Complementarity, investment incentives, and evolution of joint ventures

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Complementarity, Investment Incentives, and Evolution of Joint Ventures

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Abstract

This paper studies the dynamic evolution of a joint venture that is initially formed due to the complementary strengths of two firms. We analyze the impact of the investment choices of the two partner firms on the fate of the joint venture. Investments that improve a firm's efficiency in the activity it performs in the joint venture (complementary investments) suffer from an incentive problem since benefits of such investments are shared between the two firms. To minimize the inefficiency caused by this incentive problem, the firm whose input is more valuable to the joint venture should receive a larger share of the joint venture revenues. When each firm invests in learning about the activity performed by its partner (competing investments), the joint venture may itself fail since such investments reduce the synergy arising from complementarity. If firms can choose between the two types of investments, the joint venture suffers from a coordination problem and two type of equilibria coexist: one in which both firms make complementary investments and the joint venture survives with increased complementarity and another in which firms make competing investments and the joint venture is taken over by one of the partners.

JEL Codes: L23, F23

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1. Introduction

A fundamental theoretical rationale behind joint ventures (JVs) is that firms with complementary strengths can benefit from joint production. This theoretical idea has substantial empirical support. In a recent survey of seventy six JVs in six developing countries, more than sixty five percent of the respondents rated knowledge of local politics, government regulations, local customs, and local markets as important considerations for seeking local partners (see Miller et. al. 1995). Similarly, more than seventy percent of the local firms in developing countries sought out JVs with multinationals because of their superior product and process technologies as well as international reputation.1 Similar findings for different countries are reported in Beamish (1987) and Selassie (1995).2

Empirical evidence also indicates that a significant number of JVs terminate in their early years. For example, Kogut’s (1989) study of life histories of ninety two JVs revealed that thirty five of these failed within seven years.3 Even those that survive seem to have problems: a survey by Killing (1982) reports that thirty six percent of the partners in JVs found JVs to have performed unsatisfactorily. The more recent survey by Miller et al. (1995) also reports similar results: twenty seven percent of the JVs surveyed were not expected to survive by its partners.

Taking complementarity as the motivation for the existence of a JV, in this paper we explore the dynamic evolution of the enterprise.4 Our intuitive view of

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1JVs frequently involve firms from different countries. Intuition suggests that scope for complementarities is bound to be large when firms come from different environments. For example, from 1979 to 1993, almost one hundred and seventy five thousand foreign investment projects were approved in China, of which approximately seventy percent took the form of a JV between a local firm and a foreign firm and these accounted for approximately seventy five percent of the total inward foreign investment. (Source: Almanac of China’s Foreign Relations and Trade 1994.)

2See Mogi (1996) for a CEO’s overview of the JV between Kikkoman Coporation of Japan and President Enterprises of Japan. One strong motivation for this JV was the complementary strengths of the two firms. Also, Luo (1997) reports that guanxi (local connections) by Chinese firms were an important factor leading to JVs between Chinese firms and foreign firms.

3As Kogut (1989) notes, since such JVs are typically formed between experienced firms, one would not expect failures rates to be so high. Since typically at least one of the partner firms continues to survive, the demise of a JV is somewhat different in character from the usual failure (and shut down) of a business enterprise.

4We should note that JVs may arise for reasons other than complementarity. As noted above, local governments often favor JVs over subsidiaries of multinational firms. Yu and Tang (1992) discuss other potential motivations for formation of JVs. These include: cost reduction, risk sharing, and competition reduction. See also Marjit et. al. (1995) and Balakrishnan and Koza
the evolution of JVs is as follows. Joint production requires considerable information exchange and substantial exposure to each other’s production activity. This exposure and information exchange makes it possible (or perhaps inevitable) for each firm to learn to better perform the activity currently performed by its partner. In other words, the very act of joint production under a JV may reduce the degree of complementarity between partners due to mutual learning on their part. While some amount of learning may occur naturally due to close exposure to new techniques, substantial improvements in efficiency are likely to require costly and conscious investments by the two partners. We distinguish between investments that increase incentives for joint production (complementary investments) from those that reduce such incentives (competing investments). We show that a substantial competing investment by one or both partners reduces the synergy arising from complementarity and renders the JV an inefficient organizational form.

How empirically plausible is the argument that mutual learning occurs in JVs? Consider the following quotation from Li (1997) who reports the result of a detailed study of eight JVs in China:

It was found that learning was the major objective of both Chinese and foreign partners in forming a JV. The Chinese partners wanted to learn about process and product technology, international marketing, and modern management, whereas foreign partners wanted to learn about local marketing, local management, and product technology in China.

The possibility of learning from one’s partner was also witnessed in the JV between Honda and Rover in the United Kingdom. Pilkington (1996), in his discussion of the Rover-Honda relationship, argues that a JV can become the means “to acquire the skills and capabilities which are needed for strategic development. This certainly proved the motive in the case of Rover and Honda…” Similar factors may be the motivation behind many international JVs in the auto industry where US firms may have to sought to learn new Japanese management techniques such as just-in-time inventory. For example, consider the JV between Toyota and General Motors (GM) established in 1984 called New United Motor Manufacturing Company Inc. (NUMMI). Toyota’s unique management style and philosophy were introduced into NUMMI and GM executives made “active efforts to gain a thorough understanding of the Toyota’s management practices. Part of this (1993).
effort was the establishment of a technical liaison office near the NUMMI plant, which documented Toyota’s management practices and conveyed this information to GM. Subsequently, GM adopted many of Toyota’s practices and started using them in other plants.” (World Investment Report, 1995).

Like any other enterprise, JVs may fail for a multitude of reasons. The literature on international management, policy makers, and business consulting firms frequently contribute failure of JVs to external factors, such as demand shocks, increased competition, or government policy, as well as to internal disputes within the enterprise that may arise from cultural differences between partners and clashes between labor and management, etc. We believe that the internal evolution of the enterprise, holding constant the external environment, may hold important clues regarding the failure of JVs and that JVs may break up even in the absence of any explicit disputes between partners. Our analysis shows that the investment decisions of the two partners can very well be the crucial determinant of the survival of a JV. To our knowledge, ours is the first theoretical analysis of the dynamics of JVs based on the endogenous evolution of the degree of complementarity between partners.

In section 2 of the paper, we develop a benchmark model of a JV motivated by complementary strengths. In section 3, we examine the partners’ incentive for investments that increase the synergy level of the JV (complementary investments). We show that complementary investments are sub-optimal from the viewpoint of the enterprise since each partner enjoys only a fraction of the marginal benefit of its own investment. We also show that, to minimize this inefficiency, the firm whose input is more important to the JV should receive more than half the JV’s revenue. In section 4, we analyze investments that reduce the synergy of the JV by making partners more like each other. We show that such competing investments can indeed lead to a break up of the JV in equilibrium and that they do not suffer from incentive problems since they result in sole ownership of the enterprise.

In section 5, we bring together our insights from the previous two sections by constructing a larger game in which the two firms can choose to make either a complementary investment or a competing one. Here our analysis reveals that

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5 Using data from US-Japan JVs, Nakamura et. al. (1996) provide empirical evidence which demonstrates that if partners in a JV undergo development that makes them more like each other, the JV is likely to fail.

6 In other words, only one firm produces in the market. One could imagine a scenario where the two firms compete with each other in case the JV breaks down. In real life, sometimes JVs end due to acquisitions by one of the partners while at other times the two may compete with one another. We abstract from the latter possibility and leave it as a topic for future research.
there exist two types of Nash equilibria: one in which the partners make competing
investments leading to the failure of the JV and the other in which the JV survives
with increased profitability as both partners select complementary investments.
One may interpret this co-existence of equilibria as the intrinsic instability of JVs: those JVs choosing the complementary investment equilibrium will survive and
grow and those that happen to choose the competing equilibrium will end up in
a break-up.

Finally, section 6 concludes. Proofs of all propositions and lemmas are pre-

sented in the appendix.

2. Basic Model

Consider two firms: firm 1 and firm 2 who form a JV to produce output $z$ with
two inputs $x$ and $y$.\footnote{Our benchmark model is similar to that of Eswaran and Kotwal's (1985) model of share-
cropping and that of Bhattacharya and Lafontaine's (1995) model of franchising.}
For concreteness, think of input $x$ as management and $y$ as marketing. While both firms can supply both inputs, firm 1 is more effi-
cient at supplying $x$ and firm 2 is more efficient at supplying $y$. We model this
complementarity by employing the following production function for the JV:

$$z = (\delta_1 x_1 + \delta_2 x_2)^\alpha (\gamma_1 y_1 + \gamma_2 y_2)^\beta, \quad \alpha + \beta < 1$$

where $x_i$ ($y_i$) is the amount of input $x$ ($y$) provided by firm $i$, and $\delta_1 > \delta_2 > 1$ and
$\gamma_2 > \gamma_1 > 1$. Obviously, in the JV firm 1 supplies input $x$ while firm 2 supplies
input $y$. The production function for the JV is given by

$$z^J = A^J x^\alpha y^\beta$$

(2.1)

where $A^J = \delta_1^\alpha \gamma_2^\beta$, $x = x_1$ and $y = y_2$.\footnote{In the literature, the production function of the JV usually involves a random element, $\eta$ which has zero mean so that: $z^J = A^J x^\alpha y^\beta + \eta$. This noise term implies that the JV partners' individual efforts can not be inferred simply by observing the output, making cooperation between partners difficult. Including this random variable in our analysis would not affect our analysis because the random term disappears when we calculate the expected profits of both partners.}

Parameters $\alpha$ and $\beta$ measure the importance of the two inputs, respectively, to the JV.

Let the cost (disutility) functions of the two inputs $x$ and $y$ be given by $C(x)$
and $D(y)$, $C' > 0, C'' \geq 0, D' > 0$, and $D'' \geq 0$. For simplicity, we consider the
case where $C(x) = x$ and $D(y) = y$. 

\[5\]
The revenue generated by the JV is shared by the two partners. Let \( \theta_i \) denote firm \( i \)'s share of total revenue, where \( \theta_1 + \theta_2 = 1 \). As in Eswaran and Kotwal (1985), the two firms choose their input efforts non-cooperatively to maximize their individual profits.\(^9\) In particular, firm 1 chooses \( x \) to solve the following problem:

\[
\text{Max } \theta_1 A^J x^\alpha y^\beta - x
\]

yielding the first order condition

\[
\alpha \theta_1 A^J x^{\alpha-1} y^\beta = 1
\]

Similarly, firm 2 chooses \( y \) to solve the following problem:

\[
\text{Max } \theta_2 A^J x^\alpha y^\beta - y
\]

yielding the first order condition

\[
\beta \theta_2 A^J x^{\alpha} y^{\beta-1} = 1
\]

We can rewrite the two first order conditions as

\[
x = \alpha \theta_1 z^J \quad \text{and} \quad y = \beta \theta_2 z^J
\]

Substituting these equations back into the production function in equation (2.1) yields the JV's output as well as revenue (price is normalized to one)

\[
z^J = \left( A^J \right)^{\frac{1}{1-\alpha-\beta}} (\alpha \theta_1)^{\frac{\alpha}{1-\alpha-\beta}} (\beta \theta_2)^{\frac{\beta}{1-\alpha-\beta}}.
\]

Using the above revenue, we calculate the profits of both firms as

\[
\pi_1^J = \theta_1 z^J - x = \theta_1 (1 - \alpha) z^J
\]

and

\[
\pi_2^J = \theta_2 z^J - y = \theta_2 (1 - \beta) z^J
\]

Adding the two gives the total value of the JV

\[
\pi^J = \pi_1^J + \pi_2^J = [\theta_1 (1 - \alpha) + \theta_2 (1 - \beta)] z^J
\]

\(^9\)See Svejnar and Smith (1984) for a model of a joint venture that explores resource allocation and profit distribution among partners under various institutional scenarios. Unlike us, their main focus is on static issues.
Remark 1: Although the JV enjoys the synergy of complementarity, it suffers from the well-known problem of under-provision of inputs: each partner supplies less input than is jointly optimal since each receives only a faction of the marginal benefit of providing its input. Because of this problem, the JV does not necessarily generate higher revenue than a firm that is solely owned by one of its partners if the complementarity of assets within the JV is not very strong (i.e., if the difference between $\delta_1$ and $\delta_2$ or between $\gamma_2$ and $\gamma_1$ is not large). As we will see, this observation is important in our discussion of competing investments in section 4 below.

Using the model developed above as a building block, we next turn to some dynamic issues. The next three sections will argue that when the two partners can make investments to improve their abilities at supplying the two inputs, their investment choices determine the evolution of the JV.

3. Complementary Investments

Suppose firm 1 can improve its ability at providing $x$ by making a costly investment while firm 2 can do the same with regard to input $y$. Specifically, firm 1 can reach a target efficiency level of $\Delta_1$ by investing an amount $d_1^1(\Delta_1 - \delta_1)$, where $d_1^1$ denotes the unit cost incurred in improving the efficiency of input $x$. Similarly, firm 2 can raise its efficiency of input $y$ to $\Gamma_2y$ by investing an amount $d_2^2(\Gamma_2 - \gamma_2)$. For simplicity, we assume $d_1^2 = d_2^2 = d$.

The structure of the investment game is as follows. First the two firms choose their investment levels non-cooperatively. Next, given their efficiency at their respective activities, they choose their input levels and production takes place at the final stage. To obtain a sub-game perfect Nash equilibrium, we solve the game backwards.

At the output stage, the efficiency parameters $\Delta_1$ and $\Gamma_2$ are given. The production function facing the JV is thus given by $z^J = \Delta_1^x\Gamma_2^y x^\alpha y^\beta$. The choice of input provision is exactly as solved in section 2. Using equation (2.3) we obtain

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10 Results change in an obvious manner when investment costs are asymmetric.

11 Note that we assume that the efficiency parameters of individual inputs to the JV are observable though the level of inputs might not be so. It is hard to imagine how firms can form a JV if they do not know each other's efficiency parameters that determine the degree of complementarity of their inputs.
the total output of the JV
\[ z^J(\Delta_1, \Gamma_2, \theta_1) = (\Delta_1 \Gamma_2^{\beta})^{\frac{1}{1-\alpha-\beta}} (\alpha \theta_1)^{\frac{\alpha}{1-\alpha-\beta}} (\beta (1 - \theta_1))^{\frac{\beta}{1-\alpha-\beta}}. \]

3.1. Investment Stage

At the investment stage, taking its rival’s investment choice of \( \Gamma_2 \) as given, firm 1 chooses \( \Delta_1 (\Delta_1 \geq \delta_1) \) to maximize its JV profit net of its investment cost:

\[ \text{Max } \theta_1 (1 - \alpha) z^J(\Delta_1, \Gamma_2) - d(\Delta_1 - \delta_1) \]

The first order condition for the above problem is

\[ (\alpha \theta_1)^{\frac{\alpha}{1-\alpha-\beta}} (\beta \theta_2)^{\frac{\beta}{1-\alpha-\beta}} \theta_1 (1 - \alpha) \frac{\Delta_1^{\frac{2\alpha+\beta-1}{1-\alpha-\beta}}}{1 - \alpha - \beta} \Gamma_2^{\frac{\alpha}{1-\alpha-\beta}} = d \]  

which can be rewritten as

\[ \Delta_1 = J(\cdot) \Gamma_2^{\frac{\beta}{1-2\alpha-\beta}} \]

where

\[ J(\cdot) = \left[ \frac{(1 - \alpha) \theta_1 (\alpha \theta_1)^{\frac{\alpha}{1-\alpha-\beta}} (\beta \theta_2)^{\frac{\beta}{1-\alpha-\beta}}}{d(1 - \alpha - \beta)} \right]^{\frac{1-\alpha-\beta}{1-2\alpha-\beta}} \]

Similarly, firm 2 solves

\[ \text{Max } \theta_2 (1 - \beta) z^J(\Delta_1, \Gamma_2) - d(\Gamma_2 - \gamma_2) \]

with an analogous first order condition

\[ \Gamma_2 = K(\cdot) \Delta_1^{\frac{\alpha}{1-\alpha-2\beta}} \]

where

\[ K(\cdot) = \left[ \frac{(1 - \beta) \theta_2 (\alpha \theta_1)^{\frac{\alpha}{1-\alpha-\beta}} (\beta \theta_2)^{\frac{\beta}{1-\alpha-\beta}}}{d(1 - \alpha - \beta)} \right]^{\frac{1-\alpha-\beta}{1-\alpha-2\beta}} \]

The above first order conditions explicitly define the reaction functions of the two firms. It is easy to see that these reaction functions are upward sloping.\(^{12}\)

\(^{12}\)The second order conditions for the firms are satisfied if \( 2\alpha + \beta < 1, \alpha + 2\beta < 1 \), and the cost parameter \( d \) is sufficiently small.
Due to the complementary nature of the two firms' investments, an increase in investment by one firm increases the marginal benefit of the other firm's investment and, hence, its optimal investment.

Let \((\Delta^*_1, \Gamma^*_2)\) denote the pure strategy Nash equilibrium investment levels of firms 1 and 2, respectively. Which firm has a stronger incentive to invest? The following proposition says that two crucial factors determining the investment incentives of the two firms are the relative importance of their inputs (\(\alpha\) versus \(\beta\)) and their JV shares \(\theta_i\).

**Proposition 1:** The following hold:

(i) \(\Delta^*_1 > \Gamma^*_2\) if and only if \(\theta_1 > \frac{1}{1+\theta}\), where \(b \equiv \frac{\alpha(1-\alpha)}{\beta(1-\beta)}\),

(ii) The relative investment by firm \(i\) increases with its share of the JV.

Consider the case where the two inputs are equally important for production \((\alpha = \beta)\). In this case, part (i) of proposition one informs us that firm 1's investment is higher than firm 2's \((\Delta^*_1 > \Gamma^*_2)\) if and only if its share of the JV revenue exceeds 50%. Likewise, when the firms have equal shares in the JV \((\theta_1 = \theta_2)\), it is easy to see that firm 1 makes a higher investment than firm 2 if and only if \(\alpha > \beta\). In general, firm 1 invests more than firm 2 in equilibrium either if its share in the JV is higher than firm 1’s share or if the input it supplies to the JV is relatively important (i.e., \(\alpha\) is big). For example, suppose \(\alpha > \beta\). In this scenario, firm 1 may still invest more than its partner even when its JV share falls below 50% provided it exceeds a certain threshold (i.e. \(\theta_1 > \frac{1}{1+\theta}\)).

It is also useful to examine the channels via which changes in the firms’ shares affect equilibrium investments. Consider the effect of an increase in \(\theta_1\) on firm 1's equilibrium investment \(\Delta^*_1\). As \(\theta_1\) increases, \(\Delta^*_1\) is affected in three different ways. First: an increase in \(\theta_1\) increases the marginal benefit of firm 1’s investment (its reaction function shifts up) increasing its incentive for investment. Second, an increase in \(\theta_1\) simultaneously decreases the marginal benefit of firm 2’s investment (its reaction curve shifts down). Since the two firms’ investments are complementary, a reduction in firm 2’s investment tends to decrease firm 1’s investment. Lastly, altering the share of a firm in the JV also affects the equilibrium at the output stage. This three effects interact to determine the net effect of a change in \(\theta_1\) on the equilibrium of the investment game. While algebraic complexity does not allow us to obtain clear cut results regarding the absolute investment levels.

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13 Straightforward algebraic manipulations show that this equilibrium exists and is unique.
14 For example, governments in lesser developed countries often impose restrictions on the share of the JV that can be owned by a foreign partner.
of the two firms, part (ii) of the proposition 1 says that an increase in a firm’s JV share raises its incentive to invest, relative to its partner.\textsuperscript{15}

3.2. Under-Investment Problem and Optimal Revenue Sharing

In the equilibrium derived above, each firm makes its decision without taking into account the benefit of its investment to its partner. Thus, the investments of the two firms are too low from the viewpoint of maximizing the value of the JV. In other words, JVs are plagued not only by a static inefficiency but also a dynamic one: not only is the JV’s output too low given the investment levels (due to the under-provision of inputs problem), the partners also under-invest in improving their efficiency parameters. Thus, the investment incentives suffer doubly: the inefficiency at the output stage worsens the inefficiency at the investment stage.

The severity of the under-investment problem depends crucially, of course, on how the firms share the JV’s revenue. Next we examine the feature of the optimal revenue-sharing scheme that minimizes the inefficiency caused by the under-investment problem. Let \((\Delta_1^*, \Gamma_2^*)\) denote the Nash equilibrium of the investment game. Let \(\theta_1^*\) denote the share of firm 1 that maximizes the JV’s total profits given that firms choose their investments and inputs non-cooperatively:

\[
\theta_1^* = \text{Arg} \max_{\theta_1} \pi^{JV} - d\Delta_1^* - d\Gamma_2^* = [\theta_1(1 - \alpha) + (1 - \theta_1)(1 - \beta)] z^J - d\Delta_1^* - d\Gamma_2^*
\]

where

\[
z^J = z^J(\Delta_1^*, \Gamma_2^*, \theta_1) = \left[ (\Delta_1^*)^\alpha (\Gamma_2^*)^\beta \right]^{\frac{1}{\alpha + \beta}} (\alpha \theta_1)^{\frac{\alpha}{\alpha + \beta}} [\beta(1 - \theta_1)]^{\frac{\beta}{\alpha + \beta}}.
\]

The following proposition states that the dynamically optimal arrangement of the JV requires that a firm get a larger share of the JV than its partner if and only if its input is more important than its partner’s.

**Proposition 2:** Assume that \(\alpha + 3\beta < 1\) and \(3\alpha + \beta < 1\). Then, \(\theta_1^* > \frac{1}{2}\) if and only if \(\alpha > \beta\).

The above proposition can be understood as follows. As we mentioned earlier, the under-provision of effort problem exists at both the output stage and the investment stage. The optimal revenue sharing arrangement aims at minimizing the combined inefficiency at the two stages. At the investment stage, if a firm’s

\textsuperscript{15}A local result for absolute investment levels can be shown for the symmetric case \(\alpha = \beta, \quad \delta_1 = \gamma_2\). Under equal sharing \((\theta_1 = \theta_2)\), a small increase in a firm’s share of the JV increases its equilibrium investment while it decreases the other firm’s investment.
input is more valuable to the JV than its partner's, then its investment is also more valuable to the JV. Thus, this firm should be given a larger share of the JV revenues in order to induce it to invest more. For the output stage, it is easy to prove a 'static optimum result': when the efficiency parameters are fixed, maximizing the JV's revenue (or profits) over the shares \( \theta_i \) requires that firm 1's share be greater than \( 1/2 \) if and only if \( \alpha > \beta \).\(^{16}\) Given this result, it is not surprising that the 'dynamic optimum result' in proposition 2 holds.

We next examine the case where the two firms invest in improving their efficiency of performing their partner's activity with the hope of taking over the JV.

4. Competing Investments

Consider the case where each party can make a costly investment to improve its ability of supplying the input currently supplied by it partner in the JV. In particular, firm 1 can increase the level of \( \gamma_1 \) in order to reduce its disadvantage relative to firm 2 in performing activity \( y \), and firm 2 can invest to raise \( \delta_2 \) (its efficiency in activity \( x \)). The unit costs of investment for the firms are \( d_1 \) and \( d_2 \), respectively. Thus, by investing an amount \( d_1(\Gamma_1 - \gamma_1) \), firm 1 can raise its effectiveness of input \( y \) to \( \Gamma_1 \) from the original level \( \gamma_1 \), and firm 2 can raise its efficiency of input \( x \) to \( \Delta_2 \) by investing an amount \( d_2(\Delta_2 - \delta_2) \).

The timing of moves is as follows. The two firms simultaneously choose their investments \( \Gamma_1 \) and \( \Delta_2 \). Since such competing investments lower the synergy of the JV, the JV may cease to be the most efficient organizational form after such investments have been made. So, at the next stage of the game, the organizational form (sole ownership by one of the two firms or the JV) that leads to the highest total profits prevails. If the JV fails, a firm buys out its partner (see below) and the latter exits the market. In the last stage, production takes place under the organization form that prevails in the previous stage.

\(^{16}\)In particular, maximizing the JV’s total revenue yields firm 1’s (statically) optimal share to be \( \theta_1 = \frac{\alpha}{\alpha + \beta} \) and maximizing the JV’s total profits leads to \( \theta_1 = \frac{1 - \alpha}{1 + \sqrt{(1 - \alpha)\beta}} \). Both solutions have the feature that \( \theta_1 > 0.5 \) if and only if \( \alpha > \beta \).
4.1. Output Stage

The output decisions, of course, depend upon the organizational form under which production takes place. Given $\Gamma_1$ and $\Delta_2$, the JV continues to operate if the complementarity is still relatively strong (i.e., if $\pi^J \geq \max\{\pi_1^*, \pi_2^*\}$ where $\pi_i^*$ denotes firm $i$’s payoff as a sole owner derived below). The firms’ investments are useless in this case since the JV continues to operate based on the old efficiency parameters.

If firm 1 produces on its own, its production function is given by

$$z_1 = (\delta_1 x)^{\alpha}(\Gamma_1 y)^{\beta}$$

(4.1)

It solves the following problem:

$$\max_{x, y} z_1 - x - y$$

The first order conditions are

$$\alpha \delta_1 \Gamma_1 x^{\alpha-1} y^{\beta} = 1 \quad \text{and} \quad \beta \delta_1 \Gamma_1 x^{\alpha} y^{\beta-1} = 1$$

which can be rewritten as $x = \alpha z_1$ and $y = \beta z_1$. Solving for $z_1$ yields

$$z_1^* = (\Gamma_1)^{\frac{\beta}{1-\alpha-\beta}} (\delta_1^\alpha \alpha^\beta)^{\frac{1}{1-\alpha-\beta}}$$

(4.2)

The corresponding profit for firm 1 is given by

$$\pi_1^* = z_1^* - x - y = (1 - \alpha - \beta)z_1^*.$$ 

(4.3)

Similarly, firm 2’s optimal profit if it is the sole owner is given by

$$\pi_2^* = (1 - \alpha - \beta)z_2^* \quad \text{where} \quad z_2^* = \Delta_2^{\frac{\alpha}{1-\alpha-\beta}} (\gamma_2^\beta \alpha^\beta)^{\frac{1}{1-\alpha-\beta}}.$$ 

(4.4)

4.1.1. Buy-Out of the JV

If a firm invests a sufficient amount, the JV becomes less productive than a solely owned enterprise. If the JV fails, we assume that the firm with the more efficient form of organization (the higher $\pi_i^*$) buys out the other firm by paying the latter a price equal to $\theta_j \pi_j^*$.\(^{18}\)

\(^{17}\)The exact condition for $\pi_1^* > \pi_2^*$ can be obtained by comparing equations (4.3) and (2.6).

\(^{18}\)If firm $j$’s investment level is so low that $\pi_j^* < \pi^j$, the buy-out price equals firm $j$’s old JV revenue, $\theta_j \pi_j^*$. 

12
The formulation of this buy-out price can be understood as follows. After making a competing investment, firm 1 is capable of enjoying the payoff (gross) \( \pi_1^* \) but this requires that firm 2 be willing to sell its share of the JV. Of course, firm 2 is also capable of enjoying the (gross) payoff \( \pi_2^* \) if firm 1 agrees to sell its part of the JV. Since both firms may prefer to be buyers rather than sellers, we assume that the following procedure is used to terminate the JV. Suppose, by way of illustration, that \( \pi_1^* > \pi_2^* \) (\( > \pi_j^* \)). First, the two firms sell the JV to a “third party” at the price \( \pi_j^* \) which is then split between the partners in accordance with their shares of the JV. Then, this third party sells all the assets of the JV in an auction in which the two partners bid for the rights to the entire JV. The outcome of the auction is that the partner with the highest valuation (firm 1 in this example) wins by paying \( \pi_j^* \) to firm 1. Lastly, the (neutral) third party distributes its own profits from the auction, \( \pi_j^* - \pi_j^* \), to the partners according to their initial shares of the JV. Under the above procedure, firm i’s payoff equals the sum of the following three terms:

\[
\theta_i \pi_j^* + (\pi_i^* - \pi_j^*) + \theta_i (\pi_j^* - \pi_j^*) = \pi_i^* - (1 - \theta_i) \pi_j^* 
\]

Firm j’s payoff then equals its initial JV profits plus its fraction of the “auction” profits:

\[
\theta_i \pi_j^* + \theta_i (\pi_j^* - \pi_j^*) = \theta_i \pi_j^*. 
\]

Under the above buy-out price specification, the payoff of firm i, gross of its investment cost, is given as follows:\(^{19}\)

\[
v_i = \begin{cases} 
\pi_i^* - \theta_j \pi_j^*, & \text{if } \pi_i^* > \pi_j^* \\
\frac{1}{2}[\pi_i^* - \theta_j \pi_j^*] + \frac{1}{2} \theta_i \pi_i^*, & \text{if } \pi_i^* = \pi_j^* \\
\theta_i \pi_i^*, & \text{if } \pi_i^* < \pi_j^* 
\end{cases}
\]

One could imagine other methods of terminating the JV that result in buy-out prices different from the one that results from the procedure outlined above. For example, one could assume that firm i can buy out firm j’s share of the JV by paying it the amount \( \theta_j \pi_j^* \) – i.e. its current payoff as a partner in the JV. The problem with this price is that it ignores the fact that firm j too has the option of investing and operating the JV solely – in other words, it lets firm i choose the

---

\(^{19}\)If the firms are equally productive, i.e., if \( \pi_i^* = \pi_j^* \), the buying out party is determined by a coin toss with each firm having an equal chance of being the buyer and the seller.
terms of the buy out. By contrast, our procedure recognizes that both firms have the option of making competing investments and each firm may be unwilling to sell its share of the JV at a price which does not let it profit from the option of making a competing investment. In our view, the results that follow should go through with any procedure which allows both firms to benefit from the option of making a competing investment.

4.2. Investment Stage

Knowing that their future payoffs are given by \( v_i \) above, firms make their investment choices simultaneously. Let \( \Gamma^*_1 \) denote firm 1’s optimal investment given that it buys out the JV from its partner:

\[
\Gamma^*_1 = \text{Argmax } \pi^*_1(\Gamma_1) - (\Gamma_1 - \gamma_1)d^*_1 - \theta_2 \pi^*_2(\Delta_2)
\]

where

\[
\pi^*_1(\Gamma_1) = (1 - \alpha - \beta)(\Gamma_1)^{\frac{\beta}{\gamma_1-\alpha-\beta}}(\delta_1^\alpha \alpha \beta^\beta)^{\frac{1}{1-\alpha-\beta}}.
\]

The first order condition for the above problem is

\[
\beta(\Gamma_1)^{\frac{\alpha+2\beta-1}{\gamma_1-\alpha-\beta}}(\delta_1^\alpha \alpha \beta^\beta)^{\frac{1}{1-\alpha-\beta}} = d^*_1.
\] (4.5)

We similarly define \( \Delta^*_2 \) for firm 2’s optimal investments, assuming it buys out firm 1:

\[
\Delta^*_2 = \text{Argmax } \pi^*_2(\Delta_2) - (\Delta_2 - \delta_2)d^*_2 - \theta_1 \pi^*_1(\Gamma_1)
\]

where we must have

\[
\alpha(\Delta^*_2)^{\frac{\alpha+2\beta-1}{\gamma_2-\alpha-\beta}}(\delta_2^\beta \alpha \beta^\beta)^{\frac{1}{1-\alpha-\beta}} = d^*_2.
\] (4.6)

A question of interest is that if the two inputs are not symmetric (i.e., \( \alpha \neq \beta \)) which firm invests more as the buying out party? The following assumption proves useful in isolating the effect of the contribution parameters (\( \alpha \) and \( \beta \)) on the firms’ incentives for investment:

Assumption 1: \( \gamma_2^\beta = \delta_1^\alpha \).

Assumption 1 is a symmetry assumption which levels the playing field among the two firms when they compete in investments. It essentially means that the

\[20\] The second order condition is satisfied if \( \alpha + 2\beta < 1 \) and \( d^*_1 \) is small. Similarly, the second order condition for firm 2’s problem below holds if \( 2\alpha + \beta < 1 \) and \( d^*_2 \) is small.
two firms are equally advantageous in supplying the input in which they enjoy an efficiency advantage with respect to their partner.

From equations (4.2), (4.3), and (4.4) we know that

\[ \pi_1^* \geq \pi_2^* \iff z_1^* \geq z_2^* \iff (\Gamma_1^*)^\beta \geq (\Delta_2^*)^\alpha \]

Imposing assumption 1 implies that

\[ \pi_1^* \geq \pi_2^* \iff (\Gamma_1^*)^\beta \geq (\Delta_2^*)^\alpha. \]  \quad (4.7)

Thus, both the value of the two firm's investments as well as the importance of each partner's input to joint production play a role in determining the identity of the winner (i.e., the firm that ends up buying out the JV).

From inequality (4.7) it follows that when \( \alpha = \beta \), the firm that makes the higher investment buys out the JV. If \( \alpha > \beta \), this inequality implies that firm 1 must make a higher investment than firm 2 to be able to buy-out the JV. Note that \( \alpha > \beta \) implies that input supplied by firm 1 in the JV (input \( x \)) is more valuable than the input supplied by firm 2. Thus, the firm with the more valuable input actually has to invest a greater amount to beat out the other firm. What matters at the investment stage is the value of the activity the two firms are investing in: when \( \alpha > \beta \), firm 2 is investing in a relatively more valuable activity than firm 1 and consequently has a stronger incentive to invest.

Proposition 3: Suppose \( d_1^* = d_2^* \) and Assumption 1 holds, then \( \Gamma_1^* < \Delta_2^* \) if and only if \( \alpha > \beta \).

The above proposition informs us of the stronger investment incentive faced by the partner who supplies the weaker input to the JV. Contrast this result with the case of complementary investments: in that scenario firm 1 has a stronger incentive to invest iff \( \alpha > \beta \). Here, firm 2 has a stronger incentive to invest when \( \alpha > \beta \). The roles of the two firms are reversed under competing investments: under both scenarios, when \( \alpha > \beta \), investing in improving the efficiency of input \( x \) is more valuable.

If a firm gets bought out, its payoff equals \( \theta_i \pi_i^* \). Let \( \Gamma'_1 \) denote firm 1's optimal investment given that it is bought out by firm 2:

\[ \Gamma'_1 \equiv \text{Arg max } \theta_1 \pi_1^*(\Gamma_1) - (\Gamma_1 - \gamma_1) d_1^* \]

Similarly, define

\[ \Delta'_2 \equiv \text{Arg max } \theta_2 \pi_2^*(\Delta_2) - (\Delta_2 - \delta_2) d_2^* \]
Since $\theta_i < 1$, it immediately follows that $\Gamma_i' < \Gamma_i^*$ and $\Delta_2' < \Delta_2^*$.

Note that the buying-out party’s net payoff strictly decreases with its rival’s investment. This is because the buy-out price strictly increases with the bought-out party’s investment. Consequently, there exists a critical level of investment on firm 2’s part which makes firm 1 indifferent between buying out firm 2 and getting bought out itself. This critical investment $\Delta_2^C$ is defined by

$$
\pi_1^*(\Gamma_1') - (\Gamma_1' - \gamma_1)d_1^\alpha - \theta_2\pi_2^*(\Delta_2^C) = \theta_1\pi_1^*(\Gamma_1') - (\Gamma_1' - \gamma_1)d_1^\alpha
$$

In the above equation, the left hand side gives firm 1’s payoff given that it invests $\Gamma_1'$ and buys out firm 2 (who invests $\Delta_2^C$) whereas the right hand side gives firm 1’s payoff given that it invests $\Gamma_1'$ and sells its share of the JV to firm 2.

Similarly, we can define $\Gamma_1^C$ as follows

$$
\pi_2^*(\Delta_2^C) - (\Delta_2^C - \delta_2)d_2^\alpha - \theta_1\pi_1^*(\Gamma_1^C) = \theta_2\pi_2^*(\Delta_2^C) - (\Delta_2^C - \delta_2)d_2^\alpha
$$

That is, $\Gamma_1^C$ is the level of investment on the part of firm 1 that makes firm 2 indifferent between buying out and bought out.

Now we are ready to analyze investment competition between the two firms. For simplicity, we first consider the symmetric case where the two firms are identical in every aspect: $\theta_1 = \theta_2$, $\alpha = \beta$, $\delta_1 = \gamma_2$, and $d_1^\alpha = d_2^\alpha$. Later, we comment on the asymmetric case. In the symmetric case, we must have $\Gamma_1' = \Delta_2^*$, $\Gamma_1' = \Delta_2^*$ and $\Gamma_1^C = \Delta_2^C$. In addition, we can show the following:

**Lemma 1:** For the symmetric case, the following hold:

(i) $\Delta_2' < \Delta_2^C < \Delta_2^*$, and

(ii) The best response function of firm 1, denoted by $B_1(\Delta_2)$, is given by

$$
B_1(\Delta_2) = \begin{cases} 
\Gamma_1' & \text{if } \Delta_2 \leq \Delta_2^C \\
\Gamma_1 & \text{if } \Delta_2 > \Delta_2^C
\end{cases}
$$

and the best response function of firm 2, denoted by $B_2(\Gamma_1)$ is given by

$$
B_2(\Gamma_1) = \begin{cases} 
\Delta_2^* & \text{if } \Gamma_1 \leq \Gamma_1^C \\
\Delta_2 & \text{if } \Gamma_1 > \Gamma_1^C
\end{cases}
$$

The reaction functions can be interpreted as follows. If firm 2 does not improve its efficiency in activity $x$ at all ($\Delta_2 = \delta_2$), firm 1’s optimal investment is given
by $\Gamma^*_1$. Firm 1 will continue to invest the same amount if the investment by firm 2 is so small ($\Delta_2 < \Delta^*_2$) that firm 1 prefers to buy-out firm 2 than be bought out itself. However, when $\Delta_2 > \Delta^*_2$, firm 2’s investment, and the buying-out price as a result, is so high that for firm 1 buying out is less profitable than being bought out so that it reduces its own investment to $\Gamma^*_1$. These reaction functions yield the following proposition.

Proposition 4: The symmetric competing investment game has two pure strategy Nash equilibria: $(\Gamma^*_1, \Delta^*_2)$ and $(\Gamma^*_1, \Delta^*_2)$. In the $(\Gamma^*_1, \Delta^*_2)$ equilibrium, firm 1 buys out firm 2 whereas in the $(\Gamma^*_1, \Delta^*_2)$ equilibrium firm 2 buys out firm 1.

The above proposition establishes that investment competition between the two partners can indeed lead to the demise of the JV. In either equilibrium, a firm buys out its partner by investing the optimal amount. The bought-out party also invests in competing investment in order to receive the optimal buy-out price, though its investment is useless after the break-up of the JV.

If firms are not identical, as is normally the case, proposition 4 remains valid as long as the degree of asymmetry between the firms is not high. For example, suppose $\alpha > \beta$. Then, the best response functions of the firms still have the same shape as stated in lemma 1, and there would still be two equilibria. However, the buying-out party in the $(\Gamma^*_1, \Delta^*_2)$ equilibrium, i.e. firm 1, will invest less than the buying-out party in the $(\Gamma^*_1, \Delta^*_2)$ equilibrium, i.e. firm 2, because $\Gamma^*_1 < \Delta^*_2$ by proposition 3.

5. Both Types of Investments

The previous two sections explored two different models that highlight the incentives for two different types of investments faced by the partners in a JV. In this section, we consider a model in which each partner may invest in improving its efficiency in providing either of the two inputs. The basic insight we want to provide (or confirm) is that since complementary investments are mutually reinforcing while competing investments are mutually destructive, a JV may evolve into one of two possible equilibria: In one equilibrium, the partners both opt for complementary investments and the JV stays alive with an increased level

\footnote{Since the JV enjoys a synergy due to complementarity but suffers from the under-provision of input problem, a firm must invest a sufficient amount in order for it to become more productive than the JV and be able to buy out its partner. Here we assume that the optimal investments $\Gamma^*_1$ and $\Delta^*_2$ are sufficient to render the JV an inefficient organizational form, which must be true if, say, the costs of investment ($d^h_1$ and $d^h_2$) are sufficiently low.}
of complementarity. In another equilibrium, the two partners choose competing investments, reducing the complementarity of the JV thus causing it to fail.

To simplify the analysis, we assume that firms can make both complementary and competing investments only at fixed levels by paying some fixed investment cost. Specifically, by investing an amount $F_i$, firm $i$ can reach a target efficiency of $\Delta_i$ in input $x$, and by investing an amount $G_i$, firm $i$ can reach a target efficiency of $\Gamma_i$ in input $y$. We first consider the case where each firm has three strategies ($s_i = 0, \Delta_i$ or $\Gamma_i$). Later in this section, we examine the more general case where firms can choose both complementary and competing investments simultaneously, i.e., $\Delta_i$ and $\Gamma_i$ is also a feasible strategy.

We consider the simplest possible scenario and make the following set of natural assumptions:

$A2$. Symmetry assumption: $\theta_1 = \theta_2, \alpha = \beta, \delta_1 = \gamma_2, \delta_2 = \gamma_1, \Delta_1 = \Gamma_2 = X, \Delta_2 = \Gamma_1 = Y, F_i = F$, and $G_i = G$. In other words, the following are assumed: (i) firms share the JV revenue equally; (ii) both inputs are equally important for production; (iii) both firms are equally disadvantaged at performing the other's activity; and (iv) the feasible amount of investments of both types as well as the corresponding costs for each type of investment are the same for both firms.

In what follows, to economize on notation, we denote the initial JV revenue $\pi_i^1(\delta_1, \gamma_2)$ by just $\pi_i^1$. Note that under the symmetry assumptions, $\pi_i^1 = \pi_2^1$. When describing our other assumptions, we refer only to firm 1 although they apply to both firms.

$A3$. Unilateral incentive for a complementary investment: $\pi_i^1(X, \gamma_2) - \pi_i^1 > F$. This assumption means that a firm finds it profitable to make a complementary investment even when its partner chooses not to invest. Since a complementary investment by one firm increases the other firm's incentive for a complementary investment, assumption A3 automatically implies that $\pi_i^1(X, X) - \pi_i^1(X, \gamma_2) > F$.

$A4$. Unilateral incentive for a competing investment: $\pi_i^1(\delta_1, Y) - G > \pi_i^1$. That is, it is profitable for a firm to make a competing investment in order to buy out its partner.

5.1. High Value of a Complementary Investment

We first consider the case where the parameter values are such that

$$\pi_i^1(\delta_1, Y) < \pi_i^1(\delta_1, X).$$ (5.1)
That is, a complementary investment by either firm is sufficient to make the JV
the most profitable organizational form even if its partner makes a competing
investment.

Each firm has three strategies: \( s_i \in \{0, X, Y\} \). Under the assumptions made
above, the payoff matrix for this symmetric investment game (gross of investment
costs) is given by:

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>( X )</th>
<th>( Y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>( \pi_1' ), ( \pi_2' )</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( X )</td>
<td>( \pi_1'(X, \gamma_2) ), ( \pi_2'(X, \gamma_2) )</td>
<td>( \pi_1'(X, X) ), ( \pi_2'(X, X) )</td>
<td>-</td>
</tr>
<tr>
<td>( Y )</td>
<td>( \pi_1^*(\delta_1, Y) - \pi_2' )</td>
<td>( \pi_1^<em>(\delta_1, X) ), ( \pi_2^</em>(\delta_1, X) )</td>
<td>( \frac{1}{2}\pi_1^<em>(\delta_1, Y) ), ( \frac{1}{2}\pi_1^</em>(\delta_1, Y) )</td>
</tr>
</tbody>
</table>

Note that, since inequality (5.1) holds, only the cells \((Y, 0)\) and \((Y, Y)\) cor-
respond to a failure of the JV. The JV stays alive even under \((Y, X)\) because firm
2's complementary investment outweighs firm 1's competing investment. Under
\((Y, Y)\) each firm has a fifty percent chance of buying out the JV. Its corresponding
payoff, under the symmetry assumption A2, equals

\[
\frac{1}{2} \left[ \pi_1^*(\delta_1, Y) - \frac{1}{2}\pi_2^*(Y, \gamma_2) + \frac{1}{2}\pi_1^*(\delta_1, Y) \right] = \frac{1}{2}\pi_1^*(\delta_1, Y).
\]

We can show the following result:

**Proposition 5:** Suppose A2-A4 and inequality (5.1) hold. Then, there exist
two Nash equilibria, \((X, X)\) and \((Y, Y)\), if

\[
F - G \geq \pi_2^*(\delta_1, X) - \frac{1}{2}\pi_1^*(\delta_1, Y).
\]  

(5.2)

Otherwise, \((X, X)\) is the only Nash equilibrium.

The above proposition says that, regardless of whether inequality (5.2) holds or
not, \((X, X)\) is an equilibrium in which both firms making complementary
investments and the JV stays alive. This result follows from condition (5.1). However,
if inequality (5.2) holds, then there exists another equilibrium \((Y, Y)\) in which
both firms make competing investments and the JV fails. Given firm 1 plays \( Y \),
firm 2 can either play \( X \) in which case it keeps the JV alive, or it can play \( Y \).
Since \( X \) may be more costly than \( Y \) \((F > G)\), a scenario consistent with condition
(5.1) in that a more valuable complementary investment is also likely to be more
expensive, firm 2 will choose \( Y \) if inequality (5.2) holds. In this case, \((Y, Y)\) is also
a Nash equilibrium. We next examine the case where a competing investment is
relatively more valuable than a complementary investment.
5.2. High Value of a Competing Investment

Suppose that contrary to the case discussed above, we have

\[ \pi_i(\delta_1, Y) > \pi_i(\delta_1, X). \]  \hfill (5.3)

In other words, if firm 1 picks a competing investment, the JV ceases to be the dominant organizational form even if firm 2 makes a complementary investment. In this case the payoff matrix (gross of investment costs) for the investment game is given by:

<table>
<thead>
<tr>
<th></th>
<th>(0)</th>
<th>(X)</th>
<th>(Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(\pi_1^0, \pi_2^0)</td>
<td>- (\pi_1^0, \pi_2^0, \pi_1^0(\delta_1, \gamma_2))</td>
<td>(\pi_1^0(\delta_1, Y) - \frac{1}{2} \pi_2^0(\delta_2, X), \frac{1}{2} \pi_2^0(\delta_1, Y))</td>
</tr>
<tr>
<td>(X)</td>
<td>(\pi_1^0(\delta_1, \gamma_2), \pi_2^0(\delta_2, Y))</td>
<td>(\pi_1^0(\delta_1, \gamma_2), \pi_1^0(\delta_1, X))</td>
<td>(\pi_1^0(\delta_1, Y) - \frac{1}{2} \pi_2^0(\delta_2, X), \frac{1}{2} \pi_2^0(\delta_1, Y))</td>
</tr>
<tr>
<td>(Y)</td>
<td>(\pi_1^0(\delta_1, \gamma_2), \pi_2^0(\delta_2, Y))</td>
<td>(\pi_1^0(\delta_1, \gamma_2), \pi_1^0(\delta_1, X))</td>
<td>(\pi_1^0(\delta_1, Y) - \frac{1}{2} \pi_2^0(\delta_2, X), \frac{1}{2} \pi_2^0(\delta_1, Y))</td>
</tr>
</tbody>
</table>

This payoff matrix differs from the previous one only in \((Y, X)\) box. Now, a competing investment by either firm is sufficient to end the JV. Such a situation is likely when the efficiency improvement under a competing investment is large relative to the efficiency improvement attained under a complementary investment. Accordingly, we assume the following assumption holds:

\[ \pi_1^*(\delta_1, Y) - G - \pi_2^0(\delta_1, \gamma_2) > \pi_1^0(\delta_1, X, \gamma_2) - F. \]  \hfill (5.4)

In other words, a competing investment \(Y\) is more profitable for firm 1 than a complementary investment \(X\), given that firm 2 invests nothing.

**Proposition 6:** Suppose that assumptions A2-A4, inequalities (5.3) and (5.4) hold. Then \((X, X)\) is a Nash equilibrium of the game if

\[ \pi_1^*(\delta_1, Y) - \frac{1}{2} \pi_2^0(\delta_2, X) - G \leq \pi_1^0(\delta_1, X) - F. \]  \hfill (5.5)

Otherwise, the Nash equilibria of the game belong to the set \(\{(Y, 0), (Y, X), (Y, Y)\}\).

Under condition (5.3), a unilateral competing investment by one firm is sufficient to render the JV an inefficient organizational form even if the other firm makes a complementary investment. This tends to make the JV very unstable and likely to fail. This instability is reflected in the fact that if condition (5.5) is not satisfied, the JV fails even if one of the two firms makes a competing investment,
i.e. if inequality (5.5) is not valid then the only equilibrium pattern is the failure of the JV which takes place in either (Y, 0), (Y, X), or (Y, Y).\textsuperscript{22}

When condition (5.5) is satisfied, (X, X) can also be an equilibrium.\textsuperscript{23} Essentially, this happens when a competing investment is more costly than a complementary investment (G > F), which is consistent with the high value of a competing investment assumption (5.3). If this cost differential is relatively large, (X, X) may indeed be an equilibrium and the JV stays alive. Also note that if firm 1 deviates from (X, X) to (Y, X), it also has to pay firm 2 the buy-out price equal to \( \frac{1}{2} \pi_2^*(\delta_2, X) \).

The basic insight provided by the above two propositions is as follows. JVs suffer from an instability problem in that the investment game has two equilibria, one in which the JV stays alive and the other in which it breaks down, regardless of whether the parameter values favor the JV (condition (5.1)) or not (condition (5.3)).

6. Conclusion

The major point of this paper is that since complementarity is an important motivation for the formation of JVs, we must look to the evolution of complementarity between JV partners in order to better understand the dynamics of JVs. Using a benchmark static model of a JV based on complementarity between its partners, we have argued that the evolution of this complementarity can be determined endogenously via the investment choices made by the two partners. In the complementary investment game, we characterize how firms' incentives to increase the synergy of the JV depend on the importance of their inputs to the JV, as well as their shares of the JV's revenue. The very nature of a JV, i.e. partners share the fruit of the JV, leads to under-provision of effort in both the investment stage and the output stage. It is shown that the optimal revenue sharing scheme has the feature that the partner whose input is more important to the JV should control a majority of the JV shares.

In the competing investment game, we have examined JV partners' incentives to learn from each other, and shown that such mutual learning can indeed lead to a break-up of the JV. In the last part of the paper, we consider a model in which both

\textsuperscript{22}More restrictions on parameter values can be imposed to clarify when each of the three strategy pairs are an equilibrium. But, this is unnecessary since we are only interested in the JV breaking up in equilibrium.

\textsuperscript{23}Condition (5.4) is not needed for (X, X) to be an equilibrium.
partners can choose the type of its investment. This more general model brings together the insights of the previous two models and shows how multiple Nash equilibria co-exist even under assumptions that favor the continuation of the JV. Thus, JVs may suffer from a lack of co-ordination: complementary investments may indeed be in the interest of both parties but the very possibility of imbibing each other's skills leads firms to makes competing investments that lead to the demise of the JV.

How JV partners share the revenue generated from joint production is one of the most sensitive and crucial policy issues in many international joint ventures. Our analysis offers the insight that the share issue is not merely a matter of control, it may determine the very fate of the JV through its effect on the evolution of the complementarity between partner firms. Although we explicitly examine the share issue in only the complementary investment game, it is not hard to see that optimal determination of the JV shares, can prolong the life of the JV in both the competing investment game and the two-type investment game of section 5. In particular, when the shares are chosen to minimize the under-provision of efforts problem (i.e. to maximize the value of the JV), a buy-out becomes less likely in the competing investment game \( (\pi^*_i > \pi^j) \) is less likely to hold). Similarly, in the \( 3 \times 3 \) game of section 5, the optimal shares maximize the synergy of the JV via complementary investments making condition (5.2) in proposition 5 less likely to hold and condition (5.5) in proposition 6 more likely to hold. As a result, the \( (X, X) \) equilibrium is more likely to arise relative to the \( (Y, Y) \) equilibrium.

Finally, we offer some comments on the generality of the analysis contained in this paper. Although we use the Cobb-Douglas production function to model the complementarity of the JV partners, we believe that most of the results obtained in this paper will continue to hold in a more general model. In fact, Proposition 5 and 6 are based on general profit functions with no reference to the Cobb-Douglas production function at all. The main point of Proposition 1, namely that the partners' incentive for complementary investments increase with the importance of their inputs to the JV, obviously is a general one. The same can be said about proposition 3 which says that a firm's competing investment incentive increases with the importance of its partner's input to the JV. The Cobb-Douglas specification enables us to prove the if-and-only-if relationship between firms' incentives and the above said parameters, which we also expect to hold in other settings where the importance of inputs can be explicitly parameterized. Lastly, it is not hard to see that proposition 4 (which characterizes the equilibrium in the competing investment game) does not depend on the Cobb-Douglas production
function; the derivation of the optimal and the critical level of investment, as well as the best response function, hold generally.

7. Appendix

7.1. Proof of Proposition 1

From the first order conditions of the two firms we have:

\[
\frac{\Delta_1^*}{\Gamma_2^*} = \frac{\theta_1 (1 - \alpha) \alpha}{\theta_2 (1 - \beta) \beta} \tag{7.1}
\]

which straightforwardly implies part (ii) of the proposition.

When \( \theta_1 = 1/2 \), equation (7.1) implies that \( \Gamma_2^* > \Delta_1^* \) iff \( \beta - \alpha > (\beta - \alpha)(\beta + \alpha) \).

Since \( 1 > \beta + \alpha \), the second inequality holds iff \( \beta > \alpha \). □

7.2. Proof of Proposition 2

To prove the proposition, we need first to examine how changes in JV shares affect the equilibrium investment levels and to establish lemma 2 below.

At the Nash equilibrium, firm 1 optimizes over \( \Delta_1 \)

\[ Max \theta_1 (1 - \alpha) z'^1(\Delta_1, \Gamma_2, \theta_1) - d(\Delta_1 - \delta) \]

yielding the first order condition

\[ \theta_1 \frac{\partial z'^1(\Delta_1, \Gamma_2, \theta_1)}{\partial \Delta_1} = \frac{d}{1 - \alpha}. \tag{7.2} \]

The above equation implicitly defines firm 1’s best response function \( \Delta_1 = \Delta_1(\Gamma_2) \).

Its slope is given by

\[ \frac{\partial \Delta_1}{\partial \Gamma_2} = \frac{\frac{\partial^2 z'^1}{\partial \Delta_1 \partial \Gamma_2}}{\frac{\partial^2 z'^1}{\partial \Delta_1^2}}, \]

which is positive since \( \frac{\partial^2 z'^1}{\partial \Delta_1 \partial \Gamma_2} > 0 \) and \( \frac{\partial^2 z'^1}{\partial \Delta_1^2} < 0 \) by the second order condition of the problem.

Firm 2 maximizes over \( \Gamma_2 \)

\[ Max (1 - \theta_1)(1 - \beta) z'^1(\Delta_1, \Gamma_2, \theta_1) - d(\Gamma_2 - \gamma_2) \]
yielding the first order condition
\[
(1 - \theta_1) \frac{\partial z^J(\Delta_1, \Gamma_2, \theta_1)}{\partial \Gamma_2} = \frac{d}{1 - \beta}. \tag{7.3}
\]

The slope of firm 2’s best response function (defined implicitly by the above equation) equals
\[
\frac{\partial \Gamma_2}{\partial \Delta_1} = \frac{\delta^2 z^J}{\delta \Delta_1 \delta \Gamma_2} > 0.
\]

The Nash equilibrium is stable if the slope of firm 1’s best response function is steeper than that of firm 2 at the equilibrium. This condition can be written as:²⁴
\[
\frac{\delta^2 z^J}{\delta \Delta_1^2} \frac{\delta^2 z^J}{\delta \Gamma_2^2} > \left( \frac{\delta^2 z^J}{\partial \Delta_1 \partial \Gamma_2} \right)^2. \tag{7.4}
\]

To see how the equilibrium depends on \( \theta_1 \), we differentiate both sides of the two first order conditions (7.2) and (7.3), respectively, with respect to \( \theta_1 \), and rearrange terms, to obtain
\[
\theta_1 \frac{\delta^2 z^J}{\partial \Delta_1 \partial \theta_1} + \theta_1 \frac{\delta^2 z^J}{\partial \Delta_1 \partial \Gamma_2 \partial \theta_1} = \frac{\partial z^J}{\partial \Delta_1} - \theta_1 \frac{\delta^2 z^J}{\partial \Delta_1 \partial \theta_1},
\]
and
\[
(1 - \theta_1) \frac{\delta^2 z^J}{\partial \Delta_1 \partial \Gamma_2 \partial \theta_1} + (1 - \theta_1) \frac{\delta^2 z^J}{\partial \Gamma_2^2 \partial \theta_1} = \frac{\partial z^J}{\partial \Gamma_2} - (1 - \theta_1) \frac{\delta^2 z^J}{\partial \Gamma_2 \partial \theta_1}.
\]

Solving for \( \frac{\partial \Delta_1}{\partial \theta_1} \) and \( \frac{\partial \Gamma_2}{\partial \theta_1} \), we get
\[
\frac{\partial \Delta_1}{\partial \theta_1} = \frac{1}{\theta_1(1 - \theta_1)B} \left[ -(1 - \theta_1) \frac{\partial z^J}{\partial \Delta_1} \frac{\partial^2 z^J}{\partial \Gamma_2^2} - \theta_1 \frac{\partial z^J}{\partial \Gamma_2} \frac{\partial^2 z^J}{\partial \Delta_1 \partial \Gamma_2} + G \right]
\]
and
\[
\frac{\partial \Gamma_2}{\partial \theta_1} = \frac{1}{\theta_1(1 - \theta_1)B} \left[ (1 - \theta_1) \frac{\partial z^J}{\partial \Delta_1} \frac{\partial^2 z^J}{\partial \Gamma_2 \partial \Delta_1} + \theta_1 \frac{\partial z^J}{\partial \Gamma_2} \frac{\partial^2 z^J}{\partial \Delta_1^2} + H \right]
\]
where
\[
B = \frac{\delta^2 z^J}{\delta \Delta_1^2} \frac{\delta^2 z^J}{\delta \Gamma_2^2} - \left( \frac{\delta^2 z^J}{\partial \Delta_1 \partial \Gamma_2} \right)^2,
\]
²⁴It can be shown that for the Cobb-Douglas production function the stability condition is satisfied if and only if \( \alpha \beta < (1 - 2\alpha - \beta)(1 - \alpha - 2\beta) \) which holds if \( \alpha \) and \( \beta \) are not too large.
Note that $B > 0$ by the stability condition (7.4).

**Lemma 2:** If $\alpha > \beta$ and $\theta_1 < 1/2$, then the following hold in equilibrium:
(i) $\frac{\partial z^J}{\partial \Delta_1} > \frac{\partial z^J}{\partial \Gamma_2}$;
(ii) $\frac{\partial z^J}{\partial \theta_1} > 0$, $G > 0$, $H > 0$;
(iii) $\frac{\partial z^J}{\partial \theta_1} > 0$, if $3\beta + \alpha < 1$.

**Proof:** By the first order conditions determining $(\Delta_1^*, \Gamma_2^*)$, we get
\[
\frac{\partial z^J}{\partial \Delta_1} = \frac{(1 - \theta_1)(1 - \beta)}{\theta_1(1 - \alpha)},
\]
establishing part (i). To prove (ii), it is easily checked that both $\frac{\partial z^J}{\partial \Delta_1}$ and $\frac{\partial z^J}{\partial \Gamma_2}$ have the same sign as $\frac{\partial z^J}{\partial \theta_1}$. It is straightforward to show that the JV's output, $z^J$, as a function of $\theta_1$, is maximized at $\theta_1 = \alpha/(\alpha + \beta)$, given $\Delta_1$ and $\Gamma_2$. Thus, $\frac{\partial z^J}{\partial \theta_1} > 0$ for $\theta < 1/2$. This proves (ii).

Straightforward algebra shows that
\[
-(1 - \theta_1) \frac{\partial z^J}{\partial \Delta_1} \frac{\partial^2 z^J}{\partial \Gamma_2} > \theta_1 \frac{\partial z^J}{\partial \Gamma_2} \frac{\partial^2 z^J}{\partial \Delta_1 \partial \Gamma_2}
\]
is equivalent to
\[
\frac{1 - \theta_1}{\theta_1} > \frac{\beta}{1 - 2\beta - \alpha} \iff \theta_1 < \frac{1}{1 + \frac{\beta}{1 - 2\beta - \alpha}}.
\]
Since $\alpha + 3\beta < 1$ implies $\frac{\beta}{1 - 2\beta - \alpha} < 1$, the last inequality holds for $\theta_1 < 1/2$. This, together with $G > 0$, implies that $\frac{\partial z^J}{\partial \theta_1} > 0$.

We next prove proposition 2 by showing that when $\alpha > \beta$ the joint payoffs of the two partners $W$ where
\[
W \equiv \pi^{JV} - d\Delta_1^* - d\Gamma_2^* = [\theta_1(1 - \alpha) + (1 - \theta_1)(1 - \beta)] z^J - d\Delta_1^* - d\Gamma_2^*,
\]
increases with $\theta_1$ for all $\theta_1 \leq 1/2$. By the Envelope Theorem, we have

$$\frac{\partial W}{\partial \theta_1} = \theta_1(1 - \alpha) \frac{\partial z^J}{\partial \Gamma_2} \frac{\partial \Gamma_2}{\partial \theta_1} + (1 - \theta_1)(1 - \beta) \frac{\partial z^J}{\partial \Delta_1} \frac{\partial \Delta_1}{\partial \theta_1}$$

$$+ \theta_1(1 - \alpha) \frac{\partial z^J}{\partial \theta_1} + (1 - \theta_1)(1 - \beta) \frac{\partial z^J}{\partial \theta_1}.$$ 

First note that parts (i)-(iii) of the above lemma imply that $\frac{\partial W}{\partial \theta_1} > 0$ if

$$E \equiv \theta_1(1 - \alpha) \frac{\partial \Gamma_2}{\partial \theta_1} + (1 - \theta_1)(1 - \beta) \frac{\partial \Delta_1}{\partial \theta_1} > 0.$$

Using the expressions for $\frac{\partial \Gamma_2}{\partial \theta_1}$ and $\frac{\partial \Delta_1}{\partial \theta_1}$ and derived earlier, we get

$$\theta_1(1 - \theta_1) \cdot B \cdot E = \frac{\text{term 1}}{(1 - \theta_1)(1 - \beta) \Delta_1 + \theta_1(1 - \alpha) \Gamma_2}$$

$$+ \frac{\text{term 2}}{(1 - \theta_1)^2(1 - \beta) \frac{\partial z^J}{\partial \Delta_1} \left( \frac{\partial^2 z^J}{\partial \Gamma_2^2} - \theta_1^2(1 - \alpha) \frac{\partial z^J}{\partial \Gamma_2} \left( \frac{-\partial^2 z^J}{\partial \Delta_1^2} \right) \right)}$$

$$+ \frac{\text{term 3}}{(1 - \theta_1)(1 - \alpha) \frac{\partial z^J}{\partial \Delta_1} - \theta_1(1 - \theta_1)(1 - \beta) \frac{\partial z^J}{\partial \Gamma_2} \frac{-\partial^2 z^J}{\partial \Gamma_2 \partial \Delta_1}}.$$ 

Straightforward derivation shows that

$$R \equiv \frac{\frac{\partial^2 z^J}{\partial \Delta_1^2}}{\frac{\partial^2 z^J}{\partial \Gamma_2^2}} = \frac{\alpha}{\beta} \left( \frac{\Gamma_2}{\Delta_1} \right)^2 \frac{1 - 2\alpha - \beta}{1 - \alpha - 2\beta}.$$ 

Using equation (7.1), we obtain

$$R = \left( \frac{1 - \theta_1}{\theta_1} \right)^2 (1 - \beta)^2 \beta \frac{1 - 2\alpha - \beta}{(1 - \alpha)^2 \alpha 1 - \alpha - 2\beta}.$$ 

Thus,

$$\frac{\theta_1^2(1 - \alpha)}{(1 - \theta_1)^2(1 - \beta)} \cdot R = \frac{(1 - \beta) \beta 1 - 2\alpha - \beta}{(1 - \alpha) \alpha 1 - \alpha - 2\beta}$$

which is less than 1 because $\alpha > \beta$. This implies that term 2 in the RHS of equation (7.7) is positive.
Using the first order condition pertaining to \((\Delta_1, \Gamma_2)\), we can show that term 3 in equation (7.7) equals \((1 - 2\theta_1 d)\) which is nonnegative since \(\theta_1 \leq 1/2\) (assuming \(d \leq 1\)).

Finally, by part \((ii)\) of the above lemma, \(G > 0\) and \(H > 0\) so that term 1 must be positive. Therefore, expression \(E\) must be positive, which establishes that \(\frac{\partial W}{\partial \theta_1} > 0\) for \(\alpha > \beta\) and \(\theta_1 \leq 1/2\). Thus, the optimal share \(\theta^*_1 \geq 1/2\) if \(\alpha > \beta\). The same proof implies that if \(\alpha \leq \beta\), then firm 2’s share of JV must be greater or equal to half, namely, \(\theta^*_1 \leq 1/2\). This proves the proposition. ■

7.3. Proof of Proposition 3

From the two first order conditions (4.5) and (4.6) we have:

\[
\frac{\delta^*}{\gamma^*_2} \left[ \frac{\beta}{\alpha} \right]^{1-\alpha-\beta} \frac{[\Gamma_1^*]^{\alpha+2\beta-1}}{[\Delta_2^*]^{2\alpha+\beta-1}} = \left[ \frac{d}{d_2^*} \right]^{1-\alpha-\beta}
\]

Since \(d_1^* = d_2^*\) and assumption A1 holds, the above equation can be simplified to

\[
\frac{[\Delta_2^*]^{1-2\alpha-\beta}}{[\Gamma_1^*]^{-\alpha-2\beta}} = \left[ \frac{\alpha}{\beta} \right]^{1-\alpha-\beta}
\]  \hspace{1cm} (7.8)

If \(\alpha > \beta\), then the RHS of the above equation is greater than 1. This implies that

\(\Gamma_1^* < [\Delta_2^*]^{1-2\alpha-\beta} < \Delta_2^*\)

by noting \(1 - 2\alpha - \beta < 1 - \alpha - 2\beta\) and \(\Delta_2^* > 1\).

On the other hand, it is easy to see that \(\alpha > \beta\) is also necessary for \(\Gamma_1^* < \Delta_2^*\). In fact, suppose \(\Gamma_1^* < \Delta_2^*\) but \(\alpha \leq \beta\). Then \(1 - 2\alpha - \beta \geq 1 - \alpha - 2\beta\). This implies that the LHS of equation (7.8) is greater than 1 but the RHS is less or equal to 1. This contradiction shows that \(\alpha > \beta\) if \(\Gamma_1^* < \Delta_2^*\). ■

7.4. Proof of Lemma 1

\((i)\) For the symmetric case, denote the common profit function as \(\pi^*\) and the common cost parameter as \(d\). Let

\[
\Gamma^* = \text{Arg} \max \pi^*(\Gamma) - d\Gamma
\]

and

\[
\Gamma' = \text{Arg} \max \frac{1}{2} \pi^*(\Gamma) - d\Gamma
\]

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The critical value \( \Delta^C \) is defined by

\[
\pi^*(\Gamma^*) - d\Gamma^* - \frac{\pi^*(\Delta^C)}{2} = \frac{\pi^*(\Gamma^*)}{2} - d\Gamma^*
\]

(7.9)

Suppose \( \Delta^C \leq \Gamma^* \). Then,

\[
\frac{\pi^*(\Gamma^*)}{2} - d\Gamma^* + \frac{\pi^*(\Delta^C)}{2} \leq \frac{\pi^*(\Gamma^*)}{2} - d\Gamma^* + \frac{\pi^*(\Gamma^*)}{2}
\]

\[
= \pi^*(\Gamma^*) - d\Gamma^* < \pi^*(\Gamma^*) - d\Gamma^*
\]

which contradicts equation (7.9).

Similarly, suppose \( \Gamma^* \leq \Delta^C \). Then,

\[
\pi^*(\Gamma^*) - d\Gamma^* - \frac{\pi^*(\Delta^C)}{2} = \left( \frac{\pi^*(\Gamma^*)}{2} - d\Gamma^* \right) + \left( \frac{\pi^*(\Gamma^*)}{2} - \frac{\pi^*(\Delta^C)}{2} \right)
\]

\[
\leq \frac{\pi^*(\Gamma^*)}{2} - d\Gamma^* < \frac{\pi^*(\Gamma^*)}{2} - d\Gamma^*
\]

which also contradicts equation (7.9).

(ii) Consider the best response function of firm 1. For \( \Delta_2 < \Delta_2^C \), firm 1 prefers buying out firm 2 to being bought out by the definition of \( \Delta_2^C \). Since \( \Delta_2^C < \Gamma_1^* \) by part (i) of the lemma, investing \( \Gamma_1^* \) will indeed guarantee \( \pi_1^*(\Gamma_1^*) > \pi_2^*(\Delta_2) \) by the symmetry assumption and thus enable firm 1 to buy out the JV. Thus, \( B_1(\Delta_2) = \Gamma_1^* \). Similarly, for \( \Delta_2 > \Delta_2^C \) firm 1 prefers to be bought out by investing \( \Gamma_1^* \). Since \( \Delta_2^C > \Gamma_1^* \), investing \( \Gamma_1^* \) leads to \( \pi_1^*(\Gamma_1^*) < \pi_2^*(\Delta_2) \) and hence a buy-out by firm 2. Thus, \( B_1(\Delta_2) = \Gamma_1^* \). If \( \Delta_2 = \Delta_2^C \), firm 1 is indifferent between buying out and bought out, and \( B_1(\Delta_2^C) = \{\Gamma_1^*, \Gamma_1^*\} \). This proves part (ii).

7.5. Proof of Proposition 4

By Lemma 1, \( B_1(\Delta_2^C) = \Gamma_1^* \) (because \( \Delta_2^C \leq \Delta_2^C \)) and \( B_2(\Gamma_1^*) = \Delta_2^C \) (because \( \Delta_2^C \geq \Gamma_1^* \)). Thus, \( (\Gamma_1^*, \Delta_2^C) \) is a Nash equilibrium.

7.6. Proof of Proposition 5

First note that \((0, 0)\) is not a Nash Equilibrium (NE) by assumption A3. Also note that \((X, 0)\) is not a NE either because, given assumption A3, firm 2 wants to deviate to \((X, X)\). Next, \((Y, 0)\) is not a NE because assumption A3 and inequality (5.1) implies that firm 2 wants to move to \((Y, X)\). Furthermore, \((Y, X)\) is not a
NE either because firm 1 wants to move to \((0,X)\) to save the investment cost \(G\). Thus, by symmetry, only \((X,X)\) and \((Y,Y)\) are equilibrium candidates.

First consider \((X,X)\): Given that firm 2 plays \(X\), firm 1 prefers \(X\) to \(Y\) since assumption A3 implies that

\[
\pi_1^*(X,X) - F > \pi_1^*(\delta_1,X) > \pi_1^*(\delta_1,X) - G
\]

By assumption A3, firm 2 also prefers \(X\) to \(0\). Thus \((X,X)\) is a NE.

Next consider \((Y,Y)\) as an equilibrium candidate. Under \((Y,Y)\) each firm's payoff is \(\frac{1}{2}\pi_1^*(\delta_1,Y) - G\). Given that firm 1 plays \(Y\), firm 2 prefers \(X\) to \(0\) by assumption A3 and inequality (5.1). Thus, firm 2's best response when firm 1 plays \(Y\) is also \(Y\) if and only if

\[
\frac{1}{2}\pi_1^*(\delta_1,Y) - G \geq \pi_2^*(\delta_1,X) - F.
\]

This completes the proof.

7.7. Proof of Proposition 6

As proved in the proof of proposition 5, strategy pairs \((0,0)\), \((X,0)\) cannot be a Nash equilibrium. From assumption A3, it is obvious that \((X,X)\) is a Nash equilibrium if and only if the inequality stated in the proposition holds.

Now consider the case this inequality does not hold. In this case, firm 1's best response to firm 2's playing \(0\) or playing \(X\) are both \(Y\) (by noting assumption A3 and inequality (5.4)). This implies that, the Nash equilibrium candidates of the game in this case can only be \((Y,0)\), \((Y,X)\), and \((Y,Y)\). It is easy to see that the candidate that yields the highest payoff (net of investment costs) for firm 2 is the Nash equilibrium.

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