paper.

b. Economic Risk Rating is the overall economic risk rating, which defined by ICRG is the total points of 5 economic risk indicator components: GDP per head of population, real annual GDP growth, annual inflation rate, budget balance as percent of GDP, current account as percent of GDP.

c. Financial Risk Rating is the overall financial risk rating, which defined by ICRG is the total points of 5 financial risk indicators components: total foreign debt as percent of GDP, debt service as percent of exports of goods and services, current account as percent of exports of goods and services, international liquidity as months of import cover, and exchange rate stability as percentage change.

d. Investment profile measures government attitude toward inward investment as determined by risk to operations, taxation, repatriation and labor costs.

e. The set of variables used in this paper is based on Eicher et al. (2012), who made a comprehensive explanation of the importance of all the FDI determinants motivated by the previous literature. However, the variables we chose in this paper are different from the variables in Eicher et al. (2012) mainly due to the endogeneity problem, the differences are discussed in detail in section 4.

Blonigen et al. (2007) find that FDI into a host country may depend on the FDI in proximate countries (host's Market Potential) because it attracts more export-platform FDI into the host country<sup>90</sup>. However, it is also found that the estimated spatial interdependence is quite sensitive to the sample of countries one examines.

The effects of taxes on FDI have long been paid attention to by both international and public economists. Razin and Sadka (2007b, Ch 10) found empirically that a rise in host country tax rates reduces the quantity of local production by foreign multinational firms; whereas the increase of the source country's corporate taxes induce MNE to establish new affiliates abroad. However, Blonigen (2005) discussed the effect of Corporate Tax Rates (and Tax Treaties) on FDI and pointed out the effects of taxes on FDI can vary substantially by type of taxes, measurement of FDI activity, and tax treatment in the host and parent countries.

Bilateral investment treaties (or BITs) are a set of treaties which guarantee that certain standards can be enforced via binding investor-to-state dispute settlement outside the domestic juridical system. BITs make foreign investors more confident about the quality of the institutions and the enforceability of the law in host countries. Neumayer and Spess (2005) provide the first rigorous quantitative evidence that a higher number of BITs increases the FDI that flows to a developing country. Regional Trade Agreements (RTAs) are additional

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<sup>90</sup> A priori, the effect could go either way: positive or negative.



important factors which indirectly affect FDI through export platform and/or horizontal/vertical FDI incentives. However, RTAs might increase FDI to an export platform within the RTA, and reduce it to all other members of the RTA. To separate trade effects that arise within and between RTAs, Eicher et al. (2012) suggest including all possible individual RTAs rather than only one average catch-all RTA effect.

Financial risk is also a crucial determinant of FDI. Razin et al. (2008) include financial risk in their econometric model of FDI. Economic and Political Risk indexes have also featured prominently in recent empirical literatures to capture factors that impact the return on investment. Jinjarak (2007) provides cross country industry evidence on the relationship between the host country's macro risks and FDI activities. It is found that US FDI in industries with a higher share of vertical FDI respond disproportionately more to negative effects of macro-level demand, supply, and sovereign risks.

#### **4. Data**

The dataset in this paper is based on Eicher et al. (2012) and Razin et al. (2008). Eicher et al. (2012) has a panel which covers years 1988–2000 and includes 46 countries in their big global sample, which includes data on FDI flows, population, productivity, real GDP per capita, distance, common language, education difference, financial risk rating, market size, colony, border, GDP

growth rate, market potential, corporate tax rates, real exchange rate, investment treaties, regional trade agreements, currency unions, and political risks. Because the exchange rate is endogenous in our empirical model, we exclude the real exchange rate from the determinants for FDI, along with other variables which have long been suspected to be endogenous: log of real GDP, log of real GDP per capita and GDP growth rate. In addition, due to the assumption of the endogeneity of the exchange rate, it is necessary to select countries with flexible exchange rates in order to get a better estimation. Therefore, from the global sample in Eicher et al. (2012), twelve countries are selected based on the commonly used de facto classification scheme developed by Levy-Yeyati and Sturzenegger (2005)<sup>91</sup>. They use cluster analysis techniques to group countries' regimes on the basis of the volatility of the exchange rate relative to the relevant anchor currency<sup>92</sup>, the volatility of exchange rate changes, and the volatility of reserves. Finally, our dataset possesses an unbalanced panel that covers years 1988–2000 and includes 12 countries (5 non-OECD)<sup>93</sup>, 112 unique country pairs with 1442 total observations, of which 62 percent FDI flows are unobservable<sup>94</sup>. Due to the limited countries selected, some variables are not applicable and excluded: colony, currency unions and some regional trade agreements such as

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<sup>91</sup> In this paper, based on Levy-Yeyati and Sturzenegger (2005), we select a country as a country with flexible exchange rates if the years when its exchange rates are classified as float are more than the years when its exchange rates are classified as fix over the period 1988-2000.

<sup>92</sup> In Levy-Yeyati and Sturzenegger (2005), for each country, the volatility of its exchange rate is calculated relative to the currency of reference for this country. For example, the US dollar is the currency of reference for Australia, Canada, Chile (74-89; 99-), Colombia, Japan, Pakistan, South Africa, Turkey and UK (95-); besides, German Mark is the currency of reference for Poland, UK (87-94) and United States.

<sup>93</sup> The countries in this paper are listed in Table 3 based on our classified countries with flexible exchange rates.

<sup>94</sup> Unobservable means the data for FDI flow is either 0 or missing.

EEA, EFTA and EU.

However, there are two important variables added into the dataset, which are source and host country money supplies, which are obtained from World Development Indicators (WDI). Broad money (current LCU<sup>95</sup>) is used here for the choice of the money supply variables. Broad money is defined by the World Bank as the sum of currency outside banks; demand deposits other than those of the central government; the time, savings, and foreign currency deposits of resident sectors<sup>96</sup> other than the central government; bank and traveler's checks; and other securities such as certificates of deposit and commercial paper. In addition, an index of overall economic risk rating (obtained from International Country Risk Guide, or ICRG) has been added into the data, which is the total points of five economic risk indicator components: GDP per head of population, real annual GDP growth, annual inflation rate, budget balance as percent of GDP, current account as percent of GDP<sup>97</sup>.

Data sources are provided in Table 2 and the frequencies of FDI host/source flows are provided in Table 3. FDI flows data was acquired from the OECD International Direct Investment Database and deflated by the US CPI. It is then transformed following Eicher et al. (2012) by adding a "1" to all FDI

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<sup>95</sup> LCU means data are in current local currency.

<sup>96</sup> Resident sectors exclude government and corporations.

<sup>97</sup> Economic risks matter since they affect the investors' long term estimates of profitability. Among the five risk indicators, inflation is a principal concern of investors largely because it reduces the value of host-country currency, which lowers profits of the investments. Moreover, inflation confounds corporate attempts to produce long-term estimates of profitability. In addition, the aggregate debt indicator for the host country (such as budget balance as percent of GDP), is a measure of the country's credit risk indicating the stability of host country's economy. Therefore it could affect the confidence of the international institutions in its economy. Moreover, stronger economic performance (such as higher GDP per capita and real annual GDP growth) is also positively associated with FDI inflows. (Lewandowski, 1997).

observations, so that the dependent variable becomes  $\ln[\textit{flow} + 1]$  instead of  $\ln[\textit{flow}]$ , since  $\ln[0]$  is not defined, although this method might cause inconsistency problems on the estimates. The education difference between the source and the host countries was obtained from UN human development indicators (HDI), which provides source-host differences in average years of schooling for those over age 25, reported every ten years for 1980-2000. Linear interpolation was used for other years. Country productivities were taken from Penn World Tables 6.3's data for real GDP Chain per worker (1\$ per worker in 2005 Constant Prices). Investment treaty indicators were gained from ICSID Database of Bilateral Investment Treaties. Market potential is constructed as the sum of host's distance-weighted GDP to all other countries based on the method implemented by Blonigen et al. (2007). In Blonigen et al. (2007), the weight for a particular country is calculated using an inverse distance function where the shortest bilateral distance within the sample is divided by the distance between this particular country and the host country. So only the country with shortest bilateral distance to the host within the sample receives a weight of unity and all other distances within the sample receive a weight that declines with the increase of the bilateral distance.

**Table 2** Data Source

Variable	Source
FDI flows	International Direct Investment Database (OECD)
Money supply <sup>a</sup>	World Development Indicators (WDI)
Productivity <sup>b</sup>	Penn World Tables 6.3
Distance	Andrew Rose's website: <a href="http://www.haas.berkeley.edu/~arose">www.haas.berkeley.edu/~arose</a>
Population	World Development Indicators (WDI)
Common Language	Andrew Rose's website: <a href="http://www.haas.berkeley.edu/~arose">www.haas.berkeley.edu/~arose</a>
Common Border	Andrew Rose's website: <a href="http://www.haas.berkeley.edu/~arose">www.haas.berkeley.edu/~arose</a>
Colonial Relationship	Andrew Rose's website: <a href="http://www.haas.berkeley.edu/~arose">www.haas.berkeley.edu/~arose</a>
Education Attainment	HDI (UN human development indicators)
Market Potential	Constructed based on Blonigen et al.(2007)
Corporate Tax Rate	World Tax Database <sup>c</sup>
Investment Treaty	ICSID Database of Bilateral Investment Treaties
Regional Trade Agreement (RTA)	Andrew Rose's website: <a href="http://www.haas.berkeley.edu/~arose">www.haas.berkeley.edu/~arose</a>
CU and PTA Memberships	Eicher and Henn (2009)
Economic, Financial and Political Risk Ratings	International Country Risk Guide from PRS Group
Lagged negative FDI dummy <sup>d</sup>	Constructed based on Razin et al. (2004)

## Notes:

a. In this paper, broad money (current LCU) is selected as the money supply variables. Broad money is defined by the World Bank as the sum of currency outside banks; demand deposits other than those of the central government; the time, savings, and foreign currency deposits of resident sectors other than the central government; bank and traveler's checks; and other securities such as certificates of deposit and commercial paper. See <http://data.worldbank.org/indicator/FM.LBL.BMNY.CN> for reference.

b. We use Real GDP Chain per worker (1\$ per worker in 2005 Constant Prices) from PWT 6.3 for productivity.

c. Poland's tax rate data is not available from 1988-1990 in World Tax Database; however, according to Piotrowska and Vanborren (2008) the ratio of corporate tax revenues and corporate income in Poland was stable between 1980-2004 in the previous studies, so we estimate the tax rates from 1988-1990 based on 1991's tax rate.

d. As in Razin et al. (2004), this dummy variable is an instrument that proxies negative FDI lag, which is used to account for negative FDI flows (the liquidation of foreign subsidiaries).

**Table 3** Frequency of host/source observations, by country

	FDI hosts		FDI sources	
	N obs	Obs#0	N obs	Obs#0
Australia	83	69	75	65
Canada	39	39	39	39
Japan	67	50	108	107
Poland	55	53	32	23
Turkey	36	28	15	6
United Kingdom	96	79	116	115
United States	99	99	118	116
South Africa	39	29	39	37
Chile	41	38	27	8
Colombia	24	22	14	3
Pakistan	1	0	4	3
Philippines	49	48	34	23
Total	629	554	621	545

## 5. Robust FDI Determinants

The main interest in this paper is to identify robust determinants of the intensive and extensive margins of FDI when exchange rates are endogenous within the framework of selection bias and model uncertainty. The key explanatory variables we examine, besides the conventional gravity variables, are productivities and money supplies from source and host countries. HeckitBMA approach is implemented, which assigns the greatest weight to more parsimonious models that score much better in terms of joint likelihoods or Bayesian Information Criteria (BIC).

### *5.1 The Base Model Results*

The regression results of the baseline model in (6) are listed in Table 4. The gravity regressors: population of the host and source and distance between them get high inclusion probabilities with correct signs at both margins of FDI. Money supplies are not shown to exert effects on FDI flows; however, host country money supply reveals a decisive effect on the decision to invest. A monetary ease in the host country lowers the probability of setting up a new affiliate abroad by investors. This fact coincides with Cavallari (2010)'s argument that a home monetary expansion discourages the start-up foreign investments when exchange rate pass through is not complete.

**Table 4** Robust FDI Determinants---HeckitBMA estimatesa for both FDI flow and FDI selection equations

Variable	FDI flow			FDI selection		
	Posterior Inclusion Probability	Posterior Mean	Posterior Standard Deviation	Posterior Inclusion Probability	Posterior Mean	Posterior Standard Deviation
LOG.Mi.	0.003	0.000	0.001	0.003	0.000	0.001
LOG.Mj.	0.049	-0.003	0.015	0.946	-0.096	0.038
LOG.PRODUCTIVITYi.	1.000	1.661	0.246	1.000	1.439	0.225
LOG.PRODUCTIVITYj.	0.843	0.676	0.345	0.029	-0.012	0.078
LOG.POPULATIONi.	1.000	0.757	0.082	1.000	0.557	0.085
LOG.POPULATIONj.	1.000	0.505	0.078	0.701	0.182	0.137
LOG.DISTANCE.	0.881	-0.419	0.199	1.000	-0.576	0.120
NEG_FDI_LAG	0.118	-0.045	0.140	1.000	1.286	0.303
COM_LANGij	1.000	0.704	0.176	1.000	0.967	0.153
BORDERij	0.176	0.172	0.417	0.002	0.006	61.177
EDU_DIFFij	0.774	-0.072	0.049	0.546	-0.045	0.046
LOG.MRKT_POTENTIALj	0.068	-0.022	0.092	0.078	-0.025	0.096
TAXi	0.003	0.000	0.001	0.017	0.000	0.002
TAXj	0.003	0.000	0.001	0.077	-0.002	0.007
INVEST_TREATYij	0.003	0.000	0.011	0.011	0.002	0.025
Bi_RTaij	0.003	0.000	0.014	0.105	-0.047	0.154
NAFTAij	0.175	0.171	0.417	0.002	0.006	61.177
APECij	0.003	0.000	0.008	0.002	0.000	0.007
ECON_RISKi	0.010	0.000	0.003	0.003	0.000	0.001
FIN_RISKi	0.006	0.000	0.001	0.004	0.000	0.001
BUREAUi	0.003	0.000	0.009	0.050	-0.010	0.048
CORRUPTi	0.003	0.000	0.004	0.250	-0.047	0.090
DEMOCRATICi	0.022	0.003	0.026	0.002	0.000	0.003
ETHNIC_TENSIONi	0.006	0.000	0.006	0.003	0.000	0.003
EXTERN_CONFLICTi	0.003	0.000	0.002	0.004	0.000	0.004
GOV_STABILITYi	0.003	0.000	0.002	0.002	0.000	0.001
INTERN_CONFLICTi	0.005	0.000	0.004	0.016	-0.001	0.007
INV_PROFILEi	0.141	0.011	0.030	0.019	0.001	0.012
LAW_ORDERi	0.003	0.000	0.004	0.018	-0.002	0.015
MILITARYi	0.011	-0.001	0.014	0.035	0.005	0.027
RELIGIOUS_TENSIONi	0.012	0.002	0.018	0.003	0.000	0.005
SOCIO_ECONi	0.003	0.000	0.002	0.066	-0.005	0.022
ECON_RISKj	0.031	-0.001	0.009	0.114	0.007	0.021
FIN_RISKj	0.010	0.000	0.002	0.998	0.057	0.017
BUREAUj	0.038	-0.009	0.051	0.044	-0.008	0.041
CORRUPTj	0.013	-0.001	0.014	0.211	-0.042	0.089
DEMOCRATICj	0.003	0.000	0.004	0.003	0.000	0.005
ETHNIC_TENSIONj	0.337	0.049	0.079	0.875	0.183	0.094
EXTERN_CONFLICTj	0.074	-0.009	0.036	0.002	0.000	0.002
GOV_STABILITYj	0.009	0.000	0.004	0.040	0.002	0.011
INTERN_CONFLICTj	0.009	0.000	0.006	0.150	-0.016	0.043
INV_PROFILEj	0.003	0.000	0.002	0.215	0.018	0.038
LAW_ORDERj	0.004	0.000	0.006	0.005	0.000	0.006
MILITARYj	0.012	-0.001	0.015	0.015	0.002	0.022
RELIGIOUS_TENSIONj	0.201	0.059	0.127	0.765	0.212	0.138
SOCIO_ECONj	0.398	0.039	0.055	0.009	-0.001	0.008
PAST_FDI_DUM				1.000	1.953	0.143
IMR		0.121a	0.158			
BIC	-254.7031					
N	554			1442		

Notes:

a. HeckitBMA statistics are based on the best models selected in the selection and flow equations.

b. The posterior mean for the Inverse Mills Ratio is conditional on inclusion. Based on the posterior mean, posterior standard deviation and the sample size of the flow equation, the 95% Credible Interval for the Inverse Mills Ratio does not contain zero.

Productivities in source and host countries show strong positive effects on the intensive margin of FDI, and host productivity has negative effect on the extensive margin of FDI (although its inclusion probability is very low). This confirms Razin et al. (2008)'s findings on the conflicting effects of productivity changes on bilateral FDI flows. However, we find a strong positive relationship between the source country productivity and the extensive margin of FDI, which is at odds with Razin et al. (2008). Whether the country-pairs share a common language is also an important factor affecting the likelihood and volume of FDI flows. Greater education differences discourage FDI at both margins. That is opposite to the predictions of the knowledge-capital model which addresses the vertical FDI motivations. Additional factors that exert a negative effect on the extensive margin of FDI include such country characteristics as the ethnic and religious tension risks in the host and an economic factor: financial risk in the host<sup>98</sup>. The dummy variable which indicates the existence of past FDI source-host relations is shown to exert a decisive positive effect on the decision to invest. This variable is used as an exclusion restriction variable in Razin et al. (2008), which also finds a positive coefficient and interprets the positive effect as an indication for a lower threshold barrier for pairs of countries that had positive FDI flows in the past<sup>99</sup>. Moreover, the estimated posterior coefficient and standard deviation of the Inverse Mills Ratio implies that the 95% credible interval

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<sup>98</sup> According to the ICRG from the PRS Group, the higher risk index is associated with less risk in the country. Table 4 shows that higher risk index (meaning less risk in the host) is associated with larger amount of new FDI.

<sup>99</sup> According to Razin et al. (2008), FDI flows are actually observed only when their profitability exceeds a certain (unobserved) threshold, which is determined by the total profitability condition (depending on both the variable cost and the setup cost) for the new investment. Empirically, past FDI is used as a proxy for the lower threshold barrier.



for the coefficient on IMR does not contain zero. According to the Heckman selection methodology, it proves that selection bias is present in the data and pure OLS estimates are going to be downward biased. So it is necessary to first look into the selection (participation) stage of the FDI decision in order to avoid the omitted variables bias (IMR) that contaminates OLS estimates.

### *5.2 Sensitivity Results*

In the first sensitivity check, we eliminate the time fixed effects which have low inclusion probabilities in the baseline model estimation. The results are shown in Table 5. There is not much difference comparing to the base model regarding the robust determinants of the extensive and intensive margins of FDI. The only difference is that the host country's socioeconomic conditions become effective --- that is, better economic conditions in the host attract more FDI inflows.

**Table 5** Robust FDI Determinants (HeckitBMA estimates without time fixed effects)

Variable	FDI flow			FDI selection		
	Posterior Inclusion Probability	Posterior Mean	Posterior Standard Deviation	Posterior Inclusion Probability	Posterior Mean	Posterior Standard Deviation
LOG.Mi.	0.007	0.000	0.002	0.004	0.000	0.001
LOG.Mj.	0.089	-0.005	0.020	0.936	-0.095	0.041
LOG.PRODUCTIVITYi.	1.000	1.635	0.255	1.000	1.465	0.227
LOG.PRODUCTIVITYj.	0.850	0.666	0.342	0.033	-0.013	0.083
LOG.POPULATIONi.	1.000	0.751	0.082	1.000	0.556	0.085
LOG.POPULATIONj.	1.000	0.499	0.079	0.636	0.161	0.138
LOG.DISTANCE.	0.850	-0.396	0.212	1.000	-0.585	0.120
NEG_FDI_LAG	0.170	-0.066	0.166	1.000	1.284	0.304
COM_LANGij	0.999	0.687	0.179	1.000	0.971	0.155
BORDERij	0.221	0.216	0.458	0.003	0.009	75.719
EDU_DIFFij	0.759	-0.072	0.050	0.612	-0.051	0.047
LOG.MRKT_POTENTIALj	0.128	-0.042	0.125	0.099	-0.032	0.109
TAXi	0.006	0.000	0.001	0.021	0.000	0.002
TAXj	0.006	0.000	0.001	0.091	-0.002	0.008
INVEST_TREATYij	0.008	0.001	0.016	0.016	0.003	0.031
Bi_RTaij	0.007	0.001	0.020	0.117	-0.052	0.161
NAFTAij	0.221	NA	NA	0.003	0.009	75.719
APECij	0.009	-0.001	0.015	0.003	0.000	0.008
ECON_RISKi	0.021	0.000	0.004	0.003	0.000	0.001
FIN_RISKi	0.014	0.000	0.002	0.005	0.000	0.001
BUREAUi	0.007	-0.001	0.014	0.061	-0.012	0.054
CORRUPTi	0.007	0.000	0.007	0.270	-0.051	0.094
DEMOCRATICi	0.032	0.005	0.032	0.003	0.000	0.004
ETHNIC_TENSIONi	0.010	0.000	0.007	0.004	0.000	0.003
EXTERN_CONFLICTi	0.006	0.000	0.004	0.005	0.000	0.004
GOV_STABILITYi	0.010	0.000	0.005	0.003	0.000	0.002
INTERN_CONFLICTi	0.011	0.000	0.006	0.018	-0.001	0.008
INV_PROFILEi	0.164	0.012	0.032	0.026	0.002	0.014
LAW_ORDERi	0.006	0.000	0.007	0.019	-0.002	0.016
MILITARYi	0.020	-0.002	0.020	0.048	0.006	0.032
RELIGIOUS_TENSIONi	0.014	0.001	0.017	0.004	0.000	0.005
SOCIO_ECONi	0.008	0.000	0.004	0.075	-0.006	0.024
ECON_RISKj	0.048	-0.002	0.011	0.145	0.009	0.023
FIN_RISKj	0.020	0.000	0.003	0.997	0.059	0.017
BUREAUj	0.053	-0.012	0.060	0.045	-0.008	0.042
CORRUPTj	0.019	-0.002	0.017	0.240	-0.048	0.095
DEMOCRATICj	0.006	0.000	0.007	0.004	0.000	0.007
ETHNIC_TENSIONj	0.336	0.051	0.083	0.852	0.176	0.098
EXTERN_CONFLICTj	0.044	-0.004	0.022	0.004	0.000	0.003
GOV_STABILITYj	0.009	0.000	0.003	0.052	0.003	0.013
INTERN_CONFLICTj	0.018	-0.001	0.009	0.173	-0.019	0.046
INV_PROFILEj	0.013	0.000	0.008	0.254	0.021	0.041
LAW_ORDERj	0.010	0.000	0.010	0.007	0.000	0.007
MILITARYj	0.023	-0.003	0.021	0.019	0.002	0.025
RELIGIOUS_TENSIONj	0.189	0.050	0.112	0.715	0.193	0.141
SOCIO_ECONj	0.531	0.054	0.059	0.013	-0.001	0.010
PAST_FDI_DUM				1.000	1.949	0.144
IMR		0.110a	0.180			
BIC	-254.63					
N	554			1442		

Note: a. The posterior mean for the Inverse Mills Ratio is conditional on inclusion. Based on the posterior mean, posterior standard deviation and the sample size of the flow equation, the 95% Credible Interval for the Inverse Mills Ratio does not contain zero.

**Table 6** Robust FDI Determinants (HeckitBMA estimates with lagged measure of productivity)

Variable	FDI flow			FDI selection		
	Posterior Inclusion Probability	Posterior Mean	Posterior Standard Deviation	Posterior Inclusion Probability	Posterior Mean	Posterior Standard Deviation
LOG.Mi.	0.011	0.000	0.005	0.005	0.000	0.002
LOG.Mj.	0.027	-0.001	0.010	0.992	-0.104	0.032
LOG.PRODUCTIVITYi.	1.000	1.661	0.246	1.000	1.373	0.189
LOG.PRODUCTIVITYj.	0.384	0.294	0.400	0.012	-0.002	0.031
LOG.POPULATIONi.	1.000	0.766	0.085	1.000	0.595	0.090
LOG.POPULATIONj.	1.000	0.566	0.087	0.922	0.258	0.108
LOG.DISTANCE.	0.677	-0.291	0.241	1.000	-0.547	0.118
NEG_FDI_LAG	0.036	-0.011	0.068	1.000	1.308	0.301
COM_LANGij	0.988	0.610	0.216	1.000	0.992	0.156
BORDERij	0.361	0.432	0.636	0.005	0.013	103.824
EDU_DIFFij	0.829	-0.086	0.049	0.118	-0.007	0.022
LOG.MRKT_POTENTIALj	0.012	-0.002	0.029	0.022	-0.005	0.044
TAXi	0.012	0.000	0.003	0.030	0.000	0.003
TAXj	0.007	0.000	0.001	0.090	-0.002	0.008
INVEST_TREATYij	0.007	0.001	0.020	0.015	0.003	0.027
Bi_RTaij	0.004	0.000	0.015	0.051	-0.019	0.096
NAFTAij	0.360	NA	NA	0.005	0.013	103.824
APECij	0.003	0.000	0.008	0.006	0.000	0.013
ECON_RISKi	0.096	-0.004	0.014	0.006	0.000	0.001
FIN_RISKi	0.003	0.000	0.001	0.007	0.000	0.001
BUREAUi	0.005	-0.001	0.013	0.015	-0.002	0.020
CORRUPTi	0.004	0.000	0.006	0.265	-0.049	0.090
DEMOCRATICi	0.015	0.002	0.024	0.006	0.000	0.006
ETHNIC_TENSIONi	0.004	0.000	0.004	0.006	0.000	0.004
EXTERN_CONFLICTi	0.004	0.000	0.003	0.006	0.000	0.004
GOV_STABILITYi	0.004	0.000	0.002	0.007	0.000	0.003
INTERN_CONFLICTi	0.020	-0.001	0.011	0.015	-0.001	0.006
INV_PROFILEi	0.111	0.008	0.027	0.048	0.003	0.018
LAW_ORDERi	0.003	0.000	0.005	0.037	-0.004	0.023
MILITARYi	0.031	-0.005	0.030	0.016	0.001	0.014
RELIGIOUS_TENSIONi	0.004	0.000	0.008	0.006	0.000	0.007
SOCIO_ECONi	0.006	0.000	0.006	0.064	-0.005	0.023
ECON_RISKj	0.017	-0.001	0.005	0.123	0.007	0.022
FIN_RISKj	0.011	0.000	0.002	0.964	0.048	0.018
BUREAUj	0.030	-0.007	0.047	0.020	-0.002	0.022
CORRUPTj	0.014	-0.001	0.014	0.044	-0.006	0.033
DEMOCRATICj	0.004	0.000	0.006	0.007	0.000	0.010
ETHNIC_TENSIONj	0.340	0.051	0.081	0.998	0.248	0.067
EXTERN_CONFLICTj	0.079	-0.010	0.037	0.015	-0.001	0.010
GOV_STABILITYj	0.014	0.001	0.006	0.100	0.006	0.019
INTERN_CONFLICTj	0.008	0.000	0.005	0.119	-0.012	0.036
INV_PROFILEj	0.004	0.000	0.002	0.135	0.010	0.030
LAW_ORDERj	0.011	0.001	0.010	0.007	0.000	0.005
MILITARYj	0.006	0.000	0.007	0.008	0.000	0.008
RELIGIOUS_TENSIONj	0.657	0.214	0.172	0.934	0.276	0.106
SOCIO_ECONj	0.626	0.066	0.060	0.016	-0.001	0.010
PAST_FDI_DUM				1.000	1.924	0.144
IMR		0.139a	0.204			
BIC	-229.6274					
N	520			1330		

Note: a. The posterior mean for the Inverse Mills Ratio is conditional on inclusion. Based on the posterior mean, posterior standard deviation and the sample size of the flow equation, the 95% Credible Interval for the Inverse Mills Ratio does not contain zero.

As a further sensitivity check, the lagged productivities for source and host countries are used instead of the current period productivities in order to alleviate the suspected endogeneity problem of the productivities. The results are listed in Table 6. In this case, the host productivity loses its effectiveness on the FDI volumes. Education difference demonstrates stronger negative effect on FDI inflows compared to the baseline results, whereas it loses power in affecting the FDI participation decision. The importance of host ethnic and religious tensions is intensified in the FDI selection equation. In addition, another two factors --- religious tension and socioeconomic conditions in the host --- are added into the effective determinants of the intensive margin of FDI.

## **6. Conclusion**

The contributions of this paper could be summarized as follows: first, an empirical model of FDI decisions in a general equilibrium framework with endogenous exchange rate is setup, which is based on the recent growing literature that treats fundamental country-level macroeconomic factors as underlying exogenous variables affecting aggregate country-level FDI behavior. It is opposed to the previous empirical studies which generate conflicting results based on partial equilibrium models of FDI by modeling firm-level decisions and examine how exogenous factors, such as taxes and exchange rates, affect these firm-level decisions. This model employs aggregate money supplies from the

source and host countries as the determinants of FDI, which has policy implications on attracting country-level FDI. Along with the endogenous exchange rates, other covariates which have long been suspected to be endogenous in previous studies have been excluded in this model, such as real GDP, real per capita GDP and GDP growth rate.

Second, besides the endogeneity problem, this model also considers the possibility of model uncertainty and selection bias caused by missing data, and deal with those two problems simultaneously by incorporating HeckitBMA methodology suggested in Eicher et al. (2012). Confronting model uncertainty brought by variety of FDI theories and empirical approaches, HeckitBMA derives the posterior distribution of the estimates as the weighted average of the predictive distribution under each model. It assigns the greatest weight to more parsimonious models that score dramatically better in terms of joint likelihoods or Bayesian Information Criteria. As for selection bias, HeckitBMA allows to estimate the weighted average of different models in two separate stages of the FDI decisions: (a) the decision on whether to invest abroad or not and (b) how much to invest in a particular host country. So the gist of this paper is to deal with endogeneity, model uncertainty and selection bias simultaneously in FDI determinant studies by incorporating HeckitBMA methodology into a general equilibrium model of FDI, which depends on the underlying fundamental country-level macroeconomic factors.

Third, this paper provides strong evidence on the influence of host country

money supply to FDI participation decision. A monetary expansion in the host country is shown to deter new investments (extensive margin) from foreign countries. This fact coincides with Cavallari (2010)'s argument that a home monetary expansion discourages the start-up foreign investments when exchange rate pass through is not complete. However, there is not enough evidence that the money supplies would affect the FDI flows (intensive margin).

We find support for all gravity regressors which affect both margins of FDI. However, there is not much evidence for horizontal or export platform FDI theories. Trade agreements and Market potential do not exert robust effects on either the extensive or intensive margins of FDI. Vertical FDI theory is not strongly supported from the data either. Opposite to the predictions of the knowledge-capital model, greater education difference is found to discourage FDI at both margins. As in Razin et al. (2008), the increase of the productivities in source and host countries will raise the amount of the current investments, while lower the probability of investing. However, we find a strong positive relationship between the source country productivity and the extensive margin of FDI, which is at odds with Razin et al. (2008). Corporate tax rates and Bilateral tax treaties are shown to exert no impact on FDI, which confirms the empirical findings of Eicher et al. (2012). Socioeconomic conditions in the host country become effective to FDI flows in the model without time fixed effects or with lagged productivities.

The main limitation of this paper is the limited countries in the dataset due

to the constraint of endogenous exchange rate. However, recent empirical studies have found evidence on the impact of exchange rate regimes on bilateral FDI flows (Abbott et al., 2011, 2012). Therefore, by adding an exchange rate regime dummy vector to the FDI determinants might be helpful to expand the dataset to a global sample. Besides, the Breusch-Pagan test shows that the second stage FDI flow regression has heteroskedasticity problem. Silva and Tenreyro (2006) emphasized the importance of considering heteroskedasticity in the error terms in the usual log linear specification of the gravity equation. It is argued that under heteroskedasticity, the parameters of log linearized models estimated by OLS lead to biased and inconsistent estimates of the true elasticities. However, how to deal with heteroskedasticity in HeckitBMA setting needs to be studied further.

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