

# Time Compression Diseconomies and Sustainable Competitive Advantage

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## Abstract

A central issue in competitive strategy is the ability of firms to sustain competitive advantages, a topic that is usually treated taking existence of the competitive advantage as given. We endogenize both the existence and sustainability of competitive advantage using a duopoly model in which each firm can develop a resource that improves its competitive position. We assume time compression diseconomies where the quicker a firm develops the resource, the higher the development cost. We show that time compression diseconomies naturally give rise to resource heterogeneity and hence competitive advantage in that one firm develops the resource faster than the other. We quantify the sustainability of the competitive advantage, derive conditions under which the resource is “inimitable” and show that firm profits are non-monotonic in the extent of time compression diseconomies. We allow firms a choice between developing the resource themselves and imitating the previously developed resource of their rival. Contrary to received wisdom, we show that an innovative firm can increase sustainability and profits by decreasing causal ambiguity.

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## 1. Introduction

The notion of sustainable competitive advantage lies at the heart of competitive strategy. Despite its ubiquity in both teaching and research, a rigorous treatment of the topic is not in place, with even the definition of competitive advantage still being debated (Rumelt, 2003). While consensus in the literature has emerged that sustainable competitive advantage arises from the possession of scarce, hard to imitate resources (Barney 1991), this resource-based view is most successful in explaining the sustainability of an existing competitive advantage rather than in offering a coherent theory of both the creation and sustainability of competitive advantage (Priem and Butler, 2001). For example, it remains unclear whether a strengthening of the factors that provide barriers to imitation and hence sustainability might actually reduce profits by making it more difficult and costly to establish an advantage in the first place.

If one wants to explore rigorously both the creation and sustainability of competitive advantage, as we do, one needs a precise definition of competitive advantage. One approach is to equate competitive advantage with financial performance above the industry average (Besanko et al., 2000), an approach that dovetails nicely with the central concern of the strategy field, namely understanding the drivers of firm performance. Another approach, going back at least to Porter (1985), is to equate competitive advantage with lower production costs or greater differentiation; with more recent treatments in this stream focusing on value creation (Brandenburger and Stuart, 1996), where value creation is defined as the difference between consumer's willingness to pay for a product or service and the opportunity cost of production. An advantage of equating competitive advantage with superior value creation is that one can explore the connection between competitive advantage and profitability, in particular one can explore the extent to which the costs of establishing a competitive advantage offset the benefits. Finally, given the importance of resource scarcity for existing theories of sustainability, there needs to be a link between resources and competitive advantage.

We define competitive advantage as resource heterogeneity that gives one firm superior value creation and hence a greater *flow* of profits. Thus, we think of a firm as having a competitive advantage at a point in time, which then allows us to define the sustainability of the advantage as the length of time that the advantage lasts. We are also interested in a firm's discounted total profit, but we maintain this as a concept distinct from competitive advantage. A firm's discounted total profit is just the net present value of its profit flows minus the present value of the costs associated with resource development. With these definitions, we can explore explicitly the origin of competitive advantage, its sustainability and the extent to which the costs associated with establishing a competitive advantage offset the benefits.

The standard approach to the sustainability of competitive advantage focuses on identifying the resources that underlie the competitive advantage and analyzing the extent to which they will remain scarce (Barney, 1991). Scarcity requires that competitors cannot readily acquire the resources on factor markets and that there are barriers to competitors developing the resource internally (Barney, 1986; Dierickx and Cool, 1989). One commonly cited barrier to internal development is causal ambiguity (Lippman and Rumelt, 1982; Reed and DeFillippi, 1990), where development by competitors is impeded by a lack of understanding about either the nature of the resources or about the process by which they are created. Another frequently cited barrier to internal development is time compression diseconomies, where the cost of internal development increases exponentially as the time taken to develop the resource shrinks (Dierickx and Cool, 1989). The broad hypothesis in the received literature is that sustainability is increasing in factors like causal ambiguity and time compression diseconomies that make resource development more difficult and costly.

A focus on the factors that promote resource scarcity is clearly useful for analyzing the sustainability of existing competitive advantages. However, there is a deeper question: what allows firms to achieve superior performance in situations where competitive advantage needs to be both created and sustained? Extending

the resource-based view to encompass both the creation and sustainability of competitive advantage is problematic (Barney, 1986; Priem and Butler, 2001). Consider Lippman and Rumelt (1982) where resources are created in the presence of causal ambiguity. Although *ex post* some firms end up with a sustainable competitive advantage (because they are lucky and develop efficient resources), *ex ante* all firms have the same expected profits. That is, the competition to create a sustainable competitive advantage can compete away the rents.<sup>1</sup>

Despite the limitations of the received literature, there has been little theory building about resource development beyond the initial contributions of Lippman and Rumelt (1982) and Dierickx and Cool (1989).<sup>2</sup> We consider a simple setting where firms develop valuable resources over time and address the following questions. What gives rise to the resource heterogeneity that allows some firms to enjoy a competitive advantage? How sustainable are any advantages: Do competitors eventually match a firm's resource position, and if they do, how long does it take? Is sustainability increasing in time compression diseconomies even when one accounts for its effect on the time required to create the competitive advantage? Finally, what is the relationship between firm performance and the factors that create and sustain competitive advantage? Are profits necessarily increasing in barriers to imitation like time compression diseconomies and causal ambiguity?

We use a formal model for our theory building. There are two main benefits. First, it forces us to be precise about our assumptions and definitions, which is particularly useful in an area where researchers are using the same concepts in different ways. More importantly, a formal model helps greatly with the complexity of the phenomena under study, which involves both competition and inter-temporal

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<sup>1</sup>Although not framed in the language of competitive strategy, the result that competition for advantage can equalize profits is familiar in the industrial organization literature as well. For example, this can happen in situations where firms choose when to adopt a new technology (Fudenberg and Tirole, 1985) or where firms compete to lock-in customers in the presence of switching costs (Klemperer, 1995).

<sup>2</sup>In contrast, there has been recent theory building about factor markets (Barney and Makadok, 2001; Makadok, 2001) that explores the drivers of superior performance, particularly asymmetric information, when firms compete to buy resources.

trade-offs.

The key elements of the model are as follows. There are two competing firms that start out identical and have equal access to an opportunity to develop a resource that enhances their competitive position. There are time compression diseconomies so that the faster a firm chooses to develop the resources the greater are its cost of resource development. Firms receive a flow of profits over time and this flow increases when the firm acquires the resource and decreases when the competitor acquires it. We assume that profits increase more for the first firm to acquire the resource than for the second. This is a common feature of IO models of product competition.<sup>3</sup> We consider two possible scenarios. First, it is possible that the two firms race to develop the resource in parallel. Second, it is possible that one firm waits until an lead firm has developed and deployed the resource in the market and then seeks to imitate it. Imitation still takes time, but is generally quicker because spillovers lower the cost of any given development time. The degree of causal ambiguity determines the extent to which spillovers lower the cost of the imitator.

We find that resource development with time compression diseconomies is consistent with not just the sustainability of competitive advantage as in the received literature on the resource-based view, but with the creation of competitive advantage as well. In particular, we find that one firm always acquires the resource before the other and hence there is always a period of endogenous resource heterogeneity. Moreover, we show that resource heterogeneity is associated with performance differences across firms in that net discounted profits are not equalized. Thus, we show that resource-based performance differences are not limited to situations of luck and asymmetric information (Barney, 1986). Rather, such performance differences also arise in situations where resources need to be developed internally in the presence of time compression diseconomies. This result is made possible by introducing an

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<sup>3</sup>For example, we show that it holds in a standard Cournot model for a resource that lowers production costs. For the extreme case where the resource is required to enter the market, this assumption is equivalent to monopoly profits being greater than duopoly profits, which is satisfied under weak conditions.

explicit link between resources and product market competition, as urged by Priem and Butler (2001).

We show that some claims in the resource-based view are not robust to extending the strategy space of firms to include a choice between imitation and developing the resource on one own. Because the resource-based view starts with a situation of resource heterogeneity it has implicitly ignored this choice. Of particular interest is a result that too much causal ambiguity can actually reduce the sustainability and profits of an innovative firm. We show that there is an optimal level of causal ambiguity which is just large enough to encourage the rival to imitate (rather than develop on their own) while still providing as much sustainability as possible given that constraint.

The paper proceeds as follows. Section 2 describes the formal model. Section 3 derives the formal propositions and can be skimmed by the less technical reader. Section 4 presents the main insights from Section 3 in verbal form and gives the intuitions for the formal results. Section 5 concludes with the limitations of this study and thoughts on how these might be addressed in future work.

## 2. The Model

There are two firms indexed by  $i = 1, 2$  that are competing in an industry. *Ex ante* the firms are identical. There is an opportunity to develop a valuable resource which will increase a firm's value creation by either increasing consumer's willingness to pay or decreasing marginal costs. Examples include retail banks developing e-banking capabilities and manufacturing firms developing a new low-cost production process. Resource development takes time and denote by  $T_i$  the time that firm  $i$  takes to develop the resource. We focus on the case where  $T_1 \leq T_2$  so that if there is a leader it is firm 1. Between  $T_1$  and  $T_2$ , firm 1 has a competitive advantage and the sustainability of the advantage is given by  $T_2 - T_1$ . If firm 1 chooses to develop the resource and firm 2 does not, we say that firm 1's resource is inimitable and then firm 1 has an infinitely sustainable competitive advantage (since we are abstracting

from threats to sustainability beyond imitation).

## 2.1. The Flow of Profits

Each firm's flow of profits at a point of time depends on which firm has the resource. When no firm has the resource, profits are  $\pi_0$  for both firms. When only one firm has the resource, the firm with the resource has a competitive advantage and its profits are  $\pi_{ca} > \pi_0$ ; the firm without the resource has a competitive disadvantage and its profits are  $\pi_{cd} \leq \pi_0$ . When both firms have the resource, there is competitive parity and profits for both firms are  $\pi_{cp}$ , where it is natural to assume that  $\pi_{ca} > \pi_{cp} > \pi_0$ . It is useful to define  $\Delta_1 = \pi_{ca} - \pi_0$  and  $\Delta_2 = \pi_{cp} - \pi_{cd}$ .

An important assumption is that  $\Delta_1 > \Delta_2$ . That is, the increase in the flow of profits from developing the resource is greater for the first firm to do so than for the second firm. This is a property that is satisfied for a wide variety of IO models. For example, it holds if the firms are Cournot competitors and the resource gives a cost reduction (see below). It holds whenever the resource is required for market entry, in which case the condition simply reduces to an assumption that monopoly profits are greater than duopoly profits.<sup>4</sup>

Recall that we are imposing  $T_1 \leq T_2$ . The net present value of firm 1's profits (gross of resource development costs) are then

$$\begin{aligned} \Pi_1(T_1, T_2) &= \int_0^{T_1} \pi_0 e^{-rt} dt + \int_{T_1}^{T_2} \pi_{ca} e^{-rt} dt + \int_{T_2}^{\infty} \pi_{cp} e^{-rt} dt \\ &= \frac{\pi_0}{r} (1 - e^{-T_1 r}) + \frac{\pi_{ca}}{r} (e^{-T_1 r} - e^{-T_2 r}) + \frac{\pi_{cp}}{r} (e^{-T_2 r}), \end{aligned}$$

while the analogous expression for firm 2 is

$$\begin{aligned} \Pi_2(T_2, T_1) &= \int_0^{T_1} \pi_0 e^{-rt} dt + \int_{T_1}^{T_2} \pi_{cd} e^{-rt} dt + \int_{T_2}^{\infty} \pi_{cp} e^{-rt} dt \\ &= \frac{\pi_0}{r} (1 - e^{-T_1 r}) + \frac{\pi_{cd}}{r} (e^{-T_1 r} - e^{-T_2 r}) + \frac{\pi_{cp}}{r} (e^{-T_2 r}). \end{aligned}$$

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<sup>4</sup>The case of market entry—where the resource is required to serve the market—is a special case of our model where  $\pi_0 = \pi_{cd} = 0$ . In this case,  $\Delta_1 = \pi_{ca}$  is the profit of a monopolist and  $\Delta_2 = \pi_{cp}$  is the profits of a duopolist.

where  $r$  is a common discount rate. Firm profits are just a weighted average of the initial profits  $\pi_0$ , the final profits  $\pi_{cp}$  and the profits when there is resource heterogeneity, either  $\pi_{ca}$  or  $\pi_{cd}$ .

## 2.2. The Cost of Independent Resource Development

Let  $F(T)$  be a firm's cost of developing a resource on its own by time  $T$ . Thus, firm  $i$ 's development cost is given by  $F(T_i)$ . If a firm does not develop the resource, then  $T_i = \infty$  and we assume that  $F(\infty) = 0$ . For firms that develop the resource, time compression diseconomies imply that the costs are falling in the time taken (i.e.  $\frac{\partial F}{\partial T} < 0$ ). Moreover, we follow prior authors (Scherer, 1984 ; Dierickx and Cool, 1989) and assume that the relationship between time and costs is convex (i.e.  $\frac{\partial^2 F}{\partial T^2} > 0$ ). In particular, we consider the following functional form

$$F(T) = \begin{cases} 0 & \text{if } T = \infty, \\ F_0 + \phi K e^{-T/\phi} & \text{otherwise.} \end{cases}$$

We use an exponential functional form because it is tractable given the exponential discounting in the  $\Pi_i$  functions. Note that there is a lower bound on the development costs of  $F_0 \geq 0$ . Of particular importance is the parameterization of time compression diseconomies. Both  $\phi$  and  $K$  are candidates in that both make costs more sensitive to time (i.e.  $\frac{\partial^2 F}{\partial T \partial \phi} < 0$  and  $\frac{\partial^2 F}{\partial T \partial K} < 0$ ). However,  $\phi$  has a more profound impact on the curvature of the cost function (i.e.,  $\frac{\partial^2 F}{\partial \phi^2} > \frac{\partial^2 F}{\partial K^2} = 0$ ) and thus we use  $\phi$  to parameterize time compression diseconomies. The parameter  $K$ , as a weaker version of the concept, is still of interest.

If there is resource development, at least one firm must develop the resource independently and this must be firm 1 since we are focusing on the case where  $T_1 \leq T_2$ . Firm 1's net discounted profit is then  $V_1(T_1, T_2) = \Pi_1(T_1, T_2) - F(T_1)$ , the net present value of the flow of profits less the fixed cost of resource development.

### 2.3. Imitation versus Parallel Development

Firm 2 can be one of two possible types. The first type develops the resource in parallel to firm 1 and it has the cost function  $F(T)$ . In this case, we refer to both firm 1 and firm 2 as developers and the net profit of firm 2 is  $V_2(T_1, T_2) = \Pi_2(T_2, T_1) - F(T_2)$ .

The second possibility is for firm 2 to be an imitator that waits until firm 1's resource is deployed in the market and then seeks to save development costs by imitating firm 1's resource. Resource imitation is still time consuming, with the cost of imitation given by  $aF(T)$  where the parameter  $a \in (0, 1)$  parameterizes the extent of causal ambiguity. For example, for  $a = 1$  causal ambiguity is complete and firm 2 learns nothing from firm 1's resource deployment and its cost of resource development is if it were a developer. We assume that costs are only incurred at the time when resource development begins, i.e. at time  $T_1$  for an imitator as opposed to time 0 for a developer. We denote the development time of an imitator by  $T_{2I}$ . The net profits of an imitator is then  $V_{2I}(T_{2I}, T_1) = \Pi_2(T_{2I} + T_1, T_1) - aF(T_{2I})e^{-rT_1}$ . The total time it takes firm 2 to get the resource to market is  $T_2 = T_1 + T_{2I}$ .

### 2.4. Timing

The timing of the model is as follows. In the initial stage, firm 2's type is determined, either by history or based on rational calculations by firm 2. Firm 1 is able to observe firm 2's type. If both firms are developers, the choice of development time is assumed simultaneous since the firms are working in parallel. If firm 2 is an imitator, the choice of development times is sequential, with firm 1 choosing its development time first. As usual, we start by characterizing the subgames played either by two developers or by a developer and an imitator. We then go backwards and look at the possibility that firm 2 can choose its type. We focus on pure strategy equilibria.

## 2.5. Parameter Restrictions

We focus on interior solutions where optimal development times are strictly positive. For this it is sufficient to assume that  $\phi < 1/r$  and that  $K > \max\{\Delta_1, \Delta_2/a\}$ . We make these assumptions, which places a lower bound on the level of causal ambiguity, i.e.  $a > \Delta_2/K$ . Finally, we assume that  $F_0 < \Delta_2/r$  because otherwise firm 2 would never develop the resource on its own.<sup>5</sup> Purely to facilitate the statement of some propositions, we assume that a firm indifferent between developing the resource and not developing it, does not and that if firm 2 is indifferent between being an imitator and a developer it chooses to imitate.

## 2.6. Cournot Example

We introduce here a Cournot model of product market competition, which we use occasionally in the paper. For example we use it to generate values for the profit flows  $\pi_{ca}$ ,  $\pi_{cd}$ , etc. used in the figures. The example is a standard Cournot model of competition with linear demand  $P = 1 - q_1 - q_2$  where  $q_i$  is the output of firm  $i$ . Firms have constant marginal costs of  $c_i = c \in (0, 1/2)$  if they do not have the resource and  $c_i = (1 - \varepsilon)c$  if they have the resource. The parameter  $\varepsilon \in (0, 1)$  gives the impact of the resource on a firm's efficiency. There is a unique equilibrium, in which  $q_i = (1 - 2c_i + c_j)/3$  and profits are  $q_i^2$ . Thus for example  $\pi_{ca} = \frac{1}{9}(1 - 2(1 - \varepsilon)c + c)^2$ . For the Cournot example we have that  $\Delta_1 = \frac{4}{9}\varepsilon c(1 - (1 - \varepsilon)c)$  and  $\Delta_2 = \frac{4}{9}\varepsilon c(1 - c)$  and hence  $\Delta_1 > \Delta_2$ .

## 3. Formal Analysis

There are three main parts to the formal analysis. Section 3.1 considers development times and profits when both firms are developers. Section 3.2 considers how outcomes differ when firm 2 is an imitator. Finally, Section 3.3 considers the effect of causal ambiguity on firm 2's choice between being a developer and an imitator.

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<sup>5</sup>This is because  $\max_{T_1, T_2} V_2(T_2, T_1) < \Delta_2/r - F_0$ .

The paper is structured such that the formal analysis can be skimmed by the less technical reader because the main results and intuitions are given verbally in Section 4.

### 3.1. Two Developers

Suppose that both firms are developing the resource in parallel. Differentiating  $V_i = \Pi_i(T_i, T_{-i}) - F(T_i)$  with respect to  $T_i$  gives firm  $i$ 's first order condition

$$-\Delta_i e^{-T_i r} + K e^{-\frac{T_i}{\phi}} = 0.$$

Note that each firm's optimal time is independent of the other firm's strategy once the order of development times is set. These first order conditions have the unique solutions  $T_i^* = \frac{\phi}{1-\phi r} \ln \frac{K}{\Delta_i}$  which is positive given the assumption  $K > \Delta_i$  and  $\phi < 1/r$ . Evaluating the second order conditions at  $T_i^*$  yields

$$-\frac{1-r\phi}{\phi} \left( \frac{\Delta_i}{K^{r\phi}} \right)^{\frac{1}{1-r\phi}}$$

which is negative. We have the following,

**Proposition 3.1.** *Suppose that the firms develop the resources in parallel. (i) The equilibrium time to build for firm  $i$  is*

$$T_i^* = \frac{\phi}{1-\phi r} \ln \frac{K}{\Delta_i} > 0$$

*which is increasing in  $\phi$ ,  $r$  and  $K$  and decreasing in  $\Delta_i$ . (ii) The period of time over which firm 1 is able to sustain its competitive advantage is*

$$T_2^* - T_1^* = \frac{\phi}{1-\phi r} \ln \frac{\Delta_1}{\Delta_2}$$

*which is increasing in  $\phi$ ,  $r$  and  $\Delta_1$  and decreasing in  $\Delta_2$ . (iii) In the Cournot example, sustainability is increasing the importance of the resource for firm efficiency,  $\varepsilon$ .*

**Proof** (i) See text. (ii) Follows directly from the expression for  $T_i^*$  and by inspection. (iii) For the Cournot example we have  $\frac{\Delta_1}{\Delta_2} = \frac{1-(1-\varepsilon)c}{1-c}$  which is increasing in  $\varepsilon$ . Hence, sustainability  $T_2^* - T_1^*$  is increasing  $\varepsilon$ . ■

While the parameter  $K$  affects the development time of each firm, it does not affect sustainability, while the parameter  $\phi$  affects both absolute and relative development times.

Now consider each firm's decision as to whether or not to develop the resource. Here we are assuming either that imitation is not an option for firm 2 or equivalently that there is complete causal ambiguity  $a = 1$  and hence imitation does not lower the cost of development. Define the critical level of profit flows

$$\bar{\Delta} \equiv K^{\phi r} \left( \frac{rF_0}{1-r\phi} \right)^{1-\phi r}.$$

**Proposition 3.2.** *Suppose both firms choose between developing the resource and not having the resource. (i) Firm  $i$  develops the resource if and only if  $\Delta_i > \bar{\Delta}$ . (ii) There exists a  $\phi_i < 1/r$  such that  $\Delta_i > \bar{\Delta}$  is equivalent to  $\phi < \phi_i$ . These  $\phi_i$  are increasing in  $\Delta_i$  and hence  $\phi_2 < \phi_1$ . (iii) Firm 1 develops an inimitable resource if and only if  $\Delta_2 \leq \bar{\Delta} < \Delta_1$  or equivalently  $\phi_2 \leq \phi < \phi_1$ .*

**Proof** (i) Suppose firm 1 develops the resource at time  $T_1^*$ . Firm 2's best response is either to develop the resource at time  $T_2^*$  or to not develop it at all. The increase in profit from developing the resource is

$$\begin{aligned} \Pi_2(T_2^*, T_1^*) - \Pi_2(\infty, T_1^*) - F(T_2^*) &= \int_{T_2^*}^{\infty} \Delta_2 e^{-rt} dt - F(T_2^*) \\ &= K \left( \frac{1-r\phi}{r} \right) \left( \frac{\Delta_2}{K} \right)^{\frac{1}{1-\phi r}} - F_0. \end{aligned}$$

Hence, firm 2's develops the resource *iff*  $\Delta_2 > \bar{\Delta} \equiv K^{\phi r} \left( \frac{rF_0}{1-r\phi} \right)^{1-\phi r}$ , recalling that we assume that an indifferent firm does not develop the resource. If  $\Delta_2 > \bar{\Delta}$  then it is optimal for firm 1 to develop the resource as well because developing the resource at time  $T_1 = T_2^*$  gives firm 1 the same increase in profit as firm 2 and hence *a fortiori*

developing the resource at the optimal time  $T_1^*$  gives an even higher increment. Hence for  $\Delta_2 > \bar{\Delta}$  both firms develop the resource.

Suppose that  $\Delta_2 \leq \bar{\Delta}$ . If one firm develops the resource, the other will not do so. It is straightforward to show that  $T_1^*$  is still the optimal time to develop the resource even if the second firm is not developing it. Firm 1 is willing to be the only firm to develop the resource if

$$\begin{aligned} \Pi_1(T_1^*, \infty) - \Pi_2(\infty, \infty) - F(T_1^*) &= \int_{T_1^*}^{\infty} \Delta_1 e^{-rt} dt - F(T_1^*) \\ &= K \left( \frac{1 - r\phi}{r} \right) \left( \frac{\Delta_1}{K} \right)^{\frac{1}{1-\phi r}} - F_0. \end{aligned}$$

Hence, for  $\Delta_1 > \bar{\Delta}$  firm 1 develops the resource.

(ii) We have assumed that  $\Delta_2 > rF_0$  and  $K > \Delta_2$ . Hence,  $K > rF_0$ . Let  $\bar{\Delta}(\phi) = K^{\phi r} \left( \frac{rF_0}{1-r\phi} \right)^{1-\phi r}$  and recall that  $\phi \in (0, 1/r)$ . We have that  $\bar{\Delta}'(0) = rF_0(1 + \ln \frac{K}{rF_0}) > 0$ ; that  $\lim_{\phi \rightarrow 1/r} \bar{\Delta}(\phi) = K$  and that there is a unique  $\phi$  for which  $\bar{\Delta}'(\phi) = 0$ . Hence, there exists a unique  $\phi_i \in (0, 1/r)$  such that  $\bar{\Delta}(\phi_i) = \Delta_i$ . Moreover,  $\phi_i$  is increasing in  $\Delta_i$  because  $\bar{\Delta}'(\phi) > 0$  for  $\bar{\Delta}(\phi) < K$ . (iii) Follows immediately from part (i) and (ii). ■

Define the critical levels of causal ambiguity  $\phi_1$  and  $\phi_2$  implicitly from

$$\Delta_i \equiv K^{\phi_i r} \left( \frac{rF_0}{1 - r\phi_i} \right)^{1-\phi_i r}.$$

We find that inimitable resources arise when there is sufficient difference between being the first and second firm to develop the resource (i.e.  $\Delta_2 \leq \bar{\Delta} < \Delta_1$ ) and from intermediate levels of time compression diseconomies (i.e.  $\phi_2 \leq \phi < \phi_1$ ).

We now turn to firm profits. While firm 1 has a competitive advantage for some period of time, it also has higher costs of resource development. We are interested whether firm 1 has higher net profits and on the effect of time compression diseconomies on any profit differences. We are also interested in the effect of the opportunity to develop the resource on both firm and industry profits. Is it possible

that one or both firms might be better off if there was no possibility to develop the resource? In that case, each firm's net present value is  $\pi_0/r$ .

**Proposition 3.3.** (i) Firm 1 has higher profits than firm 2. (ii) The difference in profits is non-monotonic in the extent of time compression diseconomies  $\phi$ . (iii) There exist values of  $\phi$  such that firm 2's profits are lower than  $\pi_0/r$ , what they would be if no firm developed the resource. (iv) For  $\Delta_2$  sufficiently close to  $\Delta_1$ , there exist values of  $\phi$  such that firm 1's profits are lower than  $\pi_0/r$ .

**Proof** The results follow from the following closed form expressions for firm profits:

$$V_1(\infty, \infty) = V_2(\infty, \infty) = \int_0^\infty \pi_0 e^{-rt} dt = \pi_0/r.$$

$$V_2(\infty, T_1^*) = \frac{1}{r} \left( \pi_0 - (\pi_0 - \pi_{cd}) \left( \frac{\Delta_1}{K} \right)^{\frac{r\phi}{1-\phi r}} \right)$$

$$V_2(T_2^*, T_1^*) = \left[ \frac{1}{r} \left( \pi_0 - (\pi_0 - \pi_{cd}) \left( \frac{\Delta_1}{K} \right)^{\frac{r\phi}{1-\phi r}} + \Delta_2 \left( \frac{\Delta_2}{K} \right)^{\frac{r\phi}{1-\phi r}} \right) - \phi K \left( \frac{\Delta_2}{K} \right)^{\frac{1}{1-\phi r}} - F_0 \right]$$

$$V_1(T_1^*, T_2^*) = \frac{1}{r} \left( \pi_0 + \Delta_1 \left( \frac{\Delta_1}{K} \right)^{\frac{r\phi}{1-\phi r}} - (\pi_{ca} - \pi_{cp}) \left( \frac{\Delta_2}{K} \right)^{\frac{r\phi}{1-\phi r}} \right) - \phi K \left( \frac{\Delta_1}{K} \right)^{\frac{1}{1-\phi r}} - F_0$$

$$V_1(T_1^*, \infty) = \frac{1}{r} \left( \pi_0 + \Delta_1 \left( \frac{\Delta_1}{K} \right)^{\frac{r\phi}{1-\phi r}} \right) - \phi K \left( \frac{\Delta_1}{K} \right)^{\frac{1}{1-\phi r}} - F_0.$$

$$\begin{aligned} V_1(T_1^*, T_2^*) - V_2(T_2^*, T_1^*) &= \frac{\pi_{ca} - \pi_{cd}}{r} \left( \left( \frac{\Delta_1}{K} \right)^{\frac{r\phi}{1-\phi r}} - \left( \frac{\Delta_2}{K} \right)^{\frac{r\phi}{1-\phi r}} \right) \\ &\quad - \phi K \left( \frac{\Delta_1}{K} \right)^{\frac{1}{1-\phi r}} + \phi K \left( \frac{\Delta_2}{K} \right)^{\frac{1}{1-\phi r}} \end{aligned}$$

$$V_1(T_1^*, \infty) - V_2(\infty, T_1^*) = \frac{\pi_{ca} - \pi_{cd}}{r} \left( \frac{\Delta_1}{K} \right)^{\frac{r\phi}{1-\phi r}} - \phi K \left( \frac{\Delta_1}{K} \right)^{\frac{1}{1-\phi r}}$$

■

Figure 4.2 illustrates the properties of the profit functions and how they depend on the time compression diseconomies parameter  $\phi$  when  $F_0 = 0$ , in which case both firms develop the resource eventually. Figure 4.3 shows profits when  $F_0 > 0$ , in which case there exist critical values  $\phi_1 < \phi_2$  such that firm  $i$  only develops the resource for  $\phi < \phi_i$ .

### 3.2. A Developer and an Imitator

Suppose that firm 2 is an imitator that waits until firm 1 has completed its development. Its problem is almost the same as when it is a developer. In both cases, acquisition of the resource causes its flow of profits to increase by  $\Delta_2$ . The difference is that its costs are now a fraction  $aF(T_2)$  based on the level of causal ambiguity. Thus, we have

**Proposition 3.4.** *Suppose firm 2 imitates firm 1's resource. (i) The optimal imitation time is*

$$T_{2I}^* = \frac{\phi}{1 - \phi r} \ln \frac{aK}{\Delta_2},$$

*which is increasing in  $\phi$ ,  $r$ ,  $a$  and  $K$  and decreasing in  $\Delta_2$ . (ii) Firm 1's competitive advantage is more sustainable when firm 2 imitates than when it develops iff  $a > \Delta_1/K$ .*

**Proof** (i) Recall that the objective of an imitator is  $\Pi_2(T_{2I} + T_1, T_1) - aF(T_{2I})e^{-rT_1}$ . The first order condition is then

$$\left(-\Delta_2 e^{-rT_2} + aK e^{-\frac{T_2}{\tau}}\right) e^{-rT_1} = 0,$$

which has the unique solution  $T_{2I}^* = \frac{\phi}{1 - \phi r} \ln \frac{aK}{\Delta_2}$  and straightforward calculations show that the second order condition is satisfied for  $r < 1/\phi$ . The comparative statics follow by inspection. (ii) Sustainability when firm 2 imitates is  $T_{2I}^*$  and

sustainability when firm 2 develops is  $T_2^* - T_1^* = \frac{\phi}{1-\phi r} \ln \frac{\Delta_1}{\Delta_2}$ . The difference is

$$T_{2I}^* - (T_2^* - T_1^*) = \frac{\phi}{1-\phi r} \ln \frac{aK}{\Delta_1},$$

which is increasing in  $a$  and equal to zero for  $a = \Delta_1/K$ . ■

Now consider firm 2's decision as to whether or not to imitate the resource. The definition of  $\bar{\Delta}$  is as before.

**Proposition 3.5.** *Suppose firm 2 chooses between imitation and not having the resource. (i) Firm 2 imitates iff  $\Delta_2/a > \bar{\Delta}$ . (ii) Firm 1 develops an inimitable resource iff  $\Delta_1 > \bar{\Delta} \geq \Delta_2/a$ .*

**Proof** (i) Firm 2's increase in profit from imitating the resource is

$$\begin{aligned} \Pi_2(T_{2I}^* + T_1, T_1) - \Pi_2(\infty, T_1) - aF_D(T_{2I}^*)e^{-rT_1} &= \int_{T_{2I}^*+T_1}^{\infty} \Delta_2 e^{-rt} dt - aF(T_2^*)e^{-rT_1} \\ &= aK \left( \frac{1-r\phi}{r} \right) \left( \frac{\Delta_2}{aK} \right)^{\frac{1}{1-\phi r}} - aF_0. \end{aligned}$$

Hence, firm 2 increases its profits by developing the resource iff  $\Delta_2 > aK^{\phi r} \left( \frac{rF_0}{1-r\phi} \right)^{1-\phi r} = a\bar{\Delta}$ . (ii) For firm 1 to develop an inimitable resource it must be that the imitator does not want to, which is equivalent to  $\bar{\Delta} \geq \Delta_2/a$ , and that firm 1 wants to develop the resource given that it will be the only firm to do so, which from Proposition 3.2 occurs when  $\Delta_1 > \bar{\Delta}$ . ■

The cost savings from being an imitator increases the willingness of firm 2 to acquire the resource and hence the condition for an inimitable resource becomes harder to satisfy. For sufficiently little causal ambiguity (i.e.  $a < \Delta_2/\Delta_1$ ), resources are always imitated.

Now consider how firm 1's development time and decision to develop the resource depends on whether it faces a developer or an imitator. We rewrite the conditions from the two developer case to aide comparison. Let  $\bar{\pi} = \bar{\Delta} + \pi_0$ . Then  $\Delta_1 > \bar{\Delta}$  is equivalent to  $\pi_{ca} > \bar{\pi}$ . From Proposition 3.2, firm 1 develops the resource if and

only if  $\pi_{ca} > \bar{\pi}$  in the case where firm 2 is a developer.

**Proposition 3.6.** *Suppose firm 2 is an imitator and  $\Delta_2/a > \bar{\Delta}$  so that firm 2 imitates the resource if firm 1 develops it. (i) If firm 1 develops the resource, its optimal development time is*

$$T_{1I}^* = \frac{\phi}{1 - \phi r} \ln \frac{K}{\Delta_{1I}} > T_1^*,$$

where  $\Delta_{1I} = \Delta_1 - (\pi_{ca} - \pi_{cp})e^{-rT_{2I}^*}$ . (ii) There exists a  $\bar{\pi}_I > 0$  such that firm 1 develops the resource iff  $\pi_{ca} > \bar{\pi}_I$ . (iii) There exists an  $\bar{a} \in (\Delta_2/K, 1)$  such that  $\bar{\pi}_I > \bar{\pi}$  iff  $a < \bar{a}$ .

**Proof** Suppose that  $\Delta_2/a > \bar{\Delta}$ . If firm 1 develops the resource at time  $T_{1I}$ , then following Propositions 3.4 and 3.5 firm 2 will imitate it at time  $T_{1I} + T_{2I}^*$ . (i) Firm 1's optimal development time solves  $\max_{T_{1I}} V_1(T_{1I}, T_{1I} + T_{2I}^*)$ . The first order condition is

$$-\Delta_1 e^{-rT_{1I}} + (\pi_{ca} - \pi_{cp})e^{-r(T_{1I} + T_{2I}^*)} + K e^{-T_{1I}/\phi} = 0,$$

which has the unique solution  $T_{1I}^* = \frac{\phi}{1 - \phi r} \ln \frac{K}{\Delta_{1I}}$  where  $\Delta_{1I} = \Delta_1 - (\pi_{ca} - \pi_{cp})e^{-rT_{2I}^*}$ . The second order condition is

$$r\Delta_1 e^{-rT_{1I}} - r(\pi_{ca} - \pi_{cp})e^{-r(T_{1I} + T_{2I}^*)} - \frac{K}{\phi} e^{-T_{1I}/\phi}$$

which is negative for  $T_{1I} = 0$  and has a unique zero at  $T_{1I} = \frac{\phi}{1 - \phi r} \ln \frac{K}{r\phi\Delta_{1I}} > T_{1I}^*$ . Hence, the second order conditions are satisfied at  $T_{1I}^*$ .

(ii) Firm 1 develops the resource iff  $V_1(T_{1I}^*, T_{1I}^* + T_{2I}^*) > V_0$ . Since  $V_1(T_{1I}^*, T_{1I}^* + T_{2I}^*)$  is increasing and unbounded in  $\pi_{ca}$ , there exists a critical  $\bar{\pi}_I$  such that firm 1 develops the resource iff  $\pi_{ca} > \bar{\pi}_I$ .<sup>6</sup> (iii) Since  $T_{2I}^*$  is increasing in  $a$ , we have that  $V_1(T_{1I}^*, T_{1I}^* + T_{2I}^*)$  is increasing in  $a$  as well and hence  $\bar{\pi}_I$  is decreasing in  $a$ . For  $a = 1$ , we have  $T_{2I}^* = T_2^*$  and hence  $\bar{\pi}_I < \bar{\pi}$  because  $V_1(T_{1I}^*, T_{1I}^* + T_2^*) > V_1(T_1^*, T_2^*)$ .

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<sup>6</sup>While it must be that  $\bar{\pi} > \pi_0$ , it need not be that  $\bar{\pi} > \pi_{cp}$ .

Conversely, in the limit as  $a \rightarrow \Delta_2/K$  we have  $T_{2I}^* = 0$  and since  $V_1(T_{1I}^*, T_{1I}^*) < V_1(T_1^*, T_2^*)$  we have  $\bar{\pi}_I > \bar{\pi}$ . Thus, there exists a  $\bar{a} \in (\Delta_2/K, 1)$  that determines the relative size of  $\bar{\pi}_I$  and  $\bar{\pi}$ . ■

While firm 1 unambiguously develops the resource slower when it faces an imitator, it might be more or less likely to find development profitable, depending on the level of causal ambiguity. Since increases in causal ambiguity either deter or delay imitation, firm 1's profits are non decreasing in the level of causal ambiguity.

**Corollary 3.7.** *If firm 2 is an imitator, firm 1's profits are increasing in the level of causal ambiguity and then potentially constant.*

**Proof** For  $a \geq \Delta_2/\bar{\Delta}$ , firm 2 does not imitate and firm 1's profits,  $V_1(T_1^*, \infty)$ , are independent of  $a$ . This region may or may not exist depending on whether or not  $\Delta_2/\bar{\Delta} < 1$ . For  $a < \Delta_2/\bar{\Delta}$ , firm 2 imitates and firm 1's profits,  $V_1(T_{1I}^*, T_{1I}^* + T_{2I}^*)$ , are increasing in  $a$  because  $T_{2I}^*$  is increasing in  $a$ . ■

### 3.3. Causal Ambiguity and the Decision to Imitate

Suppose now that firm 2 has the choice between whether to be an imitator or a developer. We assume that firm 1 observes firm 2's decision before deciding whether and how fast to develop the resource. Consider the case with complete causal ambiguity.

**Proposition 3.8.** *Suppose that there is complete causal ambiguity  $a = 1$ . (i) For  $\phi$  sufficiently close to  $\phi_2$ , firm 2 strictly prefers to be an imitator, i.e.  $\lim_{\phi \rightarrow \phi_2^-} (V_{2I}^* - V_2^*) > 0$ . (ii) For  $\phi$  and  $F_0$  sufficiently small, firm 2 strictly prefers to be a developer. (iii) Firm 1 has higher profits when firm 2 is an imitator.*

**Proof** Suppose that  $a = 1$ . Then  $T_{2I}^* = T_2^*$ . (i) Consider the limit as  $\phi \rightarrow \phi_2^-$ . Firm 2's increase in profit from developing the resource net of the development cost goes to zero and hence  $V_{2I}(T_{2I}^*, T_{1I}^*) = V_2(\infty, T_{1I}^*)$  and  $V_2(T_2^*, T_1^*) = V_2(\infty, T_1^*)$ . Since  $V_2(\infty, T_1)$  is increasing in  $T_1$  and  $T_1^* < T_{1I}^*$ , firm 2 prefers to be an imitator for  $\phi$

sufficiently close to  $\phi_2$ . (ii) We have  $\lim_{\phi \rightarrow 0} V_{2I}(T_{1I}^* + T_{2I}^*, T_{1I}^*) = \lim_{\phi \rightarrow 0} V_2(T_2^*, T_1^*) = \pi_{cp}/r - F_0$  and

$$\begin{aligned} \lim_{\phi \rightarrow 0} \frac{\partial}{\partial \phi} V_2(T_2^*, T_1^*) &= (\pi_0 - \pi_{cd}) \ln \frac{K}{\Delta_1} - \Delta_2 \ln \frac{K}{\Delta_2} - \Delta_2, \quad (3.1) \\ \lim_{\phi \rightarrow 0} \frac{\partial}{\partial \phi} V_{2I}(T_{1I}^* + T_{2I}^*, T_{1I}^*) &= (\pi_0 - \pi_{cd}) \ln \frac{K}{\pi_{cp} - \pi_0} - \Delta_2 \ln \frac{(1-s)K}{\Delta_2} \left( \frac{K}{\pi_{cp} - \pi_0} \right) \\ &\quad - \Delta_2 + (1-s)rF_0 \ln \frac{K}{\pi_{cp} - \pi_0}. \end{aligned}$$

We want to show that (3.1) is bigger than (3.2) so that the profits from development are greater than the profits from imitation in the neighborhood of  $\phi = 0$ . For  $F_0 = 0$ , the difference between (3.1) and (3.2) is

$$\Delta_2 \ln \frac{K}{\Delta_2} - (\pi_0 - \pi_{cd}) \ln \frac{\Delta_1}{\Delta_2} > 0$$

where the inequality follows from  $K > \Delta_1$  and  $\Delta_2 > \pi_0 - \pi_{cd}$ . Hence, for  $\phi$  and  $F_0$  sufficiently small we have that  $V_2(T_2^*, T_1^*) > V_{2I}(T_{2I}^*, T_{1I}^*)$ .

(iii) We have  $V_1(T_1, T_2^*) < V_1(T_1, T_1 + T_2^*)$  and firm 1 has higher profits when firm 2 is an imitator. ■

Even no spillovers from firm 1's development, there exist parameters such that firm 2 may prefer to be an imitator. This is because firm 1's optimal development time is slower when it faces an imitator and slowing down firm 1 benefits firm 2. For other parameter values, firm 2 may prefer to be a developer when there are no spillovers because it acquires the resource faster.

We now show that the notion that an innovator benefits from increases in causal ambiguity—although confirmed when the innovator faces an imitator (Corollary 3.7)—need not hold when the innovator faces a rival that chooses between imitation and parallel development. Figure 4.1 plots for a specific example the profits of firm 1 and firm 2 as a function of causal ambiguity for both the case where firm 2 is a developer and the case where firm 2 is an imitator. Start with  $a = 1$ , the case addressed by Proposition 3.8. According to part (iii), firm 1 has higher profits when

firm 2 is an imitator, however, in this example firm 2 prefers to be a developer when the level of causal ambiguity is sufficiently high. By committing to a level of causal ambiguity of  $a^* < 1$ , firm 1 can cause firm 2 to prefer to be an imitator and thereby increase its profits. Thus, we have the following:

**Proposition 3.9.** *When firm 2 chooses between being a developer and an imitator, it is possible that  $a = 1$  is not profit maximizing for firm 1, in which case the optimal  $a$  is such that  $V_{2I}^* = V_2^*$ .*

## 4. Discussion and Intuitions

### 4.1. Sources of Resource Heterogeneity

A central tenant in the strategy field is the existence of resource heterogeneity across firms, which is seen as forming the basis for competitive advantage. By studying a situation where similar firms can develop a valuable resource, we elucidate the sources of resource heterogeneity. We find three distinct sources of heterogeneity. First, when firms are developing the resource in parallel we find that firms *choose* different development times. Asymmetric timing arises from the interaction of time compression diseconomies (i.e. the convexity of the  $F(T)$  function) and the greater impact of resource development on the profits of the first firm to acquire the resource (i.e.  $\Delta_1 > \Delta_2$ ). The greater payoff of the leader firm encourages it to compress time more than the follower.

The second source of heterogeneity is that one firm may choose to wait until the other firm has developed the resource (i.e. choose to be an imitator rather than a developer). The firm does this in order to benefit from spillovers and thereby lower its own costs of acquiring the resource (to  $aF(t)$ ). Note, however, that the choice of an imitation does not always increase resource heterogeneity. For low levels of causal ambiguity ( $a$ ), we show that an imitator acquires the resource faster than if it were developing the resource on its own. While the decision to pursue a strategy of imitation delays the start of a firm's resource acquisition activities, the reduction

in development costs leads an imitator to compress time more, with the net effect being ambiguous and depending on the extent of causal ambiguity.

The final source of resource heterogeneity is that it may only be profitable for one firm to develop the resource, which gives rise to the possibility of “inimitable” resources. Inimitable resources arise because resource development costs are fixed and because of the greater returns to development for the first firm. We identify two approaches to identifying inimitable resources. The first approach involves evaluating the level of time compression diseconomies ( $\phi$ ), with inimitability requiring an intermediate level of time compression diseconomies (i.e.  $\phi_1 > \phi \geq \phi_2$ ). Increases in time compression diseconomies effectively increase the level of fixed costs.<sup>7</sup> For low levels of time compression diseconomies, the fixed costs of resource development are low and both firms will develop. Conversely, for high levels of time compression diseconomies, fixed costs are so high that neither firm develops the resource. For an intermediate level, the market only supports one firm developing the resource. The second approach to identifying inimitable resources involves evaluating the difference in benefits from acquiring the resource, with inimitability being more likely the greater the difference (i.e., one needs  $\Delta_1 > \bar{\Delta} \geq \Delta_2$  for a critical value  $\bar{\Delta}$ ).

In summary, we find solid arguments for the existence of competitive advantage arising from resource heterogeneity. While past work on the origin of resource heterogeneity has emphasized uncertainty and asymmetric information (Lippman and Rumelt, 1982; Barney, 1986, Makadok and Barney, 2001), we obtain our results with a deterministic process of resource development and without asymmetric information. Given the existence of resource heterogeneity, we now consider what determines the sustainability of the resulting competitive advantages.

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<sup>7</sup>In particular, as time compression diseconomies increase, the fixed costs of resource development at a given time increase. While the effect of time compression diseconomies fade as development time is extended, discounting also reduces the NPV of the flow of profits. Consequently, time compression diseconomies always affect the fixed costs of resource development relative to the NPV of the resulting profits, and this is what drives firms’ resource development decision.

## 4.2. Sustainability of Competitive Advantage

We evaluate the assertion that sustainability is increasing in barriers to imitation such as causal ambiguity and time compression diseconomies. Consider first the case where the rival is pursuing a strategy of imitation. We find that the optimal imitation time ( $T_{2I}^* = \frac{\phi}{1-\phi r} \ln \frac{aK}{\Delta_2}$ ) is increasing in the extent of both causal ambiguity and time compression diseconomies (whether parameterized by  $\phi$  or by  $K$ ). The logic is straightforward. The greater time compression diseconomies are, the longer a firm chooses to take to imitate a resource. Similarly, the greater the causal ambiguity the more work remains to be done and the longer it takes to imitate.<sup>8</sup> Thus, we confirm the assertion that sustainability is increasing in causal ambiguity and time compression diseconomies *when the resource developer faces an imitator*.

Now consider sustainability when both firms develop the resource in parallel. Sustainability is then given by the difference in optimal development times ( $T_2^* - T_1^* = \frac{\phi}{1-\phi r} \ln \frac{\Delta_1}{\Delta_2}$ ). We find that the effect of shifts in time compression diseconomies on sustainability depends on how they are parameterized/defined. Simply scaling up the cost function (i.e. by increasing  $K$ ) has no effect on sustainability since the development time of both firms is affected equally. It is only when the cost function is both scaled up and made more convex (i.e. by increases in  $\phi$ ) that we find a positive relationship between time compression diseconomies and sustainability in this case. The increase in the curvature is critical because this amplifies the effect of the differential incentives to develop the resource ( $\Delta_1$  and  $\Delta_2$ ).

For the case of parallel development, we find that sustainability is increasing in the relative incentive to develop the resource ( $\Delta_1/\Delta_2$ ). One implication of this is that sustainability should tend to be greater for “large” resources, that is resources that have a large impact on value creation. The larger the impact on value creation the greater the difference in the incentive to acquire the resource. We show this formally in the case of cost-reducing resources in Cournot competition, but this result holds

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<sup>8</sup>In addition, sustainability is increasing in the discount rate ( $r$ ) and decreasing in the payoff to the firm from imitation ( $\Delta_2$ ).

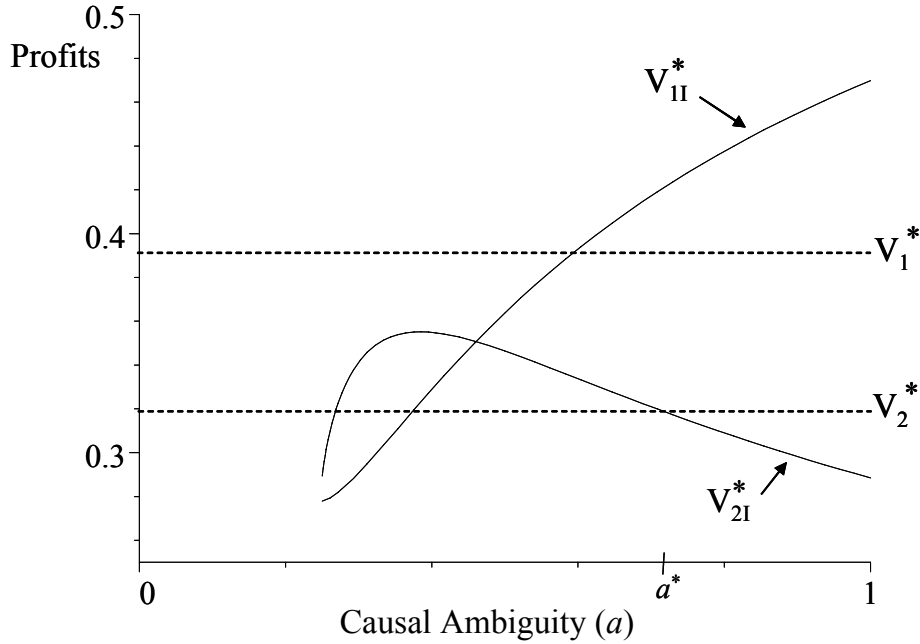


Figure 4.1: The profits of firm 1 and firm 2 as a function of causal ambiguity for both the case where firm 2 is an imitator and the case where firm 2 is a developer. The optimal level of causal ambiguity is  $a^*$ , which maximizes the level of sustainability while being just high enough to lead firm 2 to give up its own development and be an imitator. Parameters are for  $\phi = 4$ ,  $r = .1$ ,  $K = .1$ ,  $F_0 = 0$  and the profit flows from the Cournot example with  $c = .5$  and  $\varepsilon = .5$ .

in a range of models of product market competition. Finally, sustainability increases in the discount rate ( $r$ ).

One of the more striking results is that an innovating firm may want to commit to less than full causal ambiguity. This occurs when the innovating firm has the possibility to influence the rival's choice between a strategy of imitation and one of parallel development. The innovative firm prefers that the rival imitates because there is greater sustainability (as long as causal ambiguity is not too low). However, for high levels of causal ambiguity there are little cost savings from imitation and rivals may be better off developing the resource on their own because this reduces the time it takes them to acquire the resource. This gives rise to an optimal level of causal ambiguity for an innovating firm: just enough to dissuade rivals from undertaking

parallel resource development, while still maintaining as much sustainability vis-a-vis imitators as possible. Figure 4.1 shows a situation where the optimal level of causal ambiguity is less than complete (i.e.  $\phi^* < 1$ ). Note that this result requires that firms can commit to a level of causal ambiguity because the innovator always has an incentive to increase causal ambiguity after the rival chooses to be an imitator. Possible sources of commitment are licensing agreements or a reputation for openness.

To summarize, while sustainability is increasing in time compression diseconomies and causal ambiguity when a resource developer faces an imitator, we show that these relationships need *not* hold when rivals have a richer strategy space that includes the option to develop the resource on their own. When two firms are developing the resource in parallel, defining time compression diseconomies as an upward shift in the cost function leads to no relationship between a shift in time compression diseconomies and sustainability. As for causal ambiguity, an increase can actually reduce sustainability and profits by causing rivals to switch from a strategy of imitation to one of parallel resource development.

### 4.3. Imitation versus Development

The choice of resource acquisition strategy by the follower firm is of interest in its own right. We find three drivers of the firm's choice. The advantage of developing the resource on ones own is that it decreases the total time it takes to acquire the resource when the level of causal ambiguity is sufficiently high. One advantage of imitation is that it lowers the cost of development. However, we find that a firm sometimes wants to be an imitator even when there is very high causal ambiguity (even to the point of  $a = 1$ ) so that there is little to no cost savings from imitation. The reason is the third driver: the lead firm develops the resource slower when it faces an imitator than when it faces another developer. The lead firm slows down development because the period of sustainability is now independent of its development time, which is not the case when facing another developer. The slower

development time by the lead firm can benefit the follower. In particular, when the cost of resource development is close to the follower's threshold (i.e., when  $\phi$  is close to  $\phi_2$ ), there is by definition little net benefit to the follower from acquiring the resource and all that matters for profitability is the time it takes the leader to develop the resource and this is longer when the firm imitates. In other words, a firm may want to forsake its own development activities and become an imitator just to reduce the pressure on the lead firm and thereby delay the time at which the lead firm develops a competitive advantage.

#### 4.4. Link to Profitability

A final and critical element of the analysis is the link between resource heterogeneity and net profits, by which we mean the net present value of all profit flows less the cost of resource development. We are still working on this part of the analysis, but some important results have already emerged. Figure 4.2 and 4.3 illustrates the main results for the situation where the firms are developing the resource in parallel. We find that the firm with the competitive advantage (firm 1) always has higher profits: the competition to develop a competitive advantage does not compete away the excess rents. However, while relative profits are enhanced by the opportunity to develop the resource, the absolute level of profit for firm 1 may either increase or decrease. In the figures, the dashed line at  $\pi_0/r$  gives profits when firms cannot develop the resource. Sometimes the firms face a Prisoner's Dilemma where both would be better off if neither firm developed the resource, but each firm's dominant strategy is to develop the resource.

The relationship between time compression diseconomies and both absolute and relative profitability is non-monotonic. Profits for the firms tend to fall in time compression because resource development becomes more costly and more time consuming. However, the leader firm experiences an upward jump in profits when time compression diseconomies become sufficiently large ( $\phi = \phi_2$ ) so that the follower stops developing the resource and the leader firm has an inimitable resource. Once

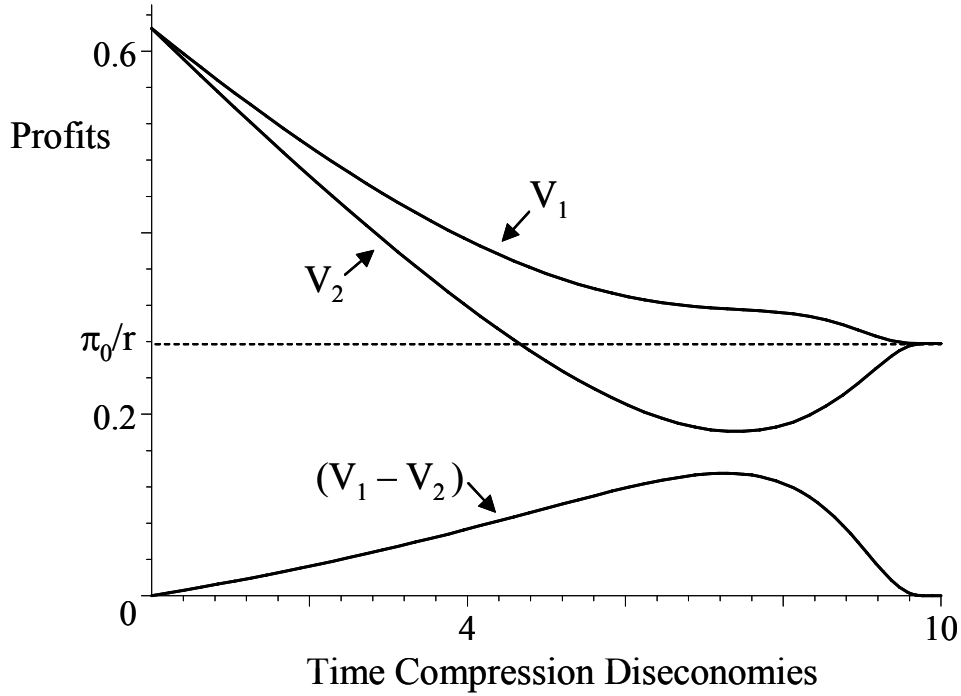


Figure 4.2: The profits of firm 1 ( $V_1$ ) and firm 2 ( $V_2$ ) as a function of the time compression diseconomy parameter  $\phi$  when  $F_0 = 0$ . The profit level  $\pi_0/r$  (dashed line) is the profit that obtains when no resource development is possible. Resource development improves both the relative and absolute profitability of the lead firm. The difference in profits ( $V_1 - V_2$ ) are non-monotonic in  $\phi$ . Parameters are  $r = .1$ ,  $K = .1$ , and the profit flows are from the Cournot example with  $c = .5$  and  $\varepsilon = .5$ .

it stops developing the resource, the profits of the follower increase in time compression diseconomies because it takes the leader firm longer to develop the resource and establish its competitive advantage. Note that the difference in profits is also non-monotonic. On the one hand, as time compression diseconomies increase, the sustainability of the leader firm's competitive advantage increases. On the other hand, the time it takes the leader firm to develop the resource becomes longer, which lowers the net present value of its advantage. One source of the non-monotonicity is that at low levels of time compression diseconomies, the first effect dominates, but at higher levels the second effect is dominant. The other source is the jump in firm

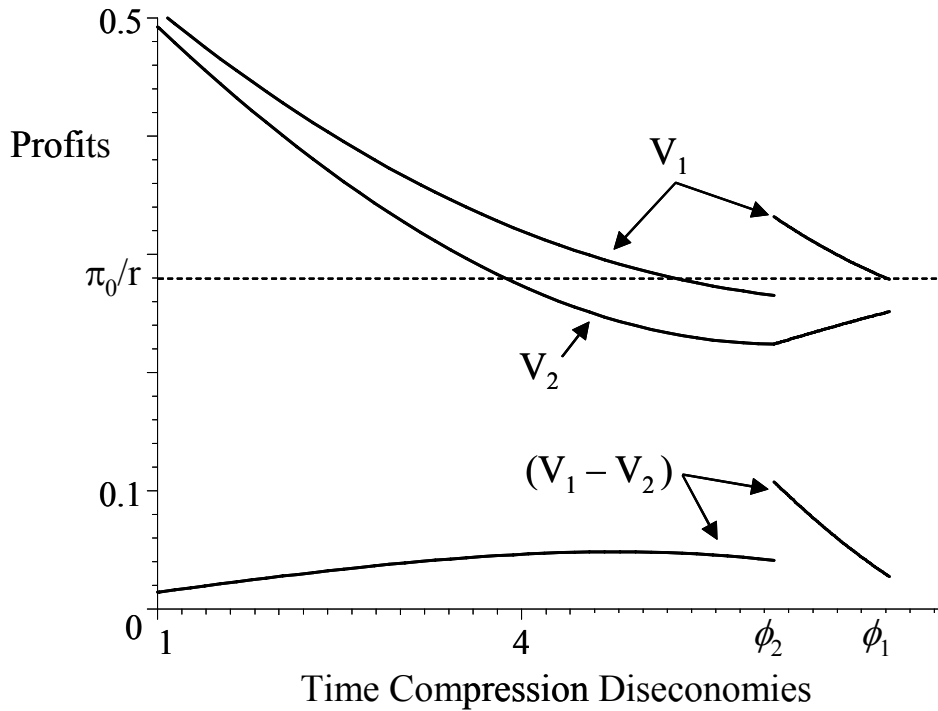


Figure 4.3: The profits of firm 1 ( $V_1$ ) and firm 2 ( $V_2$ ) as a function of the time compression diseconomy parameter  $\phi$  when  $F_0 = 0.3$ . Note the discontinuity in firm 1's profits at  $\phi_2$  where firm 2 stops developing the resource. Now both firm 1 and firm 2 may be worse off with the option to develop the resource. Parameters are  $r = .1$ ,  $K = .2$ , and the profit flows are from the Cournot example with  $c = .5$  and  $\varepsilon = .5$ .

1's profit when firm 2 gives up on resource development.

The most important point is that competition to develop the resource does not equalize rents across firms. Hence, we have resource-based performance differences in a situation without uncertainty/luck and without asymmetric information, which are the factors emphasized by Barney (1986).

## 5. Conclusion: Limitations and Future Work

Like any formal analysis, the objective of this study is to explore the logical implications of a few plausible assumptions and to abstract from numerous other factors

(uncertainty, asymmetric information, scale economies, switching costs, etc.) that might be important in a given competitive situation. Nonetheless, it is useful to highlight some of the important simplifying assumptions which future work might fruitfully address. For example, combining time compression diseconomies with uncertainty about resource values might offer to integrate traditional interest in resource development with the more recent interest in real option strategies. Clearly there are interactions: the more costly it is for firms to compress time and quickly alter their resource stocks in response to the resolution of uncertainty, the greater the option value to making flexible *ex ante* investments.<sup>9</sup>

We assume that firms' are committed to their strategy choices. The follower firm is assumed to be committed to its choice between being an imitator and a developer. Based on our analysis, we know that this assumption may matter in that there are situations where the follower would like the leader firm to think that it is imitating but then to secretly engage in parallel development. The follower's commitment could come because it is unable to keep its activities secret or because its strategy is grounded in organizational capabilities that are not easily adjusted in the short run. Nonetheless, one could extend the analysis to consider the case where the follower is not committed.

A more subtle form of commitment is commitment to development timing. Suppose that in equilibrium firm 1 is to develop the resource in one year ( $T_1^* = 1$ ) and firm 2 in 18 months ( $T_2^* = 1.5$ ). An implicit assumption in our analysis is that if firm 2 deviates and develops the resource in 9 months, then firm 1 continues with its original development plans and completes its resource development in 1 year, even though this is no longer *ex ante* optimal. Such commitment is made plausible by the fact that development costs up to 9 months are sunk and that revising complex development plans in mid course may be organizationally difficult and costly. That

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<sup>9</sup>Prior work (Pacheco-de-Almeida and Zemsky, 2003) has already shown that time consuming resource accumulation can be fruitfully incorporated into models of investment under uncertainty. However, this work assumes a fixed time to build, rather than endogenizing the resource development time by assuming time compression diseconomies as we are proposing.

is, solving the model with complete flexibility to revise timing in mid course makes little sense for a theory of resource development.

Moreover, we already know some key results for the no commitment case because this situation is treated by the literature on new technology adoption (see Hoop, 2002, for a survey) where firms decide when to adopt a new technology for which the cost of adoption is falling over time.<sup>10</sup> An important result in that literature is “rent equalization” where competition to be the first firm to adopt a new technology equalizes rents across firms (Fudenberg and Tirole, 1985). This contrasts sharply with the resource development problem that we study where rents are not equalized. Echoing the original argument of Dierickx and Cool (1989), we see that resources that firms develop internally may be much more important for performance differences than resources (like a new technology) that firms acquire on markets.<sup>11</sup>

We assume the specific functional form for the cost of resource development that is required to give us closed form results. Some of the analysis could be extended to a general convex cost function. In particular, it would be nice to have a general characterization of when a shift in time compression diseconomies increases sustainability when both firms are developing and this should be tractable. There are at least two other ways in which the analysis in this paper is not yet complete. One is a characterization of how the optimal level of causal ambiguity varies with exogenous parameters like time compression diseconomies. A second is to extend the results on firm profits to the imitator-developer case.

Ours is not a complete theory of the creation of competitive advantage. We do make considerable progress. We show that resource development in the presence of time compression diseconomies is consistent with resource heterogeneity and competitive advantage. We show that profits are not equalized by the competition to establish the competitive advantage. In addition, we characterize the sustainability

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<sup>10</sup>One exception is Reinganum (1982) which studies a model where firms are committed to their development time. However, subsequent work on new technology adoption follows Fudenberg and Tirole (1985), who argue that commitment to an adoption time is not a good assumption.

<sup>11</sup>A technically challenging extension of our work would be to solve the case where there is imperfect commitment to development timing and characterize the extent of rent equalization.

of the competitive advantage. What we do not do, is explain why one firm is able to enjoy the privileged position of being the leader in the industry. This a common limitation of formal theories of firm asymmetries, and might be best addressed using other methodologies, including industry case studies that are informed by formal theory, along the lines of what Sutton (1996) does for the theory of endogenous sunk costs.

As for large scale empirical studies, progress in this area would benefit greatly by the assembly and analysis of data sets on the timing of resource development among competing firms. While the original work on time compression diseconomies emphasized the build-up of stocks of intangible assets (such as brand), our theory emphasizes the acquisition of discrete resources (such as a call center or production process) and suggests additional possible settings for empirical work.

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