Vertical governance change for product differentiation under decreasing component costs

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Abstract

We study the real option theoretic solution to vertical governance change in Bertrand duopoly competition under mean-reverting commodity component costs. We find that, even if component costs are low and decreasing, incurring high in-house component costs is warranted to decrease product substitutability and thereby soften price competition. As the competitor enjoys softened competition but does not bear higher component costs, firms may wait for competitors to move or the industry may feature a mix in governance forms. In case both firms are integrated, vertical specialization by one increases substitutability for both, such that the competitor is likely to follow.

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1. Introduction

Why and when do firms change their governance over commodity component production capabilities? It is argued that the governance form depends on the component cost differential (Grossman and Helpman, 2005; Williamson, 1985), on the competitive advantage due to owning certain capabilities (Wernerfelt, 1984; Barney, 1991), or rather the interplay of costs and capability ownership (Jacobides and Winter, 2005). From a pure cost perspective, firm divest in-house component production to switch to an external supplier as soon as the competitive market prices for input components drop below in-house costs. However, by using an undifferentiated component design, products are more substitutable and thereby there is fiercer head-on price competition. Having control over upstream production capabilities, a firm can attune assembly and component technology, thus horizontally differentiate, and thereby soften price competition (Argyres and Bigelow, 2006). The claim is that firms seek vertical integration whenever the total additional returns of horizontal differentiation outweigh additional costs. In this paper, we study the vertical governance choice as this *trade-off between horizontal product differentiation and total costs*.

We model this cost-capability trade-off in governance using a heterogeneous Bertrand duopoly model. We assume that there are no structural discontinuities to the industry pending that complicate the governance decision. We model the development of the component cost as a mean-reverting Ornstein-Uhlenbeck Brownian motion and use the real options theory of investment (Dixit and Pindyck, 1994; Huisman, 2001) to determine the governance decisions to take.

We find that firms should not outsource if the marginal cost advantage thereof does not compensate the loss of profit due to the increase in substitutability. Conversely, if component costs are low and possibly even decreasing, incurring high in-house component production costs is warranted if this decreases substitutability and thereby lowers price competition enough. An industry may hence feature a mix in governance forms. As vertical integration by one firm softens price competition for all, while costs are born only by the vertically integrated firm, firms are engaged in an attrition game if there are no prior defined leader/ follower roles. Moreover, whenever one firm starts to outsource and thereby increases the substitutability for both, the competitor often follows to enjoy lower component cost.

2. Literature

Classical theoretical answers to whether 'to make or to buy' revolve around the transaction costs of setting up and running the supply relationship (Williamson, 1985) and the total production costs (Walker and Weber, 1984, 1987). Upon deciding to 'buy', firms need to invest in specific assets and make transaction costs to buy components on the upstream market at going market rates. Upon deciding to 'make', firms need to invest in production equipment to produce components in-house. Due to scale and scope economies and efficiency-increasing competitive pressures, component market prices are generally lower than the costs of producing components in-house. From a pure cost perspective, whether to make or buy depends on the component cost differential (cf. Grossman and Helpman, 2005; Williamson, 1985). As such, it is commendable to outsource whenever the total marginal costs of outsourcing of component production are below marginal costs of in-house production. With a competitive upstream sector, there is no clear reason from a cost perspective to pursue vertical integration if the in-house production costs are forever higher than the market price.

However, while the transaction and production cost economic perspective focuses on the role of the cost structure, the capability/resource-based view focuses on the competitive advantage of owning certain capabilities (Wernerfelt, 1984; Barney, 1991). In this paper, we take in-house production to allow an integrated solution which fine-tunes component and assembly and to thereby allow differentiation of one's product from competitors' products. Differentiation (or: lowering substitutability) softens price competition at the downstream market.

As costs and capabilities are complementary (Jacobides and Winter, 2005), we study the *trade-off* between substitutability (the reverse of the degree of horizontal differentiation) and total costs. Given this trade-off we study why and when a vertically specialized firm decides to integrate the production of a certain input component and why and when a vertically integrated firm decides to hive off component production capabilities and rather purchase input components from a specialized component supplier.

In the dyadic supply chain coordination literature, authors often either investigate a manufacturer and retailer, a component producer and final product assembler chain or abstract from the actual roles. In the literature dealing with coordination strategies when various supply chains *compete*, the simplest form is to take a duopoly in both the upstream and downstream sector.

In case of a manufacturer-retailer chain, the manufacturer sets the wholesale price (strategically) and the retailer the final market price. Under high substitutability, distribution through independent outlets (outsourcing) is preferred, while under low substitutability, distribution through owned company stores (vertical integration) is preferred, that is, with chain profits as criterion (McGuire and Staelin, 1983). This result is confirmed by Wu et al. (2009, see p.554). They extend the analysis to a repeated game and find that, for high substitutability (and sufficient discounting), there are several (non-mixed) strategy equilibria. However, even a single deviation of this strategy by one of the chains immediate triggers all chains to vertically integrate, after which the industry stays in this state indefinitely. This extends the finding that Nash equilibria in one-shot games do not contain mixes of vertically integrated and vertically disintegrated supply chains (McGuire and Staelin, 1983; Grossman and Helpman, 2005). However, Cachon and Harker (2002) find that in duopoly under scale economies, price competition becomes fierce, and that outsourcing softens price competition. Under those conditions of scale economies, firms have no incentive to integrate (again), once both firms are outsourcing.

The bilateral duopoly model has been extended to study outsourcing to a common component supplier to reap upstream scale economies (Ni et al., 2009; Shy and Stenbacka, 2003), outsourcing component production to a vertically integrated competitor (Arya et al., 2008) and even pursuing backward integration for the anticompetitive exclusion of access to a certain component (Matsubayashi, 2007).

An interesting extension investigated as a limit case, is to make the upstream or the downstream sector perfectly competitive. In case of a competitive upstream sector, downstream firms will outsource to the same supplier to enjoy cost scale economies (Shy and Stenbacka, 2003), as even is the case in a duopoly already. Component suppliers will not enter the upstream sector if their cost structure is not more favorable than that of incumbents (Arya et al., 2008). Since we focus on product differentiation, we study a competitive upstream sector to focus on strategic interaction through product differentiation (substitutability) and rule out strategic interaction effects through changes in the upstream sector.

3. Model

In Subsection 3.1, we specify the Bertrand duopoly of a sector consisting of two firms i and j ($i \neq j$). At every point in time, both firms pick the Bertrand optimal price, so firms instantaneously adjust the product price whenever the component cost or a governance form changes. In Subsection 3.2, we specify how the component costs develop and, in Subsection 3.3, we derive the firm value subject to this cost development and each of the firms' governance choice. In Subsection 3.4, we postulate our assumptions on the marginal component costs and fixed investment costs for governance change. In Subsection 3.5, we specify our choices for the substitutability levels under the various combinations of governance forms. Finally, in Subsection 3.6, we explain the timing game and the firms' roles therein.

3.1. Bertrand duopoly with heterogeneous products

In the Bertrand price competition model, we adopt the linear inverse market demand function used in heterogeneous product studies (cf. Arya et al., 2008; Ni et al., 2009; Chevalier-Roignant and Trigeorgis, 2011; Wu et al., 2009):

$$p_i = a - b(q_i + sq_j) \tag{1}$$

Hereby, p_i is the price of the product produced by firm i, q_i is the number of products that firm i produces (and sells, by assumption), and c_i is the total marginal production cost for firm i of one unit of product. Rewriting gives:

$$q_i = \frac{a - p_i}{b} - sq_j = \begin{cases} \frac{a(1-s)+sp_j-p_i}{b(1-s^2)} & s \in [0,1) \\ \frac{a-p}{2b} & s = 1 \text{ (and } p_i = p_j = p) \end{cases}$$

with $0 \leq s \leq 1$ the substitutability, and a and b parameters (with different interpretations that we discuss below) characterizing demand.
The instantaneous profit π_i of firm i is:

$$\pi_i = (p_i - c_i)q_i$$

The first order condition for a Bertrand optimal price is:

$$\frac{\partial \pi_i}{\partial p_i} = q_i(p_i) + (p_i - c_i)\frac{\partial q_i(p_i)}{\partial p_i} = \frac{a + c_i - 2p_i}{b} - s\left(q_j + (p_i - c_i)\frac{\partial q_j}{\partial p_i}\right) = 0$$

Under the assumption of simultaneous price-setting, we take $\partial q_j / \partial p_i = 0$, such that:

$$p_i^* = \frac{a(s-2) + c_i(s^2-2) - sc_j}{s^2-4} \qquad \text{and} \qquad q_i^* = \frac{a(s-2) + 2c_i - sc_j}{b(s^2-4)}$$

with profit:

$$\pi_i^* = b\left(q_i^*\right)^2 \tag{2}$$

3.2. Component cost development

The Bertrand model yields the price-based equilibrium in a one-shot game. In our case, the component cost develops over time and firms may decide to change the vertical governance over the upstream component production at some point in time. We hereby assume that component costs are *strategically* stable with regard to the governance decisions, i.e. there is no interaction of the governance decision of one firm on the *component* price the competitor pays[2]. We do not consider component price setting or bargaining, or upstream price competition, but have the price pressing effect reflect in downward trend in the component cost. In further analysis, the c_i and c_j in the Bertrand model will reflect the total marginal *product* cost, including the marginal component cost, which changes with the governance form. Furthermore, we assume that upstream cost development is uncorrelated with the downstream market size.

These costs include in-house assembly, the component market price and transactions costs in case of purchase on the upstream market, and costs for production, assembly and governance in case of in-house manufacturing. We refer to the first set of costs as 'component costs' for brevity. We assume that the component price is the developing part of the costs and generally drops due to scale advantages and price competition upstream. We assume that the component costs cannot go below a certain bottom-level c_0. To simplify further analysis, we study the relative cost difference and have the upstream component costs develop but fix the in-house production costs to c^I. In explaining the results, we assume that the only variable in the component

[2]Read Moorthy (1988) for a thoughtful study of the consequences of various types of strategic interaction on possible Nash equilibria. Read Rossini (2008) for interesting results whenever there actually is such strategic interaction through upstream component prices.

market costs is the market price.
We take the costs of using a standard component purchased at the upstream market to develop as the following variant to the mean-reverting Ornstein-Uhlenbeck process (where $c_0 < c(0)$)

$$\mathrm{d}c = (c_0 - c)\gamma \, \mathrm{d}t + (c - c_0)\sigma \, \mathrm{d}z \stackrel{d}{=} (c_0 - c)(\gamma \, \mathrm{d}t + \sigma \, \mathrm{d}z) \tag{3}$$

For $\gamma > 0$, the costs will over time converge to c_0 (from above for $c(0) > c_0$), and only for large σ temporarily go below c_0. We assume σ to be low as reductions in market prices are due to deliberately pursued scale advantages and price competition.

3.3. Value of the firm

The value of the firm changes subject to the development of components costs and (changes of) the governance forms. In real options theory, options have a certain value as long as they have not yet been exercised. In our case, the decision whether or not to exercise the option to change the governance form is based on the component costs and substitutability. The value of the option depends a.o. on the uncertainty of cost development and fixed investment costs. The option theoretic decision solutions take the form of *thresholds* on the value of that independent variable, e.g. if the market price of components drops below a specific threshold level c', then outsource. On either side of this threshold, the value of the firm is expressed as the following generic Bellman equation:

$$W(c) = \pi \, \mathrm{d}t + \frac{1}{1 + r \, \mathrm{d}t} \mathbb{E} W(c + \mathrm{d}c) \tag{4}$$

The instantaneous returns π (see equation 2) depend on the governance form and, consequently, the value function develops differently. The general solution for W is (see Appendix A):

$$W = \Pi + A_1 (c - c_0)^{\beta_1} + A_2 (c - c_0)^{\beta_2} \tag{5}$$

with the roots of the fundamental quadratic equation:

$$\beta_{1,2} = \frac{2\gamma + \sigma^2 \pm \sqrt{8r\sigma^2 + (2\gamma + \sigma^2)^2}}{2\sigma^2}$$

In the next section, we provide the generic expression for the firm value for either side of a decision threshold and derive exact value functions and decision threshold curves given governance change scenarios.
We introduce superscripts nm with $n, m \in \{M, I\}$ on W, Π and both scaling constants A_1 and A_2 to reflect the four different cases (both integrated, both outsourcing or one of the two mixed forms). The function Π^{nm} is the firm value in case both firms stick to their current governance form indefinitely:

$$\Pi^{nm} = Y_0^{nm} + Y_1^{nm}(c - c_0) + Y_2^{nm}(c - c_0)^2 \tag{6}$$

As the instantaneous payoff function π changes with the governance forms of the two firms, there are considerable differences in the coefficients Y_k^{nm} across different solutions. As we do not need the actual expression for these coefficients in further analysis, we provide the definitions of these Y_k^{nm} in Appendix C.

3.4. Cost structure

We regard the vertical governance decision as an investment decision based on lump-sum investment costs, the value of options and future payoff streams. We assume that outsourcing yields a marginal cost advantage (cf. Grossman and Helpman, 2005; Williamson, 1985). The supplier enjoys economies of specialization, increases the efficiency of production over time, and enjoys scale economies of serving multiple parties. In contrast, the downstream final product assembler suffers a relatively low production scale, non-specialized and thereby inefficient production, and furthermore higher marginal governance costs due to scope diseconomies. As costs for assembly, packaging, et cetera remain the same even when acquiring the component, we assume that the total costs of producing one unit of product completely in-house are higher than the total costs when assembling with a component purchased from an independent component supplier.
With regard to the investment costs incurred to change the governance form, we assume a competitive upstream market. Search costs and costs for contractual safeguarding against the moral hazard of suppliers are low or even absent. The firm does not need a '*system to design and monitor efficient contracts for delivery of the input*' as in Alvarez and Stenbacka (2007) and Grossman and Helpman (2005). Moreover, competition in the commodity component sector causes erosion of the upstream margin and rules out double marginalization (see e.g. Tirole, 1988). As such, the firm does not vertically integrate ('a costly irreversible investment in a production facility') to

rid oneself of the *profit maximizing markup* as in Shy and Stenbacka (2003). Rather, due to the competitive upstream sector, there presumably is a market for the component production equipment. We assume that upon outsourcing, the yet owned component production equipment can be sold at the upstream market at its day-value $C^M > 0$. On the other hand, integrating production requires purchasing of the equipment, plus transfer, training and learning costs, summing up to costs $C^I < 0$. We assume that $C^I < -C^M \ll 0$ to preclude perpetual in- and outsourcing as a way to earn money. The sign of the monetary values C^I and C^M reflects whether the focal firm receives or pays the money and is picked to generalize formal analysis later.

3.5. Substitutability

The governance forms of both firms reflect in the substitutability s of their products, thereby the prices they are able to charge (see equation 1) and finally the profit they make. In our duopoly, there are three governance form mixes possible: both firms are integrated, both are outsourcing or mixed. We assume that when both product producers purchase their components from market parties (the M, M scenario), their final products are undifferentiated, so substitutability is perfect $s^{MM} = 1$. As soon as either of the firms is vertically integrated, assembly and component are better attuned, such that the final product is different from the competing product with the standard component. Both supply chains then enjoy the lower substitutability $s^{IM} = s^{MI} < s^{MM}$. When both firms are vertically integrated, they can both horizontally differentiate and thereby realize an even lower substitutability: $0 \leq s^{II} < s^{IM} = s^{MI} < s^{MM} = 1$.
As firms decide on the vertical governance form on the basis of component cost factors *and* substitutability, there is strategic interaction of the governance form of one firm on the governance form of the other firm through the substitutability of the products.

3.6. Timing game

In deciding on their governance form, firms take into account the *development* of the component cost c. If firms are homogeneous and they move (i.e. change their governance form) at the same time, they all receive the same payoff $M(c)$. In case that firms collude and move jointly at the *optimal* collusion cost level $c = c^J$, each firm receives payoff $J(c^J)$ $(= M(c^J))$.
Since we study a duopoly industry, there is one leader and one follower. The firm that moves first, in time (say, when $c = c^L$), is called the leader and

receives payoff $L(c^L)$. The other firm that moves (in response to that), say, when $c = c^F$, is called the follower and receives payoff $F(c^F)$.

In case there is a value c' of the independent variable for which $L(c') > F(c')$, the timing game is called a preemption game. In a preemption game, there is an incentive to be the leader at least for some values of c. In the region in which $L > F$, there is some level c^* at which the leader would maximize the total discounted future value. As competitors will also move at that level c^*, and all firms will thus only get $M(c^*) < L(c^*)$, they will preempt the competitors by moving sooner, i.e. already when $c = c^* \pm \varepsilon$. As competitors also do this, the focal firm moves even earlier, etc. This continues until a further ε shift would even lower the leader value below the follower value. This point is/ these points are called the preemption point(s). In a preemption game, the leader moves at such a preemption point.
Whenever *for all* values c, we have that $L(c) < F(c)$, the timing game is called an attrition game. In an attrition game, none of the firms wants to be the leader and all firms postpone changing their governance form.
In a preemption game, there may be regions that all firms postpone governance change, but there also are regions in which firms want to be the leader (and thus seek to preempt the other firms). Note that a firm can always adopt the strategy to immediately move when another firm does so. In case there are only two firms, the follower thus always receives a payoff of at least $M(c^L)$.

We distinguish two ways to assign who will be the leader and who will be the follower: the 'exogenous' and the 'endogenous' assignment. In case of exogenous role assignment, the leader changes its governance form at the cost level which is optimal for the leader, and the follower changes its governance form after the leader and at the optimal cost level *given that it is a follower*. There is no (preemption or attrition) timing game as the firms involved simply move at the moment it is optimal according to their fixed, given strategies.
In case of endogenous assignment, we assume that firms can instantaneously change their governance form and have no prior information other than the actual governance form of the other firms. Note that under these conditions, if firms are involved in a preemption game, all firms seek to change governance at the same time (say, when $c = c^P$). From the literature of timing games (Fudenberg and Tirole, 1985; Thijssen et al., 2012) we know that each firm becomes leader with 50% probability. Note that if the follower would also

immediately change its governance form, both firms would receive the same payoff $M(c^P)$, which generally differs from $L(c^P)$ and $F(c^P)$. In equilibrium such an coordination error, i.e. both firms invest at the same time, has 0% probability of occurring.
In this paper, we discuss the governance change (and the structure of the industry over time) both for exogenous as well as endogenous role assignment.

4. Results

We assume that both firms have the same state $n \in \{M, I\}$, initially, and that the leader changes its governance form from state n to $m \in \{M, I\}$ $(m \neq n)$. The follower solves the 'optimal stopping problem' of also switching to governance form m. We derive governance decision both under the endogenous and exogenous roles. In case of the exogenous role assignment, we first solve the follower's stopping problem, and then, given the follower's strategy, solve the leader's stopping problem. We assume that a reversal of the governance decision is unlikely on the short term, but that the competitor can respond timely.
In our illustrations, we take parameters as given in Appendix B. We use the shorthand notation Δ_k^{nm} for $Y_k^{nm} - Y_k^{mm}$.

4.1. Follower optimal stopping solution

In the follower's continuation region, when the leader has already changed governance form to m, the value F^{nm} of the follower is:

$$F^{nm}(c) = \Pi^{nm}(c) + D_1(c - c_0)^{\beta_1} + D_2(c - c_0)^{\beta_2}$$

In case we investigate the I, M to M, M scenario, F^{IM} is defined on (c^{MM}, ∞). If $c \to \infty$, the option to outsource goes to zero, such that $D_1 = 0$. In case we investigate the M, I to I, I scenario, F^{MI} is defined on $[c_0, c^{II})$. If $c \downarrow c_0$, the option to integrate goes to zero, such that $D_2 = 0$. As either the first or the second option term is omitted, we use D and β for the general case.
In the follower's stopping region, both firms have changed their governance form to m, and the value F^{mm} of the follower is:

$$F^{mm}(c) = \Pi^{mm}(c) + A_1(c - c_0)^{\beta_1} + A_2(c - c_0)^{\beta_2} - C^m$$

As there are no options left, both $A_1 = A_2 = 0$. Note that if $m = I$, $C^m = C^I$ and if $m = M$, $C^m = -C^M$.

Following Huisman (2001), we assume that there exists a threshold c^{mm} for which it is optimal to wait if c in the continuation region (depending on the scenario we study, this is $c > c^{mm}$ or $c < c^{mm}$) and optimal to change the governance form once c gets into the stopping region. The value of the follower then is:

$$F(c) = \begin{cases} D(c - c_0)^{\beta} + \Pi^{nm}(c) & \text{if } c \text{ in the continuation region} \\ \Pi^{mm}(c) - C^m & \text{if } c \text{ in the stopping region} \end{cases} \tag{7}$$

The value matching and smooth pasting conditions (see Dixit and Pindyck (1994)) are used to find the threshold curve c^{mm} and option scale parameter D. We thus obtain:

$$c^F_{1,2} = c_0 - \frac{\Delta_1^{nm}(-1+\beta) \pm P^F}{2\Delta_2^{nm}(-2+\beta)} \tag{8}$$

with

$$P^F = \sqrt{(\Delta_1^{nm})^2(-1+\beta)^2 - 4(C^m + \Delta_0^{nm})\Delta_2^{nm}(-2+\beta)\beta}$$

with option scale parameter:

$$D_i = (c^F_i - c_0)^{-\beta}(\Pi^{mm}(c^F_i) - \Pi^{nm}(c^F_i) - C^m)$$

Where index i is used to associate the option scale parameter D with the candidate threshold solution c^F_i. In case $n = M$ (and hence $m = I$), then $\beta = \beta_1$, else $\beta = \beta_2$.

4.2. Leader optimal stopping solution

Now that we know when the follower will change its governance form from n to m *given* the leader has already done so, we can determine when the leader will change its governance form anticipating the response of the follower.

In the stopping region for the leader, the value of the leader for the mn mixed case (but including the costs of governance change) is:

$$L^{mn}(c) = \Pi^{mn}(c) + B_1(c - c_0)^{\beta_1} + B_2(c - c_0)^{\beta_2} - C^m$$

Although the leader does not have any options left, the value parameters B_1 and B_2 are not equal to zero. The follower still has an option to change

governance form and the value of this option changes over time. Due to interaction also the value of the leader is affected.
The first boundary condition on L states that at c^F, when the follower changes its governance from n to m, the firm value of leader and follower are equal:

$$L^{mn}(c^F) = F^{mm}(c^F) \tag{9}$$

The second boundary condition on L derives from limit cases on c.
In the II-to-MM case ($m = M$), L is defined on $[c^{mm}, \infty)$ and the option to outsource drops in value if the upstream market price for the component increases. As $\lim_{c\to\infty} L(c) = 0$, $B_1 = 0$. In the MM-to-II case ($m = I$), L is defined on $[c_0, c^{nn})$ and the option to integrate drops in value if the upstream market price for the component decreases. As $\lim_{c\downarrow c_0} L(c) = 0$, $B_2 = 0$.
We solve the general case using B and β to refer to the appropriate parameters. Due to the first condition:

$$B = (c^F - c_0)^{-\beta}(\Pi^{mm}(c^F) - \Pi^{mn}(c^F))$$

The value of the leader L in his stopping region depends on c^F.
In the continuation region for the leader, when both firms still have state n, the leader firm value L^{nn} is:

$$L^{nn}(c) = \Pi^{nn}(c) + A_1(c - c_0)^{\beta_1} + A_2(c - c_0)^{\beta_2}$$

In the II-to-MM case ($m = M$), L is defined on (c^{mn}, ∞) and the option value for outsourcing goes to zero with $c \to \infty$, so $A_1 = 0$. In the MM-to-II case ($m = I$), L is defined on $[c_0, c^{mn})$ and option value for outsourcing goes to zero with $c \downarrow c_0$, so $A_2 = 0$. The value of the leader is:

$$L(c) = \begin{cases} A(c - c_0)^{\beta} + \Pi^{mm}(c) & \text{if } c \text{ in the continuation region} \\ \Pi^{mn}(c) - C^m & \text{if } c \text{ in the stopping region} \end{cases} \tag{10}$$

Using the value matching and smooth pasting conditions, we find candidate solutions for the leader:

$$c^L_{1,2} = c_0 - \frac{\Delta_1^{mn}(-1+\beta) \pm P^L}{2\Delta_2^{mn}(-2+\beta)} \tag{11}$$

with

$$P^L = \sqrt{(\Delta_1^{mn})^2(-1+\beta)^2 - 4(\Delta_0^{mn} - C^m)\Delta_2^{mn}(-2+\beta)\beta}$$

and associated option value scale:

$$A_i = B + (c_i^L - c_0)^{-\beta}(\Pi^{mn}(c_i^L) - \Pi^{nn}(c_i^L) - C^m)$$

To prevent confusion in the notation: the index $i = 1, 2$ in A_i is to associate the option value parameter with its threshold candidate c_i^L.

4.3. Joint stopping, optimal solution and immediate following

In Subsection 3.6, we discussed two alternatives for the regular leader-follower strategy. Firstly, the follower may have the strategy to *immediately* follow the leader such that they both have value $M(c)$. Secondly, the two firms may collude to change the governance at the point in time when it is optimal to jointly move, in which case they have value $J(c, c^J)$.

The value for both firms $M(b)$ when the follower is following the leader immediately is derived from the leader value with $c^F = c$:

$$M(c) = \Pi^{mm}(c) - C^m$$

This $M(c)$ is the value that the follower will always be able to generate.

Prior to changing the governance form, both focal firms have state nn and the firm value is J^{nn} , while upon a joint switching of governance form at c^J state mm, the firm value is J^{mm}:

$$\begin{aligned} J^{nn}(c) &= \Pi^{nn}(c) + A(c - c_0)^\beta \\ J^{mm}(c) &= \Pi^{mm}(c) - C^m \end{aligned}$$

Using value matching and smooth pasting, we get the joint candidate solutions:

$$c_{1,2}^J = c_0 - \frac{\Delta_1^m(-1+\beta) \pm P^J}{2\Delta_2^m(-2+\beta)} \tag{12}$$

$$A_{1,2}^J = (\Delta_0^m + \Delta_1^m(c - c_0) + \Delta_2^m(c - c_0)^2 - C^m)(c - c_0)^\beta \tag{13}$$

Specifications for particular m and n can be found in Appendix D.

The firm value function in case of joint switching is:

$$J(c, c^J) = \begin{cases} \Pi^{nn}(c) + (\Pi^{mm} - \Pi^{nn} - C^m)\left(\frac{c - c_0}{c^J - c_0}\right)^\beta & \text{if } c \text{ in contin. region} \\ \Pi^{mm}(c) - C^m & \text{if } c \text{ in stopping region} \end{cases}$$

For the $II \to MM$ case, $n = I$ and $m = M$, the continuation region is $c \in (c^{JIM}, \infty]$ and $\beta = \beta_2$. For the $MM \to II$ case, $n = M$ and $m = I$, the continuation region is $c \in (c_0, c^{JMI}]$ and $\beta = \beta_1$.

4.4. Structure of solutions

We plot the firm value functions L, F, M and J in Figure 1 for different values of substitutability $s = s^{IM} = s^{MI}$. The left column concerns a fully integrated industry in which firms consider outsourcing, while the right column concerns a fully vertically specialized industry in which the firms consider backward integrating.

In case of endogenous firm roles, the preemption threshold is the cost level $c^X > c_0$ in the leader continuation region at which $L(c^X) = F(c^X)$. Given the non-linearity of both value functions, we determine c^X numerically.
We first study the $II \rightarrow MI \rightarrow MM$ case (left column). In the region between the preemption cost level c^X and the cost level c^F, the leader value exceeds the follower value, such that firms are involved a preemption game. Suppose that $c > c^X$ initially, then the mean reversion has c gradually decrease towards c_0. In case of endogenous assignment of the leader and follower role (see Subsection 3.6), we see that as soon as c is less than or equal to cost level c^X, the leader outsources preemptively. As soon as c is less than or equal to cost level c^F, the follower outsources as well. In case of exogenous assignment of the leader and follower roles (see Subsection 3.6), the leader will change governance form when the cost level equals or drops below c^L. The cost level c^F is the point at which it is optimal for the follower to change governance, but the follower can only change its governance form when the leader has already done so. This c^L is decreasing in $s = s^{MI}$ as a bigger increase in substitutability (from s^{II} to s^{MI}) requires lower cost to compensate for this increase in substitutability. The c^F increases in $s = s^{IM} = s^{MI}$ as the smaller the increase in substitutability (from s^{IM} to $s^{MM} = 1$), the smaller the cost advantages may be to warrant outsourcing.
The M, J curves (which are the same) plot the value in case the follower decides to *immediately* follow the leader, i.e. they both outsource at the same time. We see that the M, J curves are below F and L, such that the follower will not immediately follow the leader, nor will the follower and leader collusively outsource at the same point.[3]

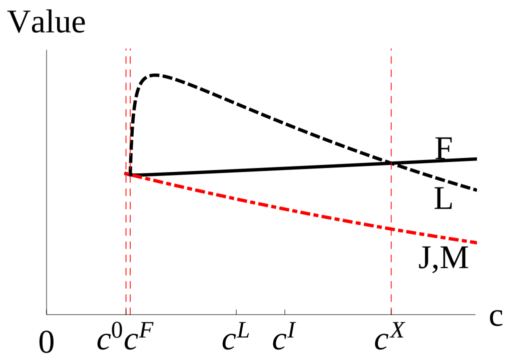
The structure of the outsourcing strategies is plotted in Figure 2. We use the results in (8) and (11) with $n = I$, $m = M$ and $C^m = -C^M$. The

[3]The value of the firms will only end up equal to the M, J curves in case of a coordination error. That is both firms outsource at the same time whereas it is only beneficial for one firm to do so. In equilibrium this happens with 0% probability (Thijssen et al., 2012).

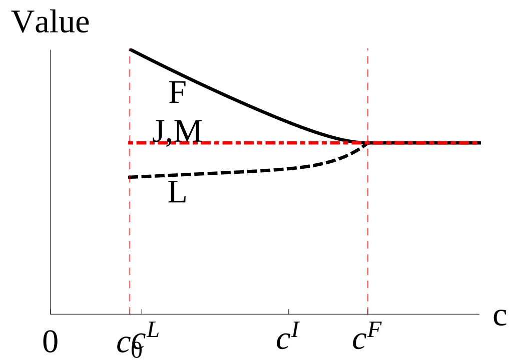
relevant solutions are listed in Appendix D.

Suppose the industry starts out in region Φ in which components are expensive and none of the firms outsources. Due to the mean-reverting process, the costs drop over time and sooner or later crosses the c^X curve. In case of the endogenous assignment of firm roles, one firm will become the leader and outsource, while the follower will remain integrated. After this, the costs have to drop below c^F before the follower will outsource. So, in this case, both firms are integrated in region Φ, only the leader is outsourcing between c^X and c^F (in regions Υ_1, Ω_1 and Ω_2), and both firms are outsourcing if the costs are below c^F and below c^L (in regions Ψ_1 and Ψ_2).
However, in case of exogenous assignment of firm roles, the leader executes the optimal outsourcing strategy and will hence only outsource when the costs drop at or below cost level c^L, while the follower will outsource when the costs drop below c^F and c^L. Whether or not the follower immediately follows the leader or not is explained as follows. If the substitutability $s = s^{IM} = s^{MI}$ exceeds s^M (region Ψ_2), the difference in substitutability $s^{MM} - s^{IM}$ is not high enough to longer justify incurring the higher marginal costs c^I and the follower also immediately outsources. If $s^{IM} < s^X$ (region Ω_1), the cost benefit $c^I - c$ is not enough to justify giving up the low substitutability (despite the higher costs) and the follower remains integrated. If $s^X < s = s^{MI} = s^{IM} < s^M$, the follower will only later outsource component production.

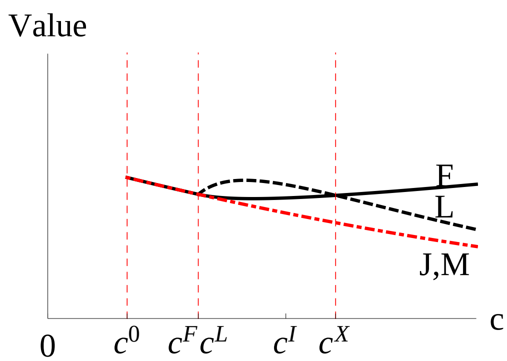
From the firm value functions L, F, M and J for the $MM \to IM \to II$ case plotted in Figure 1, we see that $L < F$ on the region (c_0, c^F). In case of endogenous role assignment, firms -under increasing costs- postpone integration until c exceeds $c^X = c^F$, i.e. integration is an attrition game. At that time, the leader and follower integrate at the same time. The relevant switching curve solutions are listed in Appendix D. The structure of the governance strategies is plotted in Figure 3. Suppose the component costs start out in region Υ_1 or Υ_2, i.e. both firms prefer remaining disintegrated. Given the mean reversion in the costs, only *temporary* excursions to higher component cost levels can trigger integration. For this to be likely, the trend parameter γ must be low relative to σ.
Suppose $s = s^{MI} < s^M$ and the component costs are in region Ω. If firms have a role assigned exogenously, the leader will integrate first. The lower substitutability becomes upon integration (i.e. the bigger the drop from s^{MM} to s^{IM}), the lower the c level at which the exogenous leader would integrate. The lower substitutability outweighs the higher marginal component costs



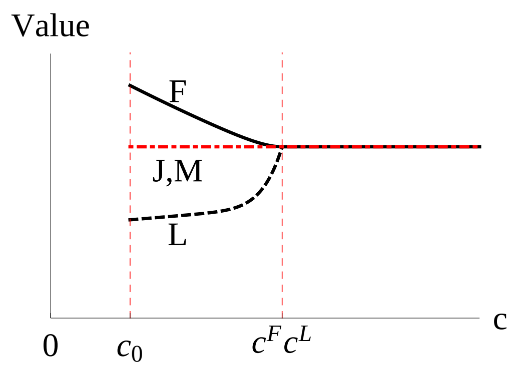
(a) II to MM, $s^{MI} = s^{IM} = 0.25$



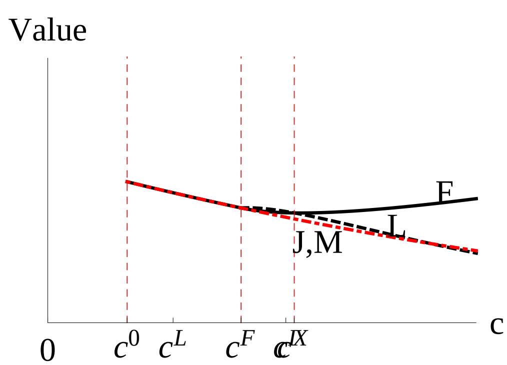
(b) MM to II, $s^{MI} = s^{IM} = 0.25$



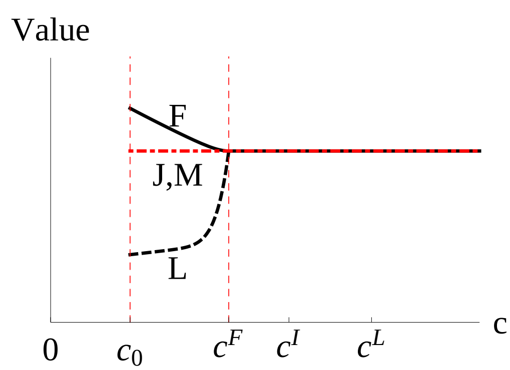
(c) II to MM, $s^{MI} = s^{IM} = 0.50$



(d) MM to II, $s^{MI} = s^{IM} = 0.50$

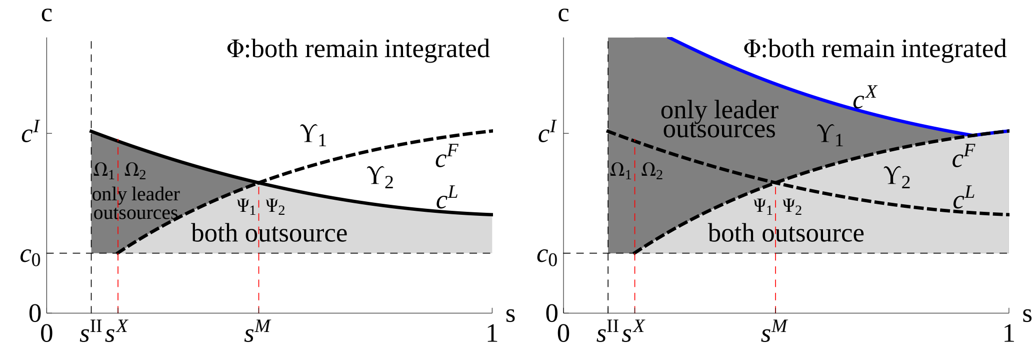


(e) II to MM, $s^{MI} = s^{IM} = 0.75$



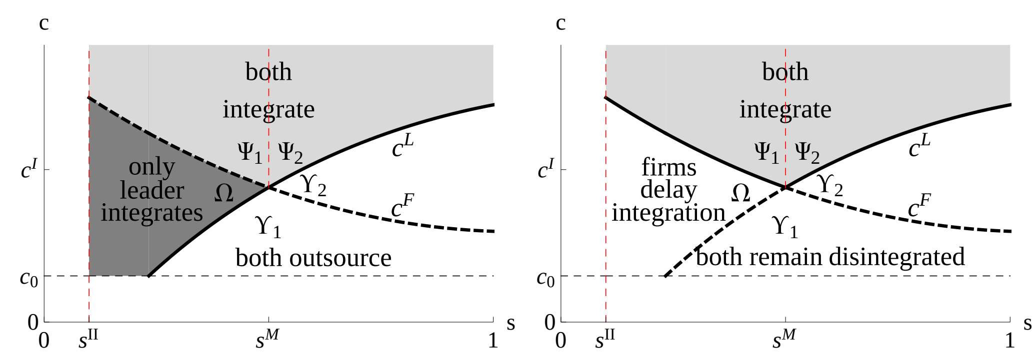
(f) MM to II, $s^{MI} = s^{IM} = 0.75$

Figure 1: Firm values of the leader L, follower F, joint movers M and J under the $II \to MM$ scenario (left column) and the $MM \to II$ scenario (right column) with developing component costs c for different levels of substitutability $s^{MI} = s^{IM}$.



(a) II to MM, exogenous (b) II to MM, endogenous

Figure 2: Switching curves and region specifications for vertical governance decisions when both firms are vertically integrated initially, both for exogenous and endogenous firm roles.



(a) MM to II, exogenous (b) MM to II, endogenous

Figure 3: Switching curves and region specifications for vertical governance decisions when both firms are outsourcing initially, both for exogenous and endogenous firm roles. In case of endogenous assignment, no firm wants to be leader and hence there is attrition. In case of exogenous assignment, the leader postpones integration.

sooner. Similarly, the smaller the further advantage of integration by the follower (the smaller the drop from $s^{MI} = s^{IM}$ to s^{II}), the higher the cost level must be for the follower to pursue integration.
If firms are assigned their roles endogenously, the leader will *postpone* integration when in region Ω. Firms rather are not the leader as he incurs the higher costs c^I (the follower does still pay the lower c), while *both* enjoy the drop in substitutability from s^{MM} to $s^{IM} = s^{MI}$). So, both firms wait for the other firm to change its governance form first. In this attrition game, the firms then only change governance form jointly when crossing $c^X = c^F$ when $s = s^{MI} = s^{IM} < s^M$. If $s > s^{IM} = s^{MI}$, both firms will integrate jointly whenever the cost level exceeds c^L, regardless of whether the roles are assigned exogenously or endogenously. In this case, the cost advantage (paying c^I rather than the high c) is so big that the drop in substitutability is justified.

5. Conclusions

In this paper, we studied the firm decision to outsource or vertically integrate the production of components given the volatile downward trending component costs, hereby mediated by whether prior leader and follower roles are assigned or not. If in-house production does not differentiate the product enough (so, does not improve profitability enough), there is no justification of incurring the higher marginal component costs of in-house production and, consequently, component production should be outsourced. This is taken as a confirmation of the classical adage to outsource non-core competences. We established that the converse is also true. Despite the fact that component market prices are lower than in-house production costs, a decrease in substitutability has firms vertically integrate to horizontally differentiate and thus decrease substitutability. Firms should vertically integrate those production capabilities that soften price competition enough to justify incurring the excess production costs.
However, integration by one firm alleviates competitive pressures *for all firms and thus reduces the need for competitors to change their own governance form.* Particularly whenever there is no exogenous leader but firms get assigned their roles endogenously, exactly this softening of price competition also for competitors has firms end up in an attrition game. So, whenever the asymmetric cost change is too big to compensate for the symmetric advantages of softened competition, firms wait for competitors to change their

governance form. This implies that whenever these 'integrate to differentiate' strategies are followed, there must be an additional willingness to pay or otherwise favorable economic condition compensating the higher costs. However, if a certain firm starts to outsource and thereby increases the substitutability for all firms, the other firms are likely to follow to also enjoy lower component cost. The higher substitutability and the bigger the component cost differential, the stronger this domino effect in outsourcing is. Although intuition is that firms will be less hesitant to change their governance form if they will have the opportunity to revert their decision, further research is needed to establish the quantitative effect.

Appendix A. General solution of Bellman equation

To use Ito calculus, we assume W is twice differentiable in c and once differentiable in t. We multiply both sides of (4) by $(1 + r\,\mathrm{d}t)/\,\mathrm{d}t$, rearrange terms, and take the limit of $\mathrm{d}t$ down to zero to obtain:

$$rW(c) = \pi + \lim_{\mathrm{d}t \downarrow 0} \frac{1}{\mathrm{d}t} \left(\mathbb{E}W(c + \mathrm{d}c) - W(c)\right) \tag{A.1}$$

We determine the last term in (A.1) by taking a Taylor series of function W:

$$\begin{aligned} W(c + \mathrm{d}c) = W(c) + \frac{\partial W}{\partial c}\,\mathrm{d}c + \frac{\partial W}{\partial t}\,\mathrm{d}t + \\ \frac{1}{2}\left(\frac{\partial^2 W}{\partial c^2}(\mathrm{d}c)^2 + 2\frac{\partial^2 W}{\partial c \partial t}\,\mathrm{d}c\,\mathrm{d}t + \frac{\partial^2 W}{\partial t^2}(\mathrm{d}t)^2\right) + \ldots \end{aligned} \tag{A.2}$$

Given the division by $\mathrm{d}t$ and the $\mathrm{d}t \downarrow 0$ in (A.1), terms $(\mathrm{d}t)^v$ with power $v > 1$ in the Taylor series will vanish. Terms $(\mathrm{d}t)^2$ and $\mathrm{d}c\,\mathrm{d}t$ -after expansion-contain a power higher than one of $\mathrm{d}t$, so these terms will vanish. However, in term

$$(\mathrm{d}c)^2 = (c_0 - c)^2\left(\gamma^2(\mathrm{d}t)^2 + \sigma^2\varepsilon^2\,\mathrm{d}t + 2\gamma\sigma\varepsilon(\mathrm{d}t)^{3/2}\right)$$

the term $\sigma^2\varepsilon^2\,\mathrm{d}t$ would still have an effect and therefore the term with $(\mathrm{d}c)^2$ in (A.2) should be taken into account in a first-order approximation:

$$\begin{aligned} \mathbb{E}W(c + \mathrm{d}c) - W(c) = \mathbb{E}\,\mathrm{d}W &= \frac{\partial W}{\partial c}\mathbb{E}\,\mathrm{d}c + \frac{\partial W}{\partial t}\,\mathrm{d}t + \frac{1}{2}\frac{\partial^2 W}{\partial c^2}\mathbb{E}(\mathrm{d}c)^2 \\ &= \frac{\partial W}{\partial c}(c_0 - c)\gamma\,\mathrm{d}t + \frac{\partial W}{\partial t}\,\mathrm{d}t \\ &\quad + \frac{1}{2}(c_0 - c)^2\frac{\partial^2 W}{\partial c^2}\left(\gamma^2(\mathrm{d}t)^2 + \sigma^2\,\mathrm{d}t\right) \end{aligned}$$

In which we have used that $\mathbb{E}\varepsilon = 0$ and $\mathbb{E}\varepsilon^2 = 1$. As W is autonomous, we have that $\partial W/\partial t = 0$, such that

$$\lim_{\mathrm{d}t \downarrow 0} \frac{1}{\mathrm{d}t} \mathbb{E}\, \mathrm{d}W = (c_0 - c)\gamma \frac{\partial W}{\partial c} + \frac{\sigma^2}{2}(c_0 - c)^2 \frac{\partial^2 W}{\partial c^2}$$

Substitution of this in (A.1) gives the following differential equation:

$$rW(c) - \gamma(c_0 - c)\frac{\partial W}{\partial c} - \frac{\sigma^2}{2}(c_0 - c)^2 \frac{\partial^2 W}{\partial c^2} = \pi \tag{A.3}$$

which has the general solution:

$$W = \Pi + A_1(c - c_0)^{\beta_1} + A_2(c - c_0)^{\beta_2}$$

with the roots of the fundamental quadratic equation:

$$\beta_{1,2} = \frac{2\gamma + \sigma^2 \pm \sqrt{8r\sigma^2 + (2\gamma + \sigma^2)^2}}{2\sigma^2}$$

Appendix B. Settings in numerical approximations

Integration costs (fixed)	C^I	1000
Recovered expenses upon outsourcing	C^M	500
Market price of component	c_0	5
In-house component production cost	c^I	15
In-house production price component	c^I	15
Vertical market size (willingness-to-pay)	a	50
Horizontal market size reciprocal	b	1.0
Interest rate	r	0.05
Component cost decrease rate	γ	0.03
Variance parameter	σ	0.1
Substitutability (both outsourcing)	s^{MM}	1
Substitutability (both integrated)	s^{II}	0.1
Substitutability (mixed)	s^{MI}, s^{IM}	0.5

Appendix C. Definitions for particular solution

$$
\begin{aligned}
Y_0^{IM} &= \frac{(2c^I + a(-2 + s^{IM}) - c_0 s^{IM})^2}{br\left(-4 + (s^{IM})^2\right)^2} \\
Y_1^{IM} &= \frac{2s^{IM}(-2c^I - a(-2 + s^{IM}) + c_0 s^{IM})}{b\left(-4 + (s^{IM})^2\right)^2 (r + \gamma)} \\
Y_2^{IM} &= \frac{(s^{IM})^2}{b\left(-4 + (s^{IM})^2\right)^2 (r + 2\gamma - \sigma^2)} \\
Y_0^{II} &= \frac{(a - c^I)^2}{br(2 + s^{II})^2} \\
Y_1^{II} &= 0 \\
Y_2^{II} &= 0 \\
Y_0^{MI} &= \frac{(2c_0 + a(-2 + s^{MI}) - c^I s^{MI})^2}{br(-4 + (s^{MI})^2)^2} \\
Y_1^{MI} &= \frac{8c_0 + 4a(-2 + s^{MI}) - 4c^I s^{MI}}{b\left(-4 + (s^{MI})^2\right)^2 (r + \gamma)} \\
Y_2^{MI} &= \frac{4}{b\left(-4 + (s^{MI})^2\right)^2 (r + 2\gamma - \sigma^2)} \\
Y_0^{MM} &= \frac{(a - c_0)^2}{br(2 + s^{MM})^2} \\
Y_1^{MM} &= \frac{2(c_0 - a)}{b(2 + s^{MM})^2 (r + \gamma)} \\
Y_2^{MM} &= \frac{1}{b(2 + s^{MM})^2 (r + 2\gamma - \sigma^2)}
\end{aligned}
$$

Appendix D. Leader, follower and joint movement solutions in strategic interaction

Case $II \to MI, IM \to MM$

Use $n = I$, $m = M$, $C^m = -C^M$ in (8) and (11):

$$
\begin{aligned}
c^L &= c_0 - \frac{\Delta_1^{MI}(-1+\beta_2) - P^L}{2\Delta_2^{MI}(-2+\beta_2)} \\
A &= B + (c^L - c_0)^{-\beta_2}(\Pi^{MI}(c^L) - \Pi^{II}(c^L) + C^M) \\
P^L &= \sqrt{(\Delta_1^{MI})^2(-1+\beta_2)^2 - 4(\Delta_0^{MI} + C^M)\Delta_2^{MI}(-2+\beta_2)\beta_2} \\
c^F &= c_0 - \frac{\Delta_1^{IM}(-1+\beta_2) + P^F}{2\Delta_2^{IM}(-2+\beta_2)} \\
D &= (c^F - c_0)^{-\beta_2}(\Pi^{MM}(c^F) - \Pi^{IM}(c^F) + C^M) \\
P^F &= \sqrt{(\Delta_1^{IM})^2(-1+\beta_2)^2 - 4(\Delta_0^{IM} - C^M)\Delta_2^{IM}(-2+\beta_2)\beta_2}
\end{aligned}
$$

Case $MM \to IM, MI \to II$

Use $n = M$, $m = I$, $C^m = C^I$ in (8) and (11):

$$
\begin{aligned}
c^L &= c_0 - \frac{\Delta_1^{IM}(-1+\beta_1) - P^L}{2\Delta_2^{IM}(-2+\beta_1)} \\
A &= B + (c^L - c_0)^{-\beta_1}(\Pi^{IM}(c^L) - \Pi^{MM}(c^L) - C^I) \\
P^L &= \sqrt{(\Delta_1^{IM})^2(-1+\beta_1)^2 - 4(\Delta_0^{IM} - C^I)\Delta_2^{IM}(-2+\beta_1)\beta_1} \\
c^F &= c_0 - \frac{\Delta_1^{MI}(-1+\beta_1) + P^F}{2\Delta_2^{MI}(-2+\beta_1)} \\
D &= (c^F - c_0)^{-\beta_1}(\Pi^{II}(c^F) - \Pi^{MI}(c^F) - C^I) \\
P^F &= \sqrt{(\Delta_1^{MI})^2(-1+\beta_1)^2 - 4(C^I + \Delta_0^{MI})\Delta_2^{MI}(-2+\beta_1)\beta_1}
\end{aligned}
$$

Case $II \to MM$

$$
\begin{aligned}
c^J &= c_0 - \frac{\Delta_1^{M}(-1+\beta_2) - P^M}{2\Delta_2^{M}(-2+\beta_2)} \\
A &= (\Delta_0^M + \Delta_1^M(c - c_0) + \Delta_2^M(c - c_0)^2 + C^M)(c - c_0)^{-\beta_2} \\
P^M &= \sqrt{(\Delta_1^{M})^2(-1+\beta_2)^2 - 4(\Delta_0^{M} + C^M)\Delta_2^{M}(-2+\beta_2)\beta_2}
\end{aligned}
$$

Case MM → II

$$
\begin{aligned}
c^J &= c_0 - \frac{\Delta_1^I(-1+\beta_1) - P^I}{2\Delta_2^I(-2+\beta_1)} \\
A &= (\Delta_0^I + \Delta_1^I(c-c_0) + \Delta_2^I(c-c_0)^2 - C^I)(c-c_0)^{-\beta_1} \\
P^I &= \sqrt{(\Delta_1^I)^2(-1+\beta_1)^2 - 4(\Delta_0^I - C^I)\Delta_2^I(-2+\beta_1)\beta_1}
\end{aligned}
$$

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