Real Options and Game Theory: When should Real Options Valuation be applied?

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1. Introduction

At a recent conference on real options, a delegate from a telecommunications company raised the following query in response to a speaker from a firm of management consultants. Paraphrasing somewhat, he said: "You've stressed the importance of 'holding the option' and delaying investment decisions. Last month a consultant from your company advised my firm, a telecoms company, to act decisively, stressing the importance of committing to the market and seizing the advantage over our rivals. Isn't all this rather contradictory?" The reply cast little light on this apparent conflict, amounting to little more than "Well, real options can't be applied everywhere."

In recent years there has been considerable interest in real options as a valuation method and investment appraisal technique. In addition to a multitude of specialist textbooks (see, among others, Trigeorgis (1996), Amram and Kulatilaka (1999) and Copeland and Antikarov (2001)), the real options approach is also now covered in standard texts such as Brealey and Myers (2000). The technique has been applied to a number of areas including valuation of oil leases, patents and real estate.

Despite initial enthusiasm, real options valuation has proved difficult to put into practice. The techniques are significantly more complex than the established investment appraisal methods of discounted cashflow (DCF), return on capital employed (ROCE) or payback period. Real options valuation requires detailed analysis of all possible future developments, and the degree of uncertainty surrounding these possibilities, not just the expected outcome. Managers are also required continuously to monitor the development of the business environment, considering whether conditions merit the exercise of a further investment opportunity, or whether they have deteriorated so far that abandonment of the project is now advisable.

Even assuming that these practical difficulties can be overcome, a fundamental issue remains to be resolved. When exactly should real options be applied? Is it always relevant, or are there situations in which the established DCF-based methods are superior? There are, even

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consultants selling the technique will admit, situations where real options could lead a firm seriously astray. In a setting where there are strategic advantages to acting quickly and seizing the advantage over one's rivals, the use of real options could cause a firm to miss important an opportunity and relinquish its position in the market.

How can we identify the situations in which real options should be abandoned in favour of more established techniques? Difficulties arise particularly when real options interact with strategic interactions between firms. There is a crucial gap in this area, causing considerable confusion. This article aims to shed some light on this issue and provide some guidance as to the market conditions under which real options valuation, or a DCF-based technique, should be applied.

2. Real Options: Can the decision be delayed?

Real options valuation can be used when all of the following three conditions apply:

(i) the future is uncertain;

(ii) the (investment) decision is irreversible, whether fully or in part;

(iii) the firm holding the (investment) option has the ability to delay.

Under these three conditions there is an option value to delaying investment. This option value should be added to the cost of making an investment – it is an 'opportunity cost' that is incurred when investment takes place. Since option values are positive, real options raise the hurdle for investment: investment should not take place until the expected net profit exceeds the option value of doing nothing that, under the above conditions, exceeds nothing. Thus, real options analysis usually implies that investment should be delayed, compared with traditional DCF analysis.

Following this description of the real options approach, the first question to be asked when a firm considers an investment opportunity is:

Question 1: Is there an 'option value' of delay?

Let us suppose that the first two conditions are met (as they generally are in most investment opportunities): the return to investment is not certain, and the investment cost cannot be recouped in full if the project is subsequently abandoned. But what about the third condition? When exactly does a firm have the ability to hold the option? This condition forms the basis of our concern.

In some settings institutional factors prevent a firm from holding its investment option beyond a certain date. Examples of this include oil leases, which lapse if development is not commenced before a pre-specified date, and patents, which expire after a legally enshrined period. In most instances, however, the investment opportunity has no contractually or legally specified expiration date. In these cases the firm could be said to have the ability to delay indefinitely – in that its option has no specified expiration date – but the market reality facing the firm is unlikely to be so simple.

In most industry settings, the ability of a firm to delay its investment (and other) decisions is crucially affected by the actions of *other firms*. When several firms compete in a market, delay by one firm is liable to result in it being pre-empted by a rival. After its rival's investment, the first firm's investment opportunity is likely to be reduced in value, and may even be forfeited entirely. Thus, a firm's ability to delay depends not only on legal and contractual niceties, but also on the actions of other firms. This leads us to the second question facing an investing firm:

> ***Question 2: Is my option to invest affected by strategic interactions with other firms?***

There is, however, a subtle but important difference between the effects of strategic interactions and the expiration of an oil lease, for instance. Contractual expiration occurs on a specific date which is known in advance and is unaffected by the actions of the holder. The loss of an investment opportunity due to the action of another firm is not pre-specified in this way: the date on which the rival will act (if at all) is not known in advance, and it may depend on what the holder itself does. Interactions between competing firms are a two-way process: firm A is affected by the actions of firm B, while firm B is also affected by firm A. To judge whether a firm has the ability to delay investment, it is necessary to understand strategic interactions between the firms in the market and so predict the behaviour of one's rivals. Thus, to answer Question 1 it is necessary to address Question 2 and to analyse these interactions.

3. Game Theory: Understanding strategic interactions

Game Theory is the approach by which interactions between interdependent players can be studied and understood. For the purposes of the present article it is unnecessary to delve deep into the intricacies of this complex subject; the interested reader may find detailed expositions in the textbooks by Rasmusen (1994) and Fudenberg & Tirole (1991), among others.

For our purposes, strategic interactions between firms can be classified into two broad types: first mover advantages (FMA) and second mover advantages (SMA). A situation involves a first mover advantage if the player gains a higher payoff by acting first rather than second, say, by investing before its rival does so. A second mover advantage exists, by contrast, if a player achieves a higher payoff by acting second, and thus prefers its rival to act first. This takes us to the next question:

> ***Question 3: Do strategic interactions involve FMA or SMA?***

Instances of FMA include patent races, systems wars, and entry into a natural monopoly industry. In a patent race, for example, the first to achieve the breakthrough gains a patent giving it an exclusive right over the technology and all latecomers gain nothing. SMA arise when the first investment yields some spillover benefit to the second mover. In contrast to

entry games that involve FMA, exit games (or wars of attrition) give rise to SMA. Spillovers of information, whereby the second mover learns from the experience of the first, also generate SMA.

The strategic game types interact with real options as follows. FMA tend to conflict with real options: the real options approach stresses the value of delay, while delay is rendered highly dangerous in the presence of FMA. A firm that holds its option to invest in the presence of FMA may find that another firm invests before it, reducing or even eliminating the value of its investment opportunity. FMA are covered in detail in Section 4. SMA, on the other hand, enhance the motivation for delay and thus tends to complement real options. These situations are considered in Section 5.

4. Strategic interactions with first mover advantage

To illustrate the implications of FMA, we start by setting out a simple game known as the 'Battle of the Sexes.' This game can be explained by reference to the following payoff matrix.

Figure 1: Battle of the Sexes

		Woman	
		Football	Opera
Man	Football	2, 1	0, 0
	Opera	0, 0	1, 2

The two players differ in their preferred pursuits: the man (stereotypically!) would most like to see a football match, while the woman would rather attend an opera. However, the couple strongly desire to be together: neither receives any payoff unless they successfully co-ordinate their leisure activities. If the woman moves first (and assuming that she can commit to her selection) she will choose Opera, and the man will copy this choice. If the man moves first, on the other hand, he will choose Football and the woman will then choose this too. Thus, whichever player moves first gains a higher payoff (2 rather than 1) and there is a FMA.

The underlying principle of this game is mirrored in many real-world industry settings. The first inventor to achieve a patent has an exclusive right over the relevant technology for many years, leaving nothing for subsequent developers (unless they can invent a sufficiently novel design of their own). In a market where 'tipping' effects are strong – this occurs in markets such as computer software and satellite broadcasting where network effects are significant – the first firm to establish a base tends to dominate the whole market in due course.

Entry into a market frequently involves FMA. Suppose that a market is initially unprofitable but is growing over time. The first firm to enter enjoys a period of monopoly profits before the market becomes sufficiently large to sustain a duopoly, while the second firm earns no profit during this time. Moreover, if there are significant costs of switching between suppliers, there is an even stronger advantage to entering the market first and getting customers signed up: the first mover continues to enjoy a strong position even after the entry

of the second firm. Note that the former source of advantage is *temporary* – the first mover gains additional profits only while its rival is waiting to enter – while the latter is *persistent*, with the first mover achieving higher profits long after the second firm has also entered the market.

When strategic interactions give rise to FMA each firm has an incentive to act just before its rival does so, thus gaining the advantage for itself. This incentive tends to give rise to pre-emption: a firm invests earlier than its rival, and before it would otherwise do so, in order to seize the strategic advantage. In this setting delay is extremely risky: a firm that delays its investment faces the danger that its rival will come in and invest before it, taking the more advantageous position and undermining the value of its investment opportunity.

The incentive to pre-empt directly conflicts with real options. Option values tend to generate delay, relative to traditional investment appraisal methods, while the fear of pre-emption is likely to induce a firm to act more quickly than would otherwise be the case. Consider the extreme case where the failure to act immediately causes the investment opportunity to be lost to a rival, throwing away the entire value of the project. In this case investment becomes a now-or-never opportunity – there is no ability to delay – and option values are entirely eliminated. Since all option values are zero, the real options approach collapses to the standard DCF method.

However, game theory tells us that the full analysis is more complicated than this. Strategic interactions are two-way: player A is affected by the actions of player B, while B is also affected by A's actions. Each player must take account not only of its rival's *actions*, but also the rival's *reaction* to its own behaviour. Thus, in making its own decisions a firm will anticipate the reactions of its rivals and try to ensure that these are as favourable to itself as possible.

Suppose that a firm is considering making a pre-emptive investment: we term this firm the leader while the second mover is denoted the follower.[2] (Using these terms, the existence of FMA implies that a firm prefers to be the leader rather than the follower.) Suppose also that subsequent investment by the follower reduces the leader's profits, as would be the case when a monopoly is undermined by entry to become a duopoly. The leader will wish to consider whether its own investment will induce its rival to invest more quickly, or whether rival investment will instead be deterred. A rapid reaction by the follower will undermine the leader's advantage, reducing the benefit of pre-emption. In this case anticipation of the follower's reaction may generate a different outcome from that described above: the (potential) leader may instead prefer to delay its investment until a time when it is optimal to invest in the knowledge that the follower will rapidly copy this action.

One example of this phenomenon is a patent race.[3] Suppose that two firms each hold the option to invest in research that will (with some probability) generate the same technological advance. The first to achieve the breakthrough is awarded a patent giving it an exclusive right over the technology for a lengthy period: this gives rise to a strong FMA and an incentive to

[2] Note that these roles are not allocated to the players in advance: the terms 'leader' and 'follower' are merely used to describe the positions of the two players, where these roles emerge endogenously from the strategic game being played between them.

[3] For a detailed analysis see Weeds (2001).

act pre-emptively. However, investment by the leader speeds up the follower's investment (as the follower's option value of delay is reduced by the leader's action) and, once the follower has invested, the firms have an equal chance of winning the patent. Thus the leader's advantage is rapidly undermined by the follower's reaction. In such an instance the leader may prefer to delay its investment until a time when it becomes optimal even in the knowledge that a patent race will ensue.[4] Investment may be delayed despite the presence of FMA, and the real options approach remains intact.[5]

This outcome may appear puzzling at first sight. A helpful analogy is provided by the behaviour of runners in a long-distance race. Contestants typically remain in a pack proceeding at a moderate pace for most of the distance, until near the end when one attempts to break away and the sprint for the finish begins. Although it would be advantageous to move ahead at any time, each runner knows that its competitors will respond by speeding up too and therefore prefers to delay the sprint finish until the most advantageous time, towards the end of the race.

To analyse a strategic situation involving FMA, the following questions must be addressed by a firm considering investing pre-emptively to become the leader:

Question 4: How will the follower's action affect my profits?

Question 5: How is the follower likely to react to my action?

Question 4 concerns the impact on the leader when the follower subsequently invests. In a competitive situation it is likely that, in addition to the existence of FMA, the subsequent action of the follower harms the leader. Therefore the answer to Question 4 is likely to be that the follower's action reduces the leader's profits. A corollary of this question is whether the FMA is temporary or persistent. Temporary FMA are lost when the follower invests, thus the follower's investment is harmful to the leader. Persistent FMA, on the other hand, imply that the leader is insulated from the follower's actions in some way, at least in part, and the effect of the follower's reaction is of smaller magnitude.

Question 5 requires an analysis of the likely reaction of the follower. Specifically, does a firm's investment cause its rival to follow rapidly, or is rival investment deterred by the action of the leader? If the leader's action deters investment by the rival, this gives added advantage to pre-emption: the leader seizes the FMA while its rival's reaction is more delayed. A rapid (and harmful) reaction by the follower, however, quickly undermines the FMA and reduces the incentive to pre-empt.

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[4] Note that the other firm takes account of the same considerations and will also choose not to pre-empt its rival, thus delay is sustainable.

[5] The analysis is somewhat complicated: the outcome is not precisely the same as the case where a single firm holds the option to invest, unaffected by rivalry. Investment is delayed but not necessarily to the same degree, and investment valuation will also differ somewhat. For illustration of this point see the numerical examples in Section 6. Option values are significant, however, and the fundamental insights of real options remain valid.

Putting the two questions together, the following predictions can be made. If FMA persist despite investment by the follower, a firm has less to fear from its rival's reaction and is likely to act pre-emptively to seize the FMA. Option values are destroyed by competition and the real option approach has little relevance. If the rival is deterred by the leader's action, further delaying its own investment, there is a strategic advantage to early investment and pre-emption is again likely. If FMA are temporary and the rival reacts rapidly to the leader's action, on the other hand, fear of the competitive reaction may induce a firm to delay investment and the real options approach is applicable. Section 7 discusses the likely outcomes under a variety of industry conditions.

The effect of competition is not merely to subtract some amount from the option value of delay. Strategic interactions fundamentally alter the character of the options available to the firm, affecting in particular whether the option to delay can be held at all, while the value of the project may vary depending whether other firms have, or have not, already invested. The situation requires careful examination to assess whether or not the strategic factors prevent the firm from holding the option, and to determine the optimal timing of investment in the light of the likely competitive reaction.

5. Strategic interactions with second mover advantage

The implications of SMA can be illustrated using another simple game, known as 'Matching Pennies.' The payoff matrix for this game is as follows:

Figure 2: Matching Pennies

		Chris	
		Heads	Tails
Pat	Heads	2, 0	0, 2
	Tails	0, 2	2, 0

Each player shows a penny, displaying either heads or tails. If the faces match, Pat gets both pennies; if they differ, Chris receives them both. Now suppose that one player, Pat, chooses first and cannot later alter this choice. Whatever face Pat chooses, Chris will choose the non-matching face and will receive both pennies, leaving Pat with nothing. Correspondingly, if Chris moves first Pat will always choose to match and will receive both coins. The player that moves second always gains the higher payoff (2 rather than 0) and there is a SMA.

The fundamental principle of this game can be seen in a number of real-world industry settings. Exit games, otherwise known as wars of attrition, involve SMA. Suppose that demand is insufficient to support two firms, but a single firm on its own is profitable. In this exit game the second mover achieves a higher payoff than the first: each firm would like its rival to quit the market first, leaving it as a profitable monopoly.

Information spillovers are another source of SMA. Suppose that demand in a market is uncertain, such that entry may be profitable or unprofitable with equal probability. The first entrant reveals the true state of demand to subsequent entrants, who learn from this and go in

if and only if the market is profitable. Informational spillovers also arise in relation to research and development, affecting settings such as pharmaceutical research and oil exploration.

In some instances a firm's investment project has higher value if another firm also invests; in this case the investments of the two firms are said to be complementary. For example, as long as competitive effects are not too strong, a firm may benefit from the advertising expenditure of other firms to the extent that this creates demand for the product class as a whole, not just the output of the particular producer. Network effects, whereby the value of a product to an individual consumer increases with the number of other consumers – a much-cited example of this being the telephone – may generate SMA. The existence of another producer and its established consumer base benefits a subsequent entrant, who gains the higher value associated with the large number of existing subscribers without having to build up this base from scratch.

As with temporary and permanent FMA, a similar distinction can be drawn between two forms of SMA. The complementarity of investment underlying SMA may either be *one-way*, benefiting the follower alone, or it may be *two-way*, such that the leader also benefits when the follower invests. Most of the cases described above are one-way. Exit of the leader benefits the firm that remains in the market, but the leader gains nothing if the follower subsequently quits. Informational spillovers tend to benefit the follower alone, though in a setting with on-going research it is possible that the activity of the follower may benefit the leader. Network effects may be two-way, however, if the leader benefits from the subsequent increase in demand generated by the follower.

If the complementarity of investment is one-way the advantage to the second mover is permanent: the first mover never benefits from the other firm's investment. Two-way complementarity, on the other hand, gives rise to a temporary SMA: while the leader alone has invested it does not benefit from the complementarity, but after the follower invests the positions of the two firms are symmetric. Thus, SMA tends to be weaker when the benefits of mutual investment are two-way.

Note that SMA provide an additional motivation for investment to be delayed. In contrast to FMA, SMA enhance the value of delay, tending to reinforce the effect of real options. Thus, SMA affect the magnitude of investment delays, rather than determining whether investment is delayed at all: the difference is one of degree rather than type.

In assessing whether an investment opportunity is affected by SMA, the following questions should be posed:

Question 6: Is investment by another firm beneficial to me?

Question 7: Is it worthwhile to delay investment in order to benefit from the other firm's action or experience?

Question 6 considers whether SMA exist, while Question 7 assesses whether this benefit is sufficient warrant delaying investment so much as to let the other firm invests first. It should be borne in mind, however, that the advantage may be symmetric: the other firm may similarly wish to delay its investment, in order to benefit by acting later as the follower. Thus, delay may be greatly increased even compared with the outcome of real options considerations.

The firm should also consider whether the benefit derived from mutual investment is one-way, benefiting the follower only, or two-way such that the leader will benefit at a later date when the follower subsequently invests. This is the focus of Question 8:

> ***Question 8: If I invest first, will I benefit from subsequent investment by the follower?***

If the answer to Question 8 is yes, the SMA is temporary and there may be less to be gained by delaying investment simply in order to be the second mover. However, even if the firm decides to invest first rather than to delay and gain the SMA, the reaction of the other firm is important: when the complementarity is two-way the leader benefits if the follower invests sooner rather than later.

If the cost of delaying in order to invest second are excessive, a firm may wish to consider whether there are measures that might be taken to speed up the other firm's investment. If the investment project can be broken into smaller steps, undertaking a preliminary investment may stimulate the other firm to invest. Alternatively some form of co-ordination may be required to overcome the tendency of each firm to wait for the other to act first. Joint research efforts, standard-setting bodies and agreed programmes of plant closures (as in the steel industry) are instances of such co-ordination.

In some settings SMA co-exist with FMA. For example, although two telephone companies each benefit from the other's customer base, as overall demand for telephony services is higher, they also compete for subscribers. Such a situation becomes complicated: there is an incentive to pre-empt, but the position of the follower may also have advantages. If the complementarity of investment is two-way, a firm may wish to pre-empt its rival but also to ensure that the other firm does not delay its investment too long. Some unexpected results are possible: for example, it is possible that when uncertainty is greater the leader will wish to invest *sooner*, rather than to delay for longer (the usual real options result).[6]

6. Impact of strategic interactions on investment valuation

As explained in Section 4, strategic situations with FMA result in one of two very different outcomes. If the incentive to pre-empt is sufficiently strong, and the fear of the follower's reaction sufficiently weak, the strategic interactions will destroy most of the option values associated with the project and early investment will occur. If the fear of a rapid reaction by

[6] For a detailed explanation see Mason & Weeds (2001).

the follower dominates the FMA, both firms delay their investment and option values are retained.

How does each of these outcomes compare with the standard DCF and real options valuations obtained when the strategic considerations are ignored? To illustrate the impact of strategic interactions numerical examples based on the model of R&D investment set out in Weeds (2001) have been calculated. The base parameters for these calculations are as follows. Investment incurs an up-front cost of 100, which is irrecoverable. The return to the project (here, the value of the patent that may be won) varies over time, with an expected annual growth rate of 2% and annual standard deviation (σ) of 25%. The risk-free rate is 5%. The strength of the FMA is captured by a 'hazard rate' term (h) measuring the expected speed of innovation, such that a higher figure gives a stronger pre-emption incentive; in the base scenario the hazard rate is 10%.

The option value of the project is calculated at the point where the option to invest is 'at the money': in other words, when the DCF value of the project is zero. Thus, the traditional investment appraisal method would be indifferent between investing and not investing. In the absence of strategic effects, however, real options would tell us that the project has strictly positive value arising from the option value of delay. The following two scenarios are compared: the value of investment if both opportunities are held by the same firm, and their (combined) value if held by two different firms that act strategically vis-à-vis one another.

The results of these calculations are shown in Table 1. The second column gives the value of the investment opportunities when held by a single firm. The third column indicates the type of outcome – pre-emptive or delayed investment – that occurs when two separate firms hold the opportunity to invest, while column four shows the combined valuation of the investment opportunities in this strategic setting. The final column gives the difference in project value between the single firm and strategic settings.

Table 1: Numerical examples

Parameter	Single firm valuation	Strategic outcome	Strategic valuation	Difference in project values
Base scenario	40	pre-emption	12	– 70%
Increase h to 20%	40	pre-emption	5	– 87%
Increase h to 50%	40	pre-emption	1	– 97%
Increase σ to 35%	51	delay	47	– 7%

The base scenario gives a project (option) value of 40 when a single firm has the opportunity to invest; since the project is at the money this is purely option value. When the investment opportunities are held by two different firms, however, a pre-emption outcome results in this case: one firm will invest rapidly as the leader, while the other invests subsequently as the follower. The (combined) value of the investment opportunities falls to 12, a loss of 70% of their value when held by a single firm.

Increasing the hazard rate (h) increases the strength of the FMA and the incentive to pre-empt, worsening the loss of option values. With h increased to 20% the strategic value of the investment opportunities falls to 5, a loss of 87% of the single firm valuation. With h at 50%, strategic interactions eliminate almost the entire option value of investment: the strategic value is just 1, a loss of 97% compared with the single firm case.

Returning to the base scenario but increasing uncertainty (σ) to 35% increases the option value of delay: the value of investment to a single firm increases to 51. Furthermore, the option value of delay is now sufficiently large to outweigh the FMA and we find that investment can be delayed in the strategic setting. In this example the (combined) value of the investment opportunities in the strategic case is 47, a loss of just 7% compared with the single firm valuation.[7]

The following conclusions can be drawn from this analysis. When FMA are strong, one firm will pre-empt its rival and most of the option value of delay is lost. In such settings, the real options approach has little relevance and its application may lead firms to make serious strategic mistakes, forfeiting important opportunities to rivals. Although project values are not precisely the same, the DCF method is a reasonably accurate rule of thumb when FMA are strong.

When FMA are sufficiently weak, or mitigated by the fear of a rapid reaction by the rival, both firms will delay their investment and option values can be retained. Project values are significantly higher than in the pre-emptive case, and are close to the single firm valuation. Again, although the match is not exact, the usual real options approach gives a reasonable approximation to the project value in this case. In the following section alternative industry characteristics that are likely to generate delayed investment, or alternatively a pre-emptive outcome, are examined to give some guidance as to when each valuation technique should be applied.

7. Which valuation technique should be used?

This section addresses the following question:

> ***Question 9: Under what industry conditions is each valuation method most appropriate?***

As we have seen, the ability to hold the option and delay investment depends on the balance between the following factors:

- the magnitude of the option values;
- the strength of the FMA;
- the fear of the follower's reaction.

[7] Even when investment can be delayed, the outcome of the strategic game between two firms differs somewhat from the single firm case: competition reduces project values a little even in this case, but as can be seen the difference is not large. For details see Weeds (2001).

A pre-emptive outcome is more likely if option values are relatively small, FMA are significant, and the follower's reaction is deterred by the leader's action and/or has little effect on the leader. Assessing any real-world industry situation requires a judgement to be made as to the relative magnitude of these factors and the likely outcome of the strategic game between the players. It is difficult to give precise guidelines and any judgement is, inevitably, somewhat subjective. The following is intended as a guide to the industry characteristics that are likely to generate each outcome – delayed or pre-emptive investment – and hence the investment appraisal rule that is most appropriate under these circumstances.

Considering each of the factors above in turn, we start by considering under what conditions option values are large. These results are well-known from option pricing theory: option values increase with greater uncertainty, the irreversibility of investment, and the duration of the investment opportunity, and are reduced by a high 'dividend yield' or opportunity cost given by the cashflows that are foregone by not investing. Thus, the real options approach is more appropriate when uncertainty is considerable, the project is highly irreversibility, the investment option is of long duration and the opportunity cost of not investing is small.

The strength of the FMA, and hence the incentive to pre-empt, can be assessed as follows. The key question is the *difference* between the expected profit accruing to the leader and that obtained by the follower: if this is substantial, the FMA is large and pre-emption is the most likely outcome. A related issue concerns the *persistence* of the FMA. If the leader's advantage persists even after the follower has invested it is likely that the leader's total payoff will be substantially larger, as its profits will be higher in perpetuity rather than only during the period up to the follower's investment. For this reason greater irreversibility of investment is likely to enhance the FMA: the initial investment choices made by the firms (say, capacity levels) are likely to persist far into the future and any advantage obtained by one firm is likely to be persistent. For example, long-lived assets with low scrap values are likely to confer significant FMA.

Whether the leader has much to fear from the follower's reaction depends on two distinct factors: the impact of the follower's investment on the leader's profits, and the speed with which this reaction is likely to occur. The *impact* of the follower's investment is related to the characteristics governing the strength of the FMA: a more persistent advantage, perhaps due to greater irreversibility of investment, implies that the follower's behaviour has less impact on the leader. Customer switching costs, for example, insulate the leader from the subsequent entrants into its market, lessening the fear of the follower's investment.

The speed with which the follower will react depends on two considerations: the effect of the leader's investment on the value of the follower's investment project, and the impact on its option value of delay. If the leader's investment greatly reduces the value of investment to the follower, perhaps because only a small market niche remains available, entry will not be profitable until the market has grown substantially. The follower's investment will not take place for some time, and may be deterred altogether. The leader has little to fear from the follower's reaction and pre-emptive investment will occur.

The follower's option value of delay may also be affected by the leader's action. Assuming that only two firms hold the option to invest, once the leader has exercised its option the follower is then free to hold its option for as long as it wishes. (Obviously, with more option-holders the second mover is also constrained by the remaining players.) However, in some

cases the leader's action undermines this option value and hastens the follower's investment. This is particularly likely when investment involves several stages or takes time to complete. One instance of this is a patent race. Suppose one firm has commenced a research project but has not yet achieved the breakthrough. The probability that the first mover will win the patent undermines the value of delay to the follower: the other firm will wish to invest immediately while it still has a chance of winning the race. Thus, the follower's reaction is more rapid, and more dangerous to the leader, when there is a chance of catch-up or leapfrogging.

The effects of various industry characteristics are summarised in Table 2. The second column gives the effect of (increasing) the characteristic on the option valuation of the investment opportunity when a single firm holds the option to invest. The third column shows the effect of the characteristic in the presence of strategic interactions when two firms hold the option to invest, indicating the effect on the firm's ability to hold the option.[8] The final column tells us which valuation tool, DCF or real options valuation (ROV), should be used when this characteristic dominates. (Though it should be borne in mind that the assessment is largely a question of degree, and furthermore a number of conflicting factors are likely to be present in any real-world situation making the judgement more complicated than this.)

Table 2: Effect of industry characteristics on investment appraisal

Characteristic	Effect on single firm option value	Strategic effect on ability to hold option	DCF or ROV?
Size of FMA	none	↓	DCF
Persistence of FMA	none	↓	DCF
Irreversibility	↑	↓	ambiguous
Uncertainty	↑	↑	ROV
Dividend yield	↓	↓	DCF
Presence of SMA	none	↑	ROV
Time to build / likelihood of catch-up	none	↑	ROV

A stronger or more persistent FMA has no effect on the pure option value to a single firm, but both reduce the ability to hold the option in a strategic setting. Thus, in both cases the DCF rule is likely to be more appropriate than real options valuation. Greater irreversibility increases the stand-alone option value, but also (assuming that the persistence of the FMA is thereby increased, as is likely to be the case) reduces the ability of competing firms to hold

[8] The results are largely derived from Weeds (2001). The findings are not always obvious: the outcome of the strategic game depends on the relative payoffs to investing pre-emptively as the leader and delaying investment until a later date. In many instances the characteristic has an impact on both payoff functions, in which case the relative magnitudes become important. Furthermore, it should be borne in mind that the payoff to the leader depends on the action of the follower, which may also be influenced by the characteristic.

the option. Thus, the effect of irreversibility is ambiguous: the situation must be studied careful to determine which effect is likely to dominate.

Greater uncertainty increases pure option values and increases the ability of firms to hold the option to invest. A higher dividend yield (or opportunity cost of holding the option) has the opposite effect: both the stand-alone option value and the ability to hold the option are reduced. Thus, the real options approach is more appropriate when the future is highly uncertain and the opportunity cost of delay is low. The presence of an advantage to the second mover, such as an informational benefit, increases the value of delay and makes it more likely that the investment option will be held. Time to build, or a greater likelihood of the follower catching up with the leader, increases the leader's fear of the follower's reaction and makes option values easier to sustain. Hence both SMA and time to build, neither of which have a direct effect on option values, increase the applicability of the real options approach.

8. Some typical industry settings

This section continues the assessment of when each valuation method is applicable by addressing the following question:

> ***Question 10: What characteristics are seen in particular industry settings, and which rule is more appropriate?***

(a) Market entry in oligopoly

Suppose that two firms are considering entry into a market where demand is growing over time, though subject to random fluctuations. Market entry is irreversible. When demand is sufficiently high one firm may profitably enter, but the second firm must wait until demand grows further before its entry becomes profitable. The leader gains monopoly profits during the period between respective entry times, but has no persistent advantage after the follower enters: from this point on the firms are symmetric. There is a FMA but it is temporary, not persistent, and the follower is not deterred from entering the market. The FMA may be sufficiently small that option values can be retained and the real options approach retains its relevance.

Suppose now that consumers incur a switching cost if they change supplier. This gives the first mover a persistent advantage: the leader will receive higher demand than the follower and its profits will be higher in perpetuity, not just prior to the follower's entry. Pre-emptive entry confers a greater advantage and, furthermore, the leader has less to fear from the follower's entry into the market. In this case, option values are likely to be destroyed by pre-emption and the DCF rule is more appropriate.

Suppose instead that the original situation is varied by the addition of technological progress. Production costs fall as technology advances, but a firm is locked into the cost level that pertains when it invests. In the duopoly game between two firms the player with lower costs achieves higher profits. Thus there is an advantage to acting second: there is a SMA that partly counteracts the FMA described above. The SMA enhances the value of delay,

increasing the likelihood that investment options can be held. Again, it is likely that the real options approach can be applied.

(b) Natural monopoly sectors

Consider a situation with two potential entrants into an industry that is a natural monopoly, i.e. that can sustain just a single producer. Suppose further that asset lives are lengthy and investment is entirely irreversible. These features fit the transportation networks found in utility sectors such as gas, electricity and water. Under these conditions the FMA is large and persistent – in fact, this is the limiting case where the value to the 'second mover' is zero as it cannot profitably enter the market. Since the FMA is so strong, and rival entry is entirely deterred, option values cannot be sustained and the DCF approach is the relevant one.

Once the incumbent is established in the market, however, the situation changes. There is no longer any potential threat of competition and the incumbent is the only firm holding the option to invest. The market structure in this case gives the firm a *de facto* proprietary right over the investment option. The incumbent therefore has the ability to delay exercising the option as long as it wishes, and the real options approach regains its relevance.

(c) Network markets

A network market is one where network effects – the feature that the value of the product to an individual consumer increases with the network of other users – are strong. The usual consequence of network effects is that a single operator comes to dominate the market. Systems wars have occurred in various sectors including satellite broadcasting (Sky v. BSB), video cassette recorders (VHS v. Betamax) and computer operating systems (Microsoft v. Apple Mac).

In network markets a phenomenon known as 'tipping' frequently occurs: an early lead by one firm induces subsequent purchasers to copy this choice and the market rapidly tips in favour of this operator. With tipping effects, there is a strong and persistent FMA. The follower is unlikely to be able to catch up once its rival is seen as the most likely winner of the systems war. In such a market pre-emptive investment is likely and real options is not applicable.

(d) Patent races

A patent race takes place when a number of firms undertake research in the hope of winning a patent. Given the 'winner takes all' nature of the patent system, there is a strong FMA. However, if research takes time to complete and its outcome is uncertain, there is some prospect that the second firm to commence research might leapfrog the leader and seize the patent. Investment by one firm will tend to induce the second to invest too: once the leader invests there is some probability that it will make the breakthrough and the follower's option to invest will then expire. Thus the follower is likely to respond rapidly to the leader's action, which will deter pre-emptive investment. Option values may be retained and the real options approach remains relevant.

In addition, there may also be SMA in the form of spillovers of information from the leader to the follower: for example, the follower may benefit by learning which research avenues have

proved unfruitful. Such SMA increase the value of delay and raise the likelihood of investment being delayed.

9. Conclusion: Implications for strategic management

There are two parts to any situation involving options (real or financial) with flexible exercise dates: calculation of the option value and derivation of the optimal exercise rule. In assessing an investment project with option characteristics managers must follow the optimal exercise rule in order to achieve the maximum value. This requires managerial skill, and even more so when the setting involves strategic interactions with other firms in addition to the usual real options features.

In addition to assessing the extent of (stand-alone) option values, the firm's managers must ensure that they understand the strategic interactions with other firms affecting them and, in making their decisions, consider the likely actions of other firms and their reactions to their own decisions. This paper has attempted to set out the way in which the characteristics of an industry influence the nature of these interactions, and to give some guidance on when the real options approach is, and is not, relevant as an investment tool.

If possible, managers will wish to influence rivals' behaviour to operate in their own favour. The aim is to avoid harmful reactions by rival firms, or to lessen their effects, and to stimulate investment by other firms when this confers some benefit. Real options may provide an additional motivation for mergers or joint ventures: when options interact joint management is desirable. The benefits of merger are generally assessed in terms of maximising current cashflows or cost minimisation. However, a potential benefit of merger may be the ability to improve the management of future investment options and increase their value: this benefit may be present regardless of whether there are any current cost synergies to be gained. When options interact, their combined value is not additive: there is an additional gain due to the enhanced ability to hold the option and choose its exercise date optimally. This principle may be extended to diversification into sectors that are currently unrelated but are likely to converge in the future: diversification gives firms options over future synergies between these areas, including the ability to exercise these options optimally.

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