FIGHTING OVER UNCERTAIN DEMAND: INVESTMENT COMMITMENT VERSUS FLEXIBILITY

by

Gerda Dewit
National University of Ireland, Maynooth

Dermot Leahy
University College Dublin

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Abstract: This paper examines the trade-off between strategic investment commitment and flexibility under oligopoly. Facing demand uncertainty, firms decide whether to commit to investment early or wait until the uncertainty has been resolved. Two endogenous timing games are considered which differ in their characterisation of commitment. We show how uncertainty, the cost of capital and cost differences between firms demarcate the equilibrium outcomes. It is shown that a lower cost firm will forego flexibility at higher uncertainty. The nature of commitment will determine whether and for which ranges of uncertainty and costs, leader-follower investment arises. A brief welfare analysis is provided.

Key Words: Uncertainty, Investment Commitment, Flexibility, Oligopoly, Action Commitment, Observable Delay.

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Address Correspondence: Gerda Dewit, National University of Ireland, Maynooth, Department of Economics, Maynooth, Ireland, *tel.:* (+)353-(0)1-7083776, *fax:* (+)353-(0)1-7083934, *E-mail:* Gerda.Dewit@may.ie; Dermot Leahy, University College Dublin, Department of Economics, Belfield, Dublin 4, Ireland, *tel.:* (+)353-(0)1-7067620, *fax:* (+)353-(0)1-2830068, *E-mail:* Dermot.M.Leahy@ucd.ie .

1. Introduction

Investment decisions are typically made under uncertainty and once implemented are at least partially irreversible. The irreversible nature of investment has been widely discussed, not least in the industrial organisation literature in the context of strategic commitment. The idea that firms may have an incentive to commit in advance to high investment levels in order to affect the strategic environment in which future outputs are chosen is now well understood[1]. However, the literature on strategic behaviour has largely ignored the fact that most investment decisions are made against a backdrop of uncertainty regarding future economic conditions. By contrast, other recent work on investment takes this stylised fact as a starting point by assuming that uncertainty naturally shapes the environment in which investment decisions are examined. In their option value approach, Dixit and Pindyck (1994) stress the importance of delaying investment so as to retain flexibility.

The purpose of this paper is to study the trade-off between investment commitment and flexibility in an oligopoly setting[2]. The theme of commitment versus flexibility in a strategic environment is not entirely new. Appelbaum and Lim (1985) considered to what extent an incumbent firm, threatened by entry from a competitive fringe, should pre-commit to output or keep its output flexible instead. Sadanand and Sadanand (1996) and Spencer and Brander (1992) examine models with uncertainty where two firms compare commitment versus flexibility with respect to their output decisions. Spencer and Brander also show, in an alternative model with uncertainty, how the same trade-off affects the investment timing of *one* firm in a set-up where the other firm cannot invest or commit[3].

The model we consider is closest to this last set-up, but here *two* rival firms have a choice between investing early or later when future demand conditions are uncertain. Ours is the

[1] Tirole (1988) provides a textbook treatment of this issue.

[2] Our paper examines microeconomic aspects of the trade-off between investing early or late. From a macroeconomic perspective, uncertainty induced investment delay, while enhancing flexibility, may lead to a slowdown in economic growth (Hassett and Metcalf, 1999; Darby et al., 1999).

[3] Vives (1989) focuses on technological flexibility, which is quite different from the flexibility in timing discussed here. In his model higher investment can lower the slope of the marginal cost curve and there need not be a trade-off between flexibility and strategic commitment. Boyer and Moreaux (1997) examine how technological flexibility choices depend on specific industry characteristics. They emphasise that their model is not concerned with endogenous investment timing.

first paper of which we are aware to examine an endogenous *investment* timing game in which *both* firms can choose whether to commit or delay. We assume two periods with uncertainty in period one, which is resolved in period two. If investment takes place in period one, then capital is chosen before the resolution of demand uncertainty, implying a loss of flexibility required for adjusting to unexpected demand shocks. However, if capital is chosen in period two, the firm retains the flexibility to cope with unexpected demand fluctuations. This choice of when to invest naturally gives rise to endogenous timing decisions in the investment game[4].

There are two distinct reasons why a firm may want to invest early. On the one hand, if its rival delays, it can enjoy the benefits of investment leadership by adopting an aggressive stance and investing early. On the other hand, if its rival also invests early, defensive investment commitment allows a firm to avoid the loss of market share associated with being a follower. We show that the strength of the incentives to invest aggressively and defensively hinges on the precise form investment commitment takes. We demonstrate this by considering two different investment timing games. In the first game, firms invest early by selecting the investment *level* to which they are then committed. In the second game, firms first commit to the timing of their investment but do not yet fix the actual capital level. After choosing *when* to invest, firms then select investment levels, having observed the timing choices made earlier. This second form of commitment arises when a firm can credibly indicate when it will invest without actually being committed to a particular level of investment[5]. Following Hamilton and Slutsky (1990) who first introduced this distinction in endogenous timing games, we refer to the former game as one of "Action Commitment" and to the latter as one of "Observable Delay"[6].

[4] Since the mid 1980s there has been considerable interest in the question of endogenous timing in the choice of strategic variables in oligopolistic markets. See for instance Gal-Or (1985), Dowrick (1986), Boyer and Moreaux (1987), Hamilton and Slutsky (1990), Spencer and Brander (1992), Sadanand and Sadanand (1996), Canoy and Van Cayseele (1996) and van Damme and Hurkens (1999). There has also been an interest in timing in the strategic trade literature (see for instance Arvan (1991) and Collie (1994)).

[5] This could occur if, for instance, the firm enters into time-specific contracts that are too costly to break, before finalising its investment choice.

[6] Hamilton and Slutsky restrict attention to price and output games and do not look at investment decisions. In addition, they assume no uncertainty and are not concerned with the tradeoff between commitment and flexibility.

Whether Action Commitment or Observable Delay is a more appropriate characterisation of investment rivalry depends on whether firms can observe and respond to each other's investment timing *before* actual investment levels are chosen[7]. It cannot be claimed in general that one is more "realistic" than the other[8]. For that reason, it does not seem possible to opt for one game over the other without considering the specific features of the investment project.

In section two of the paper we set up the basic model in which two rival firms choose capital and output for a market characterised by demand uncertainty. In section three the Action Commitment version of the model is solved for different levels of uncertainty, both for symmetric firms and for the case in which one firm has a cost advantage. In section four we compute the equilibrium of the Observable Delay game for different levels of uncertainty and cost asymmetries. In section five some welfare issues are discussed. Section six concludes.

2. The model: Investment with demand uncertainty

Two firms produce an identical product and choose capital and output, denoted respectively by k_i and q_i ($i = 1,2$). Firms face uncertainty about market demand. This is captured by an inverse demand function with a stochastic component:

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

with $Q = q_1 + q_2$ and $u \in [\underline{u}, \overline{u}]$ the stochastic demand component with zero mean and variance s^2. Firm i's total cost, TC^i, is given by:

$$TC^i = (c_i - k_i)q_i + \frac{k_i^2}{2h} \text{ with } TC^i_{k_i} = -q_i + \frac{k_i}{h} \text{ and } TC^i_{q_i} = c_i - k_i \tag{2}$$

[7] Both Action Commitment and Observable Delay have been considered in earlier work that discusses *output* flexibility versus commitment. In their output choice models Sadanand and Sadanand (1996) employ Action Commitment and, without mentioning it explicitly, Spencer and Brander (1992) use the Observable Delay approach.

[8] Observable Delay corresponds to the real-world case where it takes a significant amount of time before the precise size of the investment project is irrevocably fixed, whereas Action Commitment better describes a scenario in which the time between the planning and implementation of an investment project is short.

The parameter η is inversely related to the cost of capital and c_i is a positive constant. $TC^i_{k_i}$ and $TC^i_{q_i}$ are defined respectively as the marginal cost of capital and the marginal production cost. Investing in capital reduces the marginal cost of production. Without loss of generality, we assume that the constant term in firm two's marginal production costs is at least as high as its rival's is ($c_1 \leq c_2$). The profits of firm i are given by:

$$\pi_i = pq_i - TC^i \qquad i = 1,2 \tag{3}$$

The model consists of two periods. There is uncertainty about demand in the first period, which is resolved at the start of period two. Firms decide whether to commit to their capital in the first period or postpone investment to the second period. For simplicity, we assume throughout that firms are risk neutral. Hence, their investment timing decisions follow from maximising expected profits. Nevertheless, firms will value flexibility because expected profits are increasing in the variance of demand[9].

Outputs are always chosen simultaneously in period two, that is, after uncertainty has been resolved. The equilibrium output for firm i is[10]:

$$q_i = \frac{1}{3}\left(2A_i - A_j + 2k_i - k_j + u\right) \tag{4}$$

with $A_i \equiv a - c_i$ and $i, j = 1,2 \quad i \neq j$

When capital is chosen in period one, it is set before output. But, if it is chosen in period two, it is determined simultaneously with output. If a firm chooses to invest early, it determines its capital in period one by maximising expected profits ($\max_{k_i} E\pi_i$). Commitment to capital in the first period gives firms a strategic advantage because it allows them to influence future outputs to their advantage. However, by doing so, the firm reduces its output flexibility compared to when it delays investment until period two. In the latter case, period-two profits are maximised with respect to capital ($\max_{k_i} \pi_i$) and the investment

[9] The positive effect of the variance on *ex ante* expected profits is due to the fact that the actual *ex post* realisation of profits is convex in u. Spencer and Brander (1992) adopt a similar approach. Risk aversion would simply strengthen the gains from remaining flexible.
[10] We focus on interior solutions only.

level will be chosen in accordance with any unexpected shocks in demand (i.e, $k_i = k_i(u)$ with $\frac{\partial k_i}{\partial u} > 0$). This will enhance the firm's output flexibility.

As discussed above, expected profit is increasing in the variance of demand. Due to the indirect effect of capital on output, the positive effect of the variance on expected profits is larger under investment flexibility than under commitment. Hence, our model captures the fact that, in practice, investors who value flexibility have an incentive to delay investment when they face significant uncertainty.

We examine two different games in which firms face this trade-off between flexibility and commitment. In the first game, commitment takes the form of "Action Commitment", meaning that, if a firm decides to invest early, it commits not only to invest in period one, but also to a particular *level* of capital. In other words, Action Commitment implies compressing the timing and level of investment into a single action. The nature of commitment is different in the second game, which will henceforth be labelled as the game with "Observable Delay". In that game, firms first decide the timing of their investment but not yet the actual level of the capital. These timing decisions of the firms are assumed to be too costly to reverse. After the timing decisions have been made, firms select their investment level, now knowing in which period the rival will invest. So, a firm that chooses to commit, determines its capital level after the investment timing choices are made, but before uncertainty has been resolved. In the remainder of this section we will discuss features that are common to both the Action Commitment and the Observable Delay games.

There are four possible timing combinations in either game: (C_1, C_2), (C_1, D_2), (D_1, C_2) and (D_1, D_2), where C_i and D_i refer to commitment and delay, respectively. Under Observable Delay, these combinations are the *candidate* timing equilibria. In two of these candidate equilibria, firms choose their capital simultaneously (see table 1): they both invest early (C_1, C_2), or alternatively, choose to delay (D_1, D_2). In those cases, firms' choices of capital per unit output are symmetric, but larger for investment commitment than for delay (i.e., $\frac{k_i^{cc}}{Eq_i^{cc}} > \frac{k_i^{dd}(u)}{Eq_i^{dd}(u)}$). In the other two candidate equilibria ((C_1, D_2),(D_1, C_2)), one firm is a Stackelberg leader in investment, while the other is a follower. The committed capital level per unit output chosen by the leader is larger than that chosen by either firm when both firms commit ($\frac{k_1^{cd}}{Eq_1^{cd}} = \frac{k_2^{dc}}{Eq_2^{dc}} > \frac{k_i^{cc}}{Eq_i^{cc}}$). Under Action Commitment, it is also straightforward to show that there are four candidate equilibria. These also correspond to the four possible timing combinations[11]. The capital levels for each of the four candidate equilibria in Action Commitment are the same as those in the corresponding equilibria under Observable Delay. Thus, the capital levels chosen under Action Commitment are also represented by the expressions in table 1.

Table 1: Capital levels for the different candidate equilibria under Action Commitment and Observable Delay[a]

	C_1, C_2	C_1, D_2	D_1, C_2	D_1, D_2
k_1	$k_1^{cc} = \frac{4}{3} hEq_1^{cc}$	$k_1^{cd} = \frac{2(2-h)}{3-2h} hEq_1^{cd}$	$k_1^{dc}(u) = hq_1^{dc}(u)$	$k_1^{dd}(u) = hq_1^{dd}(u)$
k_2	$k_2^{cc} = \frac{4}{3} hEq_2^{cc}$	$k_1^{cd}(u) = hq_2^{cd}(u)$	$k_2^{dc} = \frac{2(2-h)}{3-2h} hEq_2^{dc}$	$k_2^{dd}(u) = hq_2^{dd}(u)$

[a] The first [second] superscript on the k_i and the q_i variables refers to the commitment (*c*) or delay (*d*) decision by firm one [two].

In the next two sections, we derive and discuss the investment timing pattern that emerges from each game. Since the analysis involves many unwieldy algebraic expressions, graphical simulations are extensively used to ease the exposition. This approach allows us to minimise the number of equations we give in the text, but does not reduce the generality of our

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[11] To see this for Action Commitment, define $r_i(k_j)$ as firm *i*'s ***first***-period capital reaction function. If firm two delays, then (depending on s^2 and other parameters) firm one's best response is either delay or play k_1^{cd}. If k_1^{cd} is played, firm two's best response is either delay or $r_2(k_1^{cd})$. But, k_1^{cd} is not the best reply to $r_2(k_1^{cd})$ (hence, $(k_1^{cd}, r_2(k_1^{cd}))$ is not an equilibrium). So, if firm two delays, the only possible equilibria are (k_1^{cd}, D_2) and (D_1, D_2). If firm two commits to a particular capital level $\hat{k}_2$, firm one's best response is either delay or $r_1(\hat{k}_2)$. But $(r_1(\hat{k}_2), \hat{k}_2)$ is only an equilibrium if $\hat{k}_2 = k_2^{cc}$ (and $r_1(k_2^{cc}) = k_1^{cc}$). If firm one delays, firm two leads and plays k_2^{dc}. So, if firm two commits, the only

analysis in any way. We consider both situations in which firms have symmetric and asymmetric production costs. For completeness, our analysis exhausts *all* the qualitatively different cases.

3. Action Commitment versus flexibility

In this section we look at the game with Action Commitment. The sequence of the moves is illustrated in figure 1. If a firm decides to commit, it has to do so by choosing an investment *level* in stage one. However, if investment delay is preferred, the firm chooses its capital investment flexibly in the second period. Which of the candidate equilibria represented in table 1, if any, eventually prevail, depends crucially on the level of uncertainty (s^2), the h-parameter (which is inversely related to the marginal cost of capital) and the cost asymmetry between firms. It is natural to start with the symmetric case. Afterwards, the effect of asymmetric costs is examined.

[Figure 1 about here]

3.1 The symmetric cost case

Investment timing under symmetry ($A_1 = A_2$) is shown in $\bar{s}^2, h$-space (where $\bar{s}^2 \equiv s^2 / A_1^2$ is the normalised variance) in figure 2[12]. This figure gives loci along which a firm is indifferent between commitment and delay, given a particular investment timing choice of its rival. At levels of uncertainty ($\bar{s}^2$) above the relevant locus, the firm prefers to delay, given the choice made by its rival. At levels of uncertainty below the locus, it will commit. There are two distinct indifference loci for each firm given rival commitment, but, as will become clear from our discussion below, there is only one indifference locus for each firm given that its rival delays. So, there is a total of three indifference loci for each firm. In the symmetric case, the loci for firm one naturally coincide with those for firm two.

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possible equilibria are (k_1^{cc}, k_2^{cc}) and (D_1, k_2^{dc}). Thus, there are the four candidate equilibria under Action Commitment, one for each of the four possible timing combinations.

[12] Throughout the paper the h-values are limited to guarantee interior solutions and by stability considerations.

[Figure 2 about here]

To find the equilibria in different regions of $\bar{s}^2, h$-space we proceed by asking when each of the *candidate* equilibria will *not* be an equilibrium. We will first consider the candidate equilibrium (D_1, D_2). On the highest locus in figure 2, each firm is indifferent between commitment and delay given investment delay by its rival. Given rival delay, firm one, in deciding when to invest, compares the profits $Ep_1(D_1, D_2)$ and $Ep_1(C_1, D_2)$, taking into account that its rival reacts to its investment timing decision. For instance, on the locus ($Ep_1(C_1, D_2) = Ep_1(D_1, D_2)$) firm one is indifferent between choosing k_1^{cd} in period one and delaying its capital choice until period two (when it will choose $k_1^{dd}(u)$). Below this locus, (D_1, D_2) cannot be an equilibrium.

The highest locus in figure 2 also demarcates the maximum uncertainty upper limit for the leader-follower equilibria, (C_1, D_2) = (k_1^{cd}, D_2) and (D_1, C_2) = (D_1, k_2^{dc}). In other words, (C_1, D_2) (and by symmetry (D_1, C_2)) cannot be an equilibrium above this locus, since in that region $Ep_1(k_1^{cd}, D_2) < Ep_1(D_1, D_2)$. The lowest of the three loci in the figure provides the lower bound for leader-follower equilibria. Below this locus we have $Ep_1(C_1, k_2^{dc}) > Ep_1(D_1, k_2^{dc})$, and hence firm one will wish to deviate from delay given that firm two chooses the investment leadership capital level, k_2^{dc}.

We now turn to the candidate equilibrium (C_1, C_2). This is an equilibrium at $\bar{s}^2 = 0$, when there are no flexibility advantages of delaying and both firms commit, regardless of the timing strategy of their rival. Next, consider the range of $\bar{s}^2$ and h over which $(C_1, C_2) = (k_1^{cc}, k_2^{cc})$ cannot be an equilibrium. For concreteness and without loss of generality, let us consider possible deviations by firm one from this equilibrium. Given k_2^{cc}, there is a locus (the second highest in figure 2) along which firm one is indifferent between commitment and delay. Above this locus, we have $Ep_1(C_1, k_2^{cc}) < Ep_1(D_1, k_2^{cc})$, hence, firm one wants to delay and therefore (C_1, C_2) cannot be an equilibrium. On or below the locus, firm one will not wish to deviate from k_1^{cc} (by symmetry, firm two will not want to deviate from k_2^{cc} in that region). Thus, commitment by both firms will be an equilibrium at all uncertainty levels that are not above this locus.

In figure 2, the $\bar{s}^2, h$-space is divided into four areas by the firms' indifference loci. In area IV, both firms delay investment. In this region the level of uncertainty is too high for firms to forego flexibility. Delaying investment is preferred by each firm, independently of the rival's timing choice, hence delay by both is the unique equilibrium. In area III, there are two leader-follower equilibria. Here, if one firm commits, the other firm knows that it cannot influence its competitor's *level* of investment by its own investment timing, since Action Commitment implies choosing an irrevocably fixed level of capital in stage one. So, given rival commitment, early investment leaves rival capital unaffected and merely leads to a small strategic effect on future outputs. This small strategic gain from commitment is outweighed by the benefits from capital flexibility because uncertainty is still sufficiently high in region III. So, each firm prefers to delay *if* its rival commits. On the other hand, if a firm's rival delays, commitment will be chosen since it allows that firm to manipulate both the rival's capital and output choice. Only in region I is uncertainty so low that commitment by both firms, the outcome that would prevail under certainty, is the unique equilibrium. Finally, in region II, the two leadership equilibria and commitment by both firms are sustained as equilibria. Note, however, that this region is very narrow, especially at low values of h [13]. One could argue that region II is merely a fuzzy boundary between areas I and III, caused by the inherent stickiness of early investment with Action Commitment.

In figure 2, a firm's indifference locus given rival delay is above, and rises much faster in h than the loci given rival commitment. Intuitively, the relative value of investment commitment is much higher if the rival firm remains flexible than if the latter invests strategically. This suggests that "*defensive commitment*", that is, strategic investment to avoid becoming the follower, tends to have a relatively low value in this game compared to "*aggressive commitment*" to become a leader. It is for this reason that for intermediate levels of uncertainty we get investment leadership despite the fact that firms are *ex ante* identical. It is worth mentioning that a leadership equilibrium implies a real *ex post* difference between the firms, with the leader having a higher capital investment and lower marginal production costs than the follower in equilibrium.

3.2. Cost asymmetry

Now, suppose there is an asymmetry between firms, $c_2 > c_1$ (implying $A_2 < A_1$). Then, there are two possible scenarios, depending on the degree of cost asymmetry.

First, consider cases with a "large" cost asymmetry. This refers to relative cost differences for which the low-cost firm's indifference loci ***all*** lie above those of its higher-cost rival. Figure 3 illustrates this for $A_2 = 0.8 A_1$. Here, unlike in figure 2, firms' indifference loci no longer coincide. However, only three of the six loci are relevant and these are shown in the diagram. The three loci delineate four regions, each with its own set of investment timing equilibria. While both firms delay investment in area IV, the low-cost firm emerges as the investment leader in region III. Here, compared to area III in figure 2, the cost asymmetry has eliminated one of the two equilibria. The relative benefits of commitment are higher to the low-cost firm than to its high-cost competitor. Because the former has a higher price-cost margin than its rival, it stands to gain relatively more from investing strategically and hence from producing a larger future output. When uncertainty is very low (i.e., in region I), even the high-cost firm commits and commitment by both firms is once again the unique equilibrium. Region II forms a fuzzy boundary between region I and III, where commitment by both firms and investment leadership by the low-cost firm are equilibria. In this narrow band, the low-cost firm will always choose to commit but firm two's optimal investment timing depends on its rival's level of committed investment.

[Figure 3 about here]

[13] For instance, at $h = 0.15$, region II is only 0.00060 wide in terms of $\overline{s}^2$, while this distance narrows down even further to a $\overline{s}^2$-range of 0.00005 at $h = 0.05$.

The third and final possible scenario (in addition to the symmetric case and cases with large cost asymmetries) prevails when the cost asymmetry is sufficiently "small", implying that the relative cost disadvantage of the high-cost firm is not large enough for ***all*** its indifference loci to lie below its rival's. The diagram for "small" cost asymmetries is shown in figure 4 and combines features of the symmetric case and the large cost asymmetry case. For small values of h (i.e., high marginal cost of capital), the picture is similar to the one for "large" cost asymmetries, shown in figure 3. For relatively high values of h, an area with multiple investment leadership equilibria emerges and hence features of the symmetric case appear, particularly at intermediate levels of uncertainty. As α approaches one, the area with (C_1, D_2) vanishes and the picture collapses to the one for the symmetric case.

[Figure 4 about here]

4. Commitment versus flexibility under Observable Delay

With Observable Delay, firms observe each other's investment timing before determining their actual level of investment. The structure of the game is shown in figure 5. Note that period one now consists of two stages. In the first stage, firms decide on their investment timing and determine the level of investment later (i.e., in stage two if they opt for commitment, and in stage three if they prefer delaying investment). Because firms observe the outcome of the investment timing stage, the nature of commitment is less "sticky" than under Action Commitment. This feature changes the nature of commitment compared to the previous game and has several important implications.

[Figure 5 about here]

First, as a result of the two-step commitment, the two indifference loci for rival commitment that prevailed under Action Commitment, here collapse into a single indifference locus (see, for instance, figure 6). Consider, for instance, firm one's investment timing decision in stage one, given that firm two chooses to commit but can only fix its capital level in stage two. Firm one will compare its expected profits from also committing, $E\pi_1(C_1, C_2)$, to those from delaying investment, $E\pi_1(D_1, C_2)$, knowing that its investment timing choice will affect the optimal level of firm two's capital in stage two (k_2^{cc} if C_1 and k_2^{dc} if D_1). Because each firm now takes into account the effect of its own investment timing decision on its rival capital level, there is only one indifference locus given rival commitment, implying that each firm now only has two indifference loci in total.

Second, by contrast to the game under Action Commitment, the indifference locus for a particular firm given rival commitment is above and steeper than its corresponding locus given rival delay. This suggests that under Observable Delay firms tend to commit more for defensive than for aggressive reasons, that is, more out of fear of ending up as the follower than to gain a first-mover advantage. Under Action Commitment, the opposite was true. There, *"aggressive commitment"* was more valuable than *"defensive commitment"*.

Like in the previous game, there are three qualitatively different cases. Case I occurs under symmetry, Case II prevails when there is a "large" cost asymmetry between firms and Case III occurs for "small" cost asymmetries. Figures 6, 7 and 8 show the diagrams of the Observable Delay game in $\bar{s}^2, h$-space for each of these respective scenarios.

Case I, in which firms are symmetric ($A_1 = A_2$), is graphically represented in figure 6. In the discussion we mainly point out the differences with the previous game. Unlike in the corresponding symmetric case under Action Commitment, investment leadership does not arise as an equilibrium in any region of the graph. Instead, the two equilibria that can prevail at intermediate levels of uncertainty are commitment by both firms, or investment delay by both (see region II in figure 6). In area II, a firm only invests early if its rival does so as well. Its own commitment guarantees that the rival's strategic investment is smaller, thereby avoiding severe reductions in future outputs. This confirms the intuition that strategic investment here occurs out of a predominantly defensive motivation. Also, the area where both firms choose to commit is larger than under Action Commitment, illustrating that commitment is relatively more attractive to firms under Observable Delay. Moreover, the "fuzziness" of the boundary between the lower regions, observed under Action Commitment (see region II in figure 2), has disappeared completely.

[Figure 6 about here]

Consider now the effect of cost asymmetries on firms' investment timing. Cost asymmetry implies that the indifference loci of the two firms no longer coincide (see figures 7 and 8). The discussion first covers cases where the cost asymmetry is "large" (Case II). Like in section three, a "large" cost asymmetry refers to cases in which the relative cost difference causes ***all*** the indifference loci of the low-cost firm to lie above those of the rival firm. Such a case is shown in the diagram in figure 7. As under Action Commitment, investment leadership by the low-cost firm prevails at intermediate levels of uncertainty (i.e., region II in figure 7), because the relative value of commitment is higher for the low-cost firm than for its high-cost counterpart. However, given the same cost asymmetry, the area where investment leadership occurs is smaller here than under Action Commitment, since the high-cost firm has an increased incentive to invest defensively. Consequently, here, as in the symmetric case, the region of commitment by both firms is larger than under Action Commitment. Note that, again, the boundary demarcating the region between investment leadership and commitment by both is now a one-dimensional curve instead of a fuzzy band. This reflects the fact that the two indifference loci that demarcated the edges of that band under Action Commitment are replaced by just one indifference locus under Observable Delay.

[Figure 7 about here]

Case III, prevailing for "small" cost asymmetries between firms is illustrated in figure 8. Again, this case takes a hybrid form, combining features of the symmetric case and "large" cost asymmetry cases. When the marginal cost of capital is high (i.e., at low h), investment leadership by the low-cost firm is the equilibrium at intermediate levels of uncertainty (see region IIa), while commitment and delay by both firms are the equilibria in region IIb. In other words, when capital investment is expensive, the low-cost firm will, even as a leader, invest relatively little. Hence, the damage to the high-cost firm in terms of induced future output reductions will not be very large. For that reason, the latter prefers to stay flexible. However, as h rises and investment becomes cheaper, a firm that does not invest in period one while its rival does, exposes itself to substantial future market share losses. In region IIb, the high-cost firm chooses therefore to commit, in spite of the relatively high level of uncertainty, so as to protect its future share of the market.

[Figure 8 about here]

We conclude this section with a comparative overview of the outcomes under Action Commitment and Observable Delay. Superimposing the corresponding $\overline{s}^2, h$-diagrams of the two games allows us to compare them, given the same ranges of uncertainty and other parameter values.

Table 2: Investment timing under Action Commitment and Observable Delay

	$\overline{s}^2$	**Action Commitment**	**Observable Delay**
COST SYMMETRY	Very High	(D_1, D_2)	(D_1, D_2)
	High	(D_1, D_2)	(D_1, D_2); (C_1, C_2)
	Intermediate	(C_1, D_2); (D_1, C_2)	(C_1, C_2)
	Low	(C_1, D_2); (D_1, C_2) (C_1, C_2)	(C_1, C_2)
	Very Low	(C_1, C_2)	(C_1, C_2)
"LARGE" COST ASYMMETRY	Very High	(D_1, D_2)	(D_1, D_2)
	High	(C_1, D_2)	(C_1, D_2)
	Intermediate	(C_1, D_2)	(C_1, C_2)
	Low	(C_1, D_2); (C_1, C_2)	(C_1, C_2)
	Very Low	(C_1, C_2)	(C_1, C_2)

Without showing this combined graph explicitly[14], the outcomes are shown in Table 2 for the symmetric case as well as for the case with "large" cost asymmetries[15]. The bands of

[14] The combined diagram can be easily obtained from superimposing figures 2 and 6 for the symmetric case, and figures 3 and 7 for the case with a "large" cost asymmetry.

uncertainty levels range from the upper zone (labelled as "very high") to the lowest one (labelled as "very low"). The comparison clearly indicates the relative importance of defensive commitment under Observable Delay, reflected in the emergence of (C_1, C_2) as an equilibrium, even at "high" levels of uncertainty. Unlike under Observable Delay, (C_1, C_2) never co-exists with (D_1, D_2) under Action Commitment. With Action Commitment, the leader-follower equilibria occur at "intermediate" and "low" levels of uncertainty, whereas they can never occur under symmetry with Observable Delay.

With "large" cost asymmetries, the investment timing outcomes of the two games are more similar to each other than under symmetry[16]. The main difference between the two cases is that, at "intermediate" levels of uncertainty, the high-cost firm is willing to follow under Action Commitment but reacts with defensive commitment under Observable Delay. Overall, there is less commitment under Action Commitment than under Observable Delay.

5. Welfare issues

In the previous sections, we discussed which of the four candidate investment timing equilibria would prevail for various levels of uncertainty. However, it is by no means guaranteed that, from that set of candidate equilibria, the market selects the one that yields the highest level of welfare. In our partial equilibrium set-up, welfare is naturally defined as the sum of expected consumer surplus and expected industry profits. Given that welfare function, we ask what the best timing outcomes are from a social perspective and whether they differ from those generated by the market.

Although capital commitment raises the social cost of investment and foregoes the social benefits from flexibility, it will also lead to higher production and therefore lower prices for consumers. In figures A.1 and A.2 in the appendix, we compare the actual market equilibrium of the investment timing game under Observable Delay with the socially

[15] The "small" cost asymmetry case is omitted from table 2 because it combines features of both the symmetric case and cases with "large" cost asymmetries.

[16] As mentioned earlier, "small" cost asymmetries combine features of the symmetric and the "large" cost asymmetry cases. Hence, the comparison between Action Commitment and Observable Delay at "small" cost asymmetries will combine features of the two comparisons represented in table 2.

preferred timing outcomes for different parameter values[17]. When firms are symmetric, we find that the socially preferred timing outcomes coincide with the market outcomes at fairly high and at fairly low uncertainty. In the former case, both firms delay, whereas they both commit in the latter case. At moderate levels of uncertainty however, commitment by both firms can arise, but delay by both is socially preferred. Thus we conclude that the market generates too much strategic commitment in the symmetric case. When there is a substantial cost asymmetry between firms, we find that having the low-cost firm as the leader is socially preferred unless uncertainty is very high. Even under certainty, the consumers benefit from the low-cost firm being the leader and producing all the extra output. However, at low uncertainty levels both firms commit, implying that too much commitment is generated by the market, while at fairly high uncertainty both firms delay implying too little commitment from a social perspective. Only at intermediate levels of uncertainty, when the market generates a leader-follower outcome, or at very high levels of uncertainty, when delay by both firms is socially preferred, do the market outcome under observable delay and the socially preferred one coincide.

So far we have discussed which of the four candidate investment timing equilibria yield the highest welfare *without* government intervention. However, it is clear that government intervention could improve welfare since the oligopoly distortion implies that firms are producing too little. In addition, when firms are investing strategically they choose more than the socially cost-minimising capital level. The standard instruments to deal with these distortions are production subsidies and capital taxes. Moreover, besides affecting the levels of output and investment, the government may also wish to change firms' investment timing. Firms often will invest too early and lose their flexibility, implying that the government may want to engage in commitment deterrence[18]. Hence, a first-best package of policies will simultaneously and directly address these three possible inefficiencies of underproduction, overinvestment and inflexibility.

[17] A similar comparison between market and socially preferred outcomes under Action Commitment would follow directly from replacing firms' indifference loci in figures A.1 and A.2 by those that are relevant under Action Commitment, represented respectively in figures 2 and 3.
[18] Dewit and Leahy (1999) consider policies to deter commitment in an open economy setting.

6. Conclusion

We have analysed the trade-off between strategic investment commitment and flexibility in an oligopoly setting. Two different forms of investment commitment were considered. Under both forms of commitment, the degree of cost asymmetry between the firms, together with the degree of uncertainty, plays a crucial role in determining equilibrium outcomes. In particular, we find that the low-cost firm values strategic commitment more highly than its high-cost rival. This implies that the low-cost firm will remain committed at higher levels of uncertainty and that a natural leader-follower equilibrium will exist if uncertainty is neither too low or too high.

Cost symmetry puts the differences between the two forms of commitment into sharper relief. We have shown that the form commitment takes, alters the relative advantages of aggressive versus defensive commitment. More specifically, due to the greater inflexibility of investing early in the latter game, the gains from defensive commitment are much lower under Action Commitment than under Observable Delay. As a result, under Action Commitment, though not under Observable Delay, leader-follower outcomes can even occur when firms are *ex ante* identical, implying that the firms end up with different cost and capital investment levels.

Finally, there are several avenues along which our analysis could be extended. First, our discussion has been confined to interior solutions, implying that both firms always produce positive quantities. However, in the presence of fluctuating demand, some firms may not enter when demand turns out to be low. This raises the issue of firms engaging in probabilistic entry deterrence. A second interesting extension would be to allow for asymmetric information. We could assume that there is uncertainty about demand or cost parameters, which is initially private information. For instance, when a local firm competes with a foreign rival, it may have more accurate information about local market demand than its rival. These issues surrounding corner solutions and incomplete information are still awaiting future research.

Appendix

In figures A.1 and A.2, the actual investment timing outcome under Observable Delay is indicated by superscript m, while the socially preferred outcome is superscripted by s. The areas in which the market outcome differs from the socially preferred investment timing, are highlighted by a shaded label.

[Figure A.1 about here]

[Figure A.2 about here]

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Figure 1: The structure of the game under Action Commitment

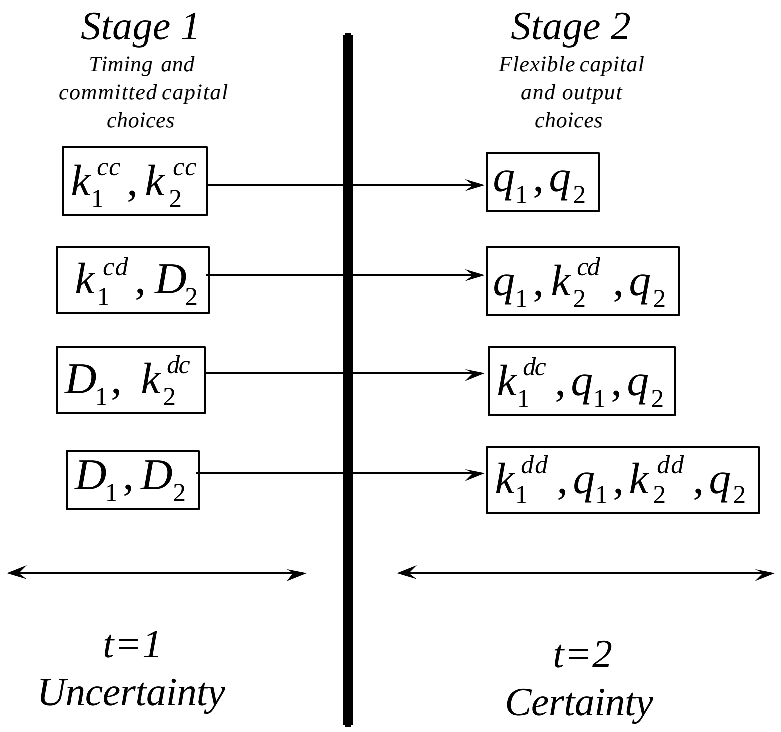


Figure 2 : The game under Action Commitment for the symmetric case (A1=A2)

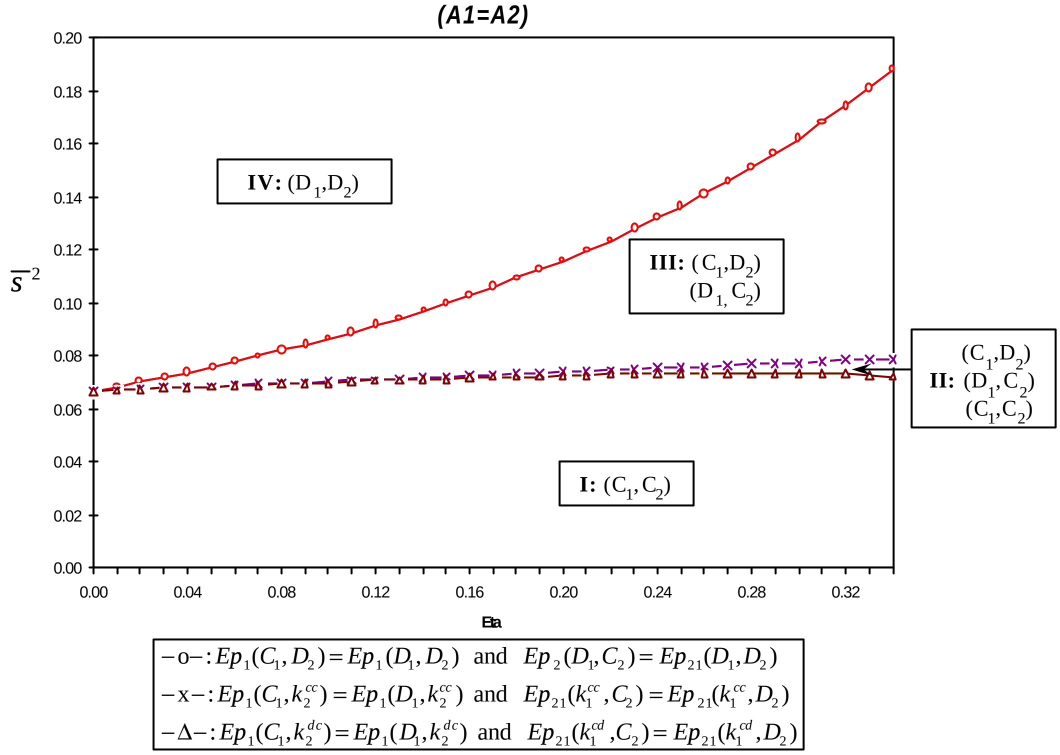


Figure 3: The game under Action Commitment for "large" cost asymmetries ($A^2 = 0.8A^1$)

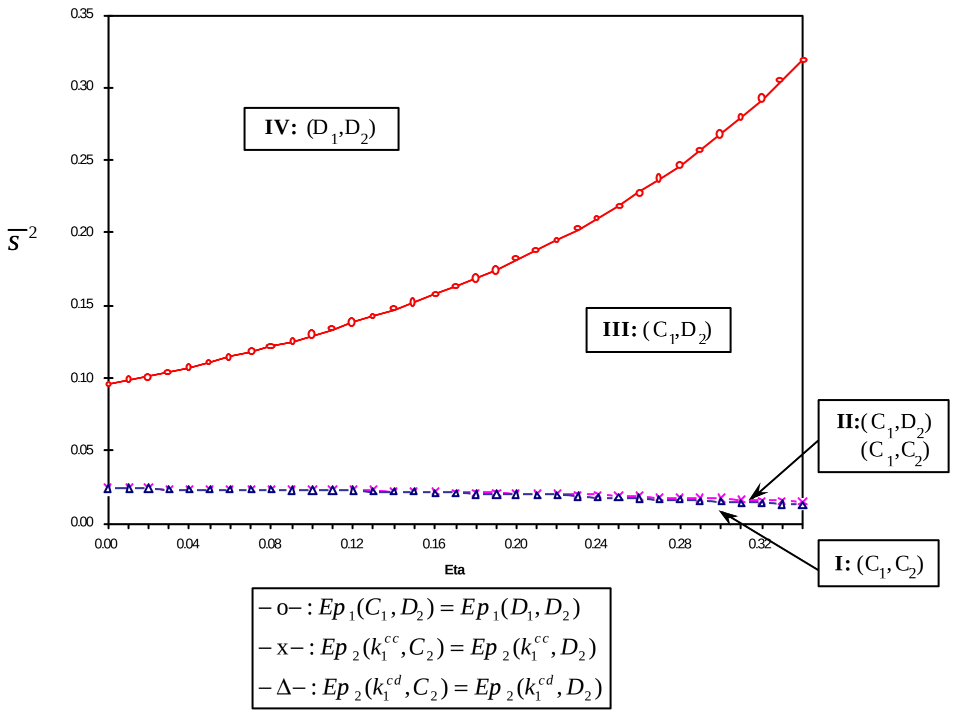


Figure 4 : The game under Action Commitment for a "small" cost asymmetry (A2=0.97A1)

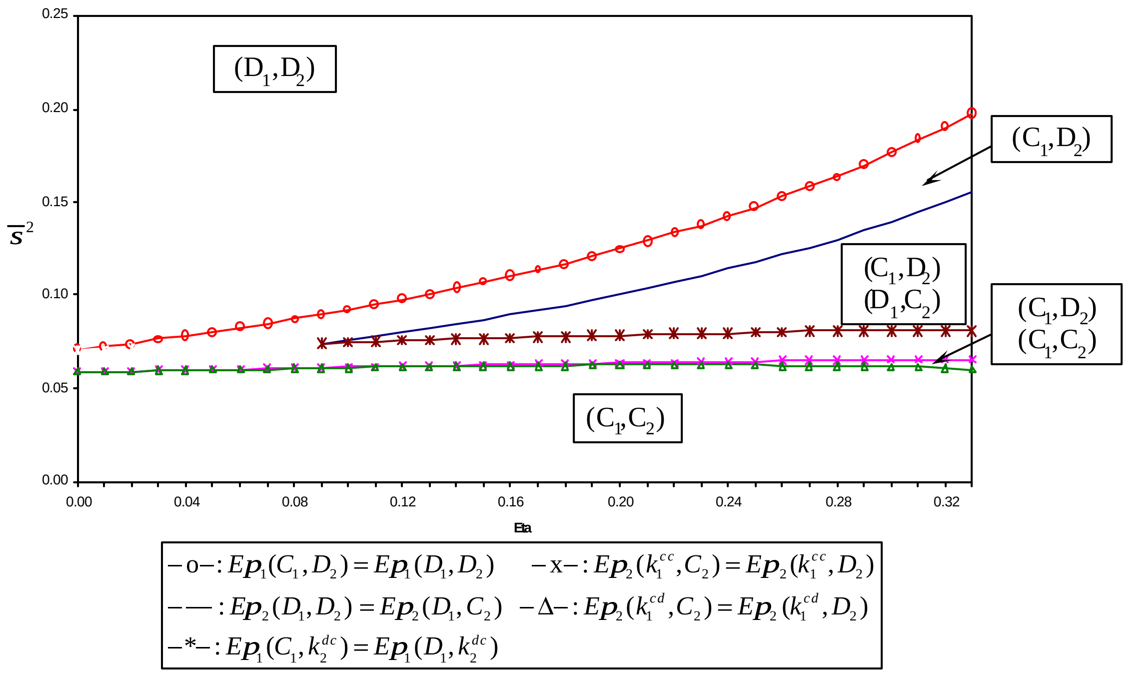


Figure 5: The structure of the game under Observable Delay

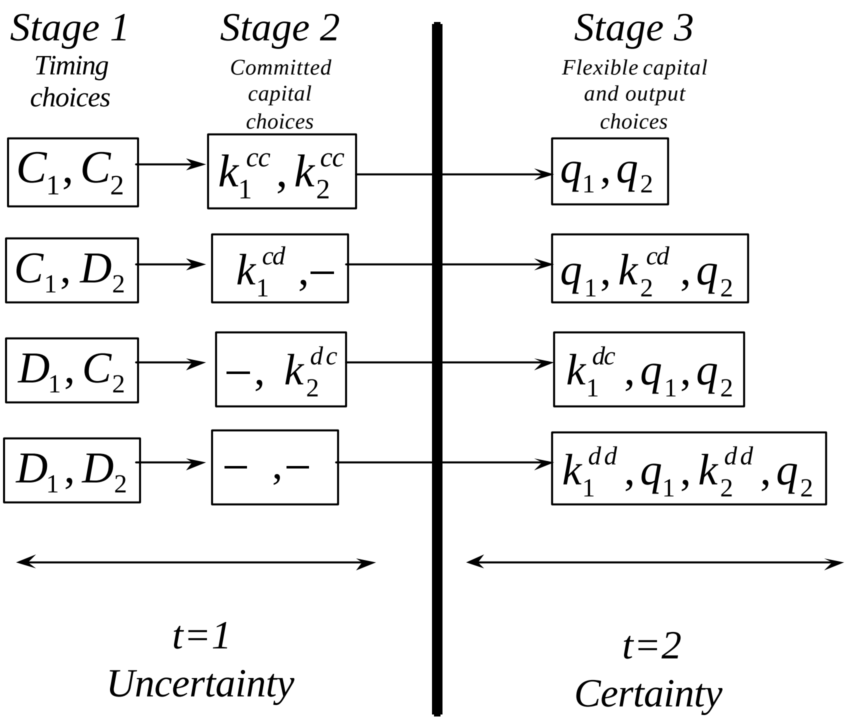
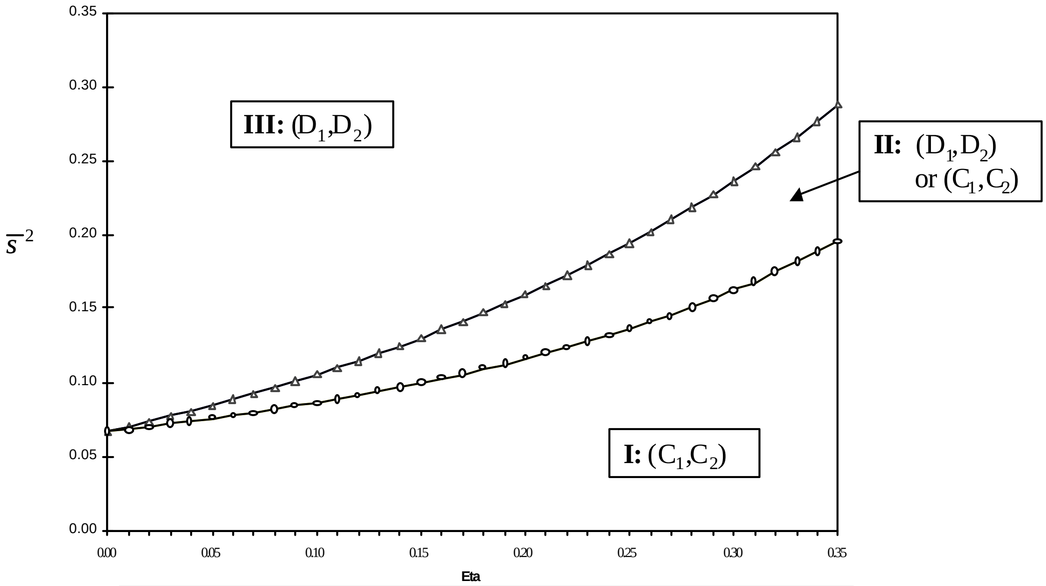


Figure 6: The game under Observable Delay for the symmetric case (A_1=A_2)



$-\Delta-$: $Ep_1(C_1,C_2) = Ep_1(D_1,C_2)$ and $Ep_2(C_1,C_2) = Ep_2(C_1,D_2)$
$-\text{o}-$: $Ep_1(C_1,D_2) = Ep_1(D_1,D_2)$ and $Ep_2(D_1,C_2) = Ep_2(D_1,D_2)$

Figure 7: The game under Observable Delay for a "large" cost asymmetry (A2=0.8A1)

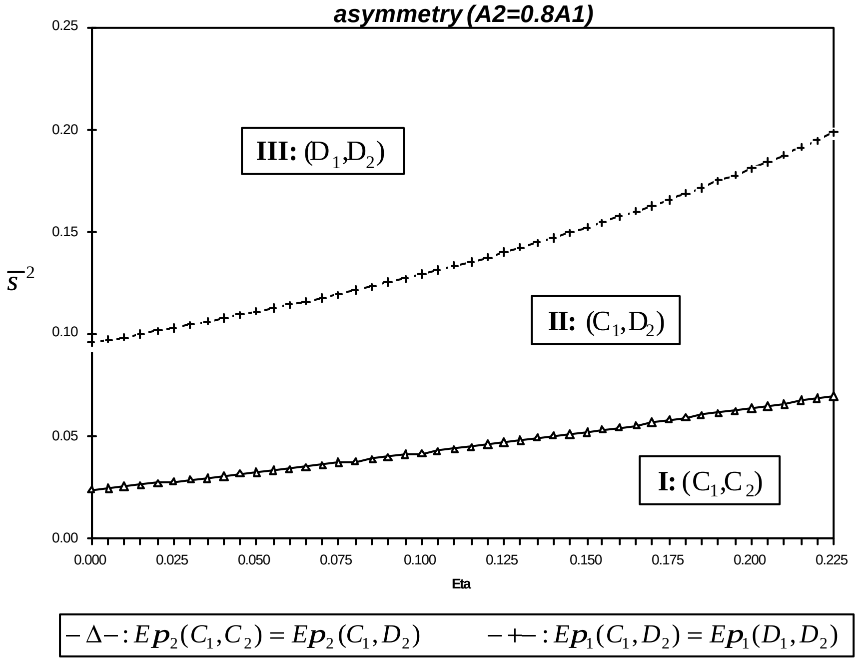


Figure 8: The game under Observable Delay for "small" cost asymmetries (A_2=0.97 A_1)

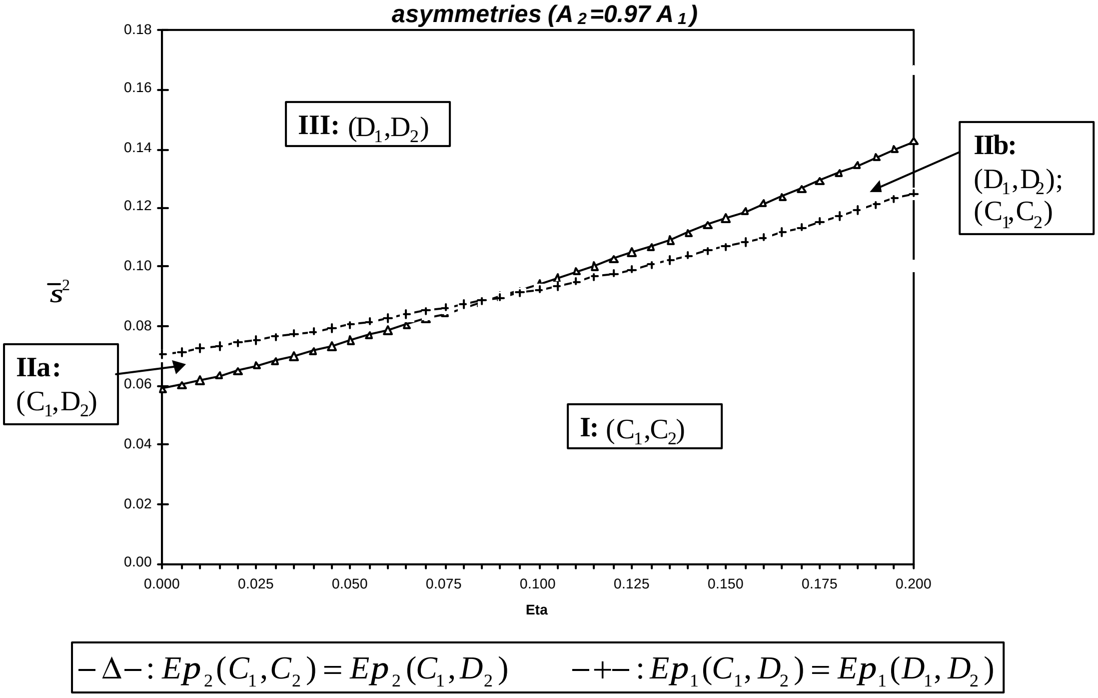
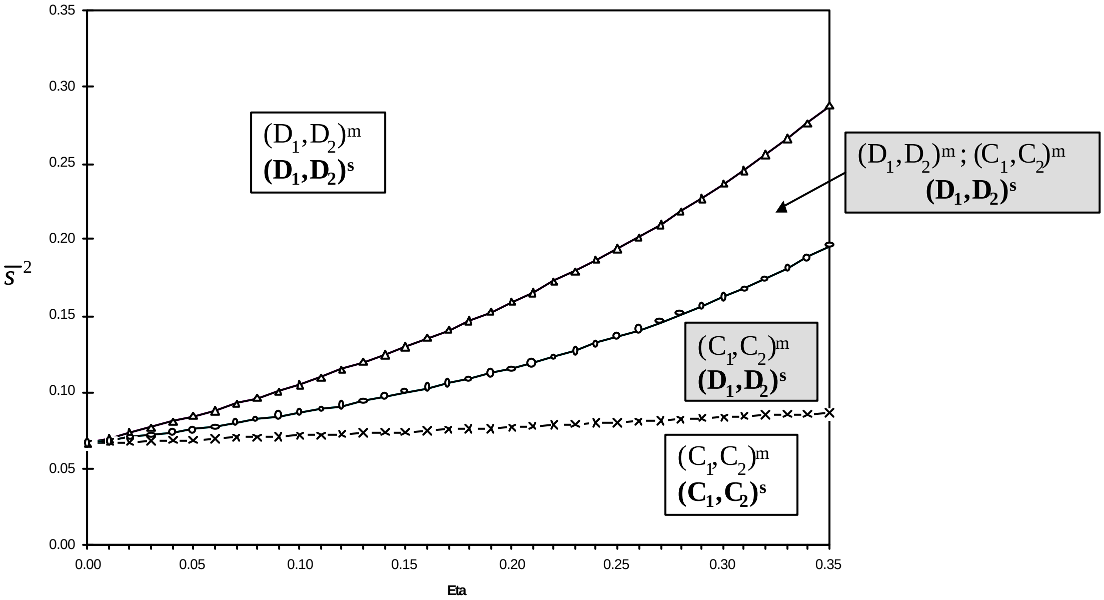
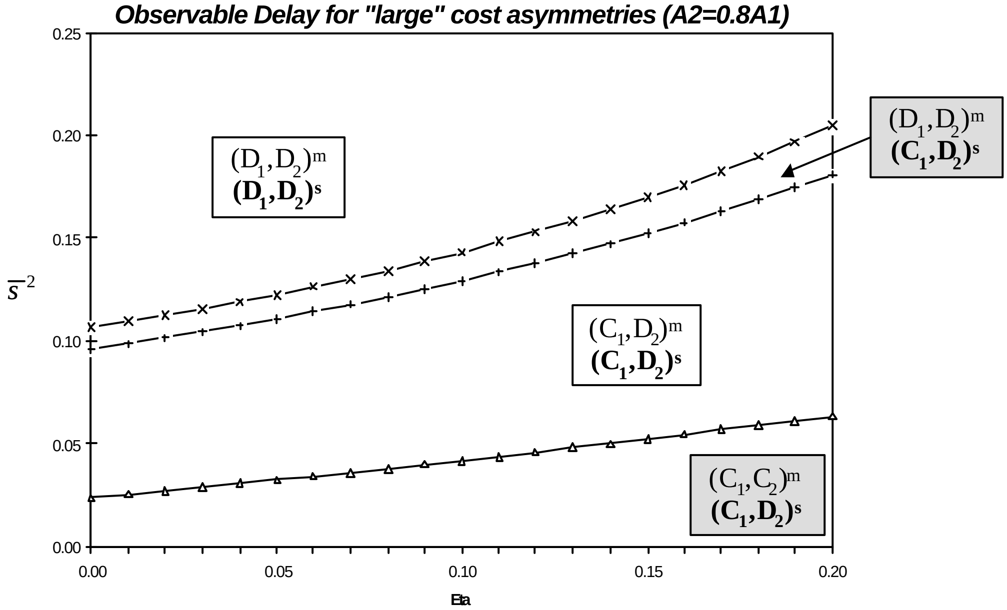


Figure A.1: Market outcomes versus socially preferred outcomes for Observable Delay in the symmetric case (A1= A2)



$$-\Delta-: Ep_1(C_1,C_2)=Ep_1(D_1,C_2) \quad \text{and} \quad Ep_2(C_1,C_2)=Ep_2(C_1,D_2)$$
$$-\text{o}-: Ep_1(C_1,D_2)=Ep_1(D_1,D_2) \quad \text{and} \quad Ep_2(D_1,C_2)=Ep_2(D_1,D_2)$$
$$-\text{x}-: EW(C_1,C_2)=EW(D_1,D_2)$$

Figure A.2 : Market versus socially preferred outcomes under Observable Delay for "large" cost asymmetries (A2=0.8A1)



$$-\Delta-: Ep_2(C_1,C_2)=Ep_2(C_1,D_2)$$
$$-+-: Ep_1(C_1,D_2)=Ep_1(D_1,D_2)$$
$$-\text{x}-: EW(C_1,D_2)=EW(D_1,D_2)$$