ISSN 2282-6483

Alma Mater Studiorum - Università di Bologna
DEPARTMENT OF ECONOMICS

Coordinating R&D efforts for quality improvement along a supply chain

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Quaderni - Working Paper DSE N°1054

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February 15, 2016

Abstract

The optimal design of two-part tariffs is investigated in a dynamic model where two firms belonging to the same supply chain invest in R&D activities to increase the quality of the final product. It is shown that the replication of the vertically integrated monopolist's performance can be attained using a TPT in which the fee is a linear function of either the upstream R&D effort or product quality itself. The possibility of relying on R&D figures appearing in the upstream firm's balance sheet is desirable as quality enhancement might not be observable or verifiable.

Keywords: innovation, product quality, vertical separation, vertical integration, outsourcing.

JEL Codes: C73, L12, O31

*I would like to thank Claudio Dalle Donne for precious comments and suggestions. The usual disclaimer applies.

1 Introduction

The purpose of this paper is to design optimal contracts allowing a vertical supply chain to exactly replicate the profit performance, R&D investments and product quality level of a vertically integrated monopolist in a dynamic model where quality improvement requires costly R&D efforts by the firms along the vertical channel or by different divisions of the same firm under vertical integration. Before illustrating the contents of the ensuing analysis, I briefly offer an overview of the context in which our contribution inserts itself.

The downward distortion of product quality in monopoly markets is a long-standing issue in the theory of industrial organization. The incentive for a monopolist to undersupply quality in order to increase its own ability of extracting surplus from consumers has been highlighted by Spence (1975) and Mussa and Rosen (1978) and then further investigated by several other authors.[1] Quality supply has also repeatedly received attention in the fields of operations research, marketing and management,[2] where it has been often connected with the optimal coordination of supply chains.[3] The latter aspect refers to the fact that the quality level characterising the final product, as seen from the consumers's viewpoint, is indeed the outcome of the contributions (in the form of advertising or R&D) of different firms along the supply chain,

[1]The related literature is too large to be exhaustively accounted for. See Itoh (1983), Maskin and Riley (1984), Besanko, Donnenfeld and White (1987) and Champsaur and Rochet (1989), *inter alia*. For a survey, see Lambertini (2006).

[2]The bulk of the related literature is summarised in Feichtinger, Hartl and Sethi (1994) and Jørgensen and Zaccour (2004).

[3]In these disciplines, product quality is sometimes treated as an equivalent of goodwill (brand equity) or the demand level, as in El Ouardighi and Pasin (2006), El Ouardighi and Kim (2008) and Matsubayashi and Yamada (2008); other times it is treated as a hedonic feature of the product as seen from the consumers' standpoint, as in Shi, Liu and Petruzzi (2013).

or different divisions of the same firm in the case of vertical integration.

This particular aspect links the discussion about quality supply to a parallel debate concerning firms' make-or-buy decisions or, equivalently, the choice between carrying out production and R&D in house and outsourcing, with the related contractual problems which obviously accompany the latter, any time some relevant feature of the component being outsourced is subject to opportunistic behaviour (i.e., moral hazard) on the part of the OEM supplier. When this happens, with the supplier underinvesting along some key dimension, a hold-up problem obtains, to the disadvantage of the outsourcing firm facing the final customers.[4]

Here, I compare a vertically integrated monopolist with two divisions investing to increase product quality versus the alternative industry structure in which the product quality level is the outcome of the efforts of two independent firms connected along a vertical supply chain. In the latter case, the contractual relation takes the form of a two-part tariff which may be designed in several alternative ways, thereby generating different outcomes. The model is defined in continuous time, over an infinite horizon. It is therefore an optimal control model when a vertically integrated firm is considered, and a differential game with sequential moves at every instant if instead two independent firms are assumed to exist along the supply chain. From an analytical point of view, the procedure follows the same steps as in Lambertini (2014), where an analogous approach is used to design optimal contracts in a supply chain where firms have to build up goodwill over time.[5]

The main results can be spelled out as follows. After characterising the

[4]The hold-up phenomenon arising under opportunistic behaviour is a major issue in the theory of the firm ever since Williamson (1975, 1979) and has been extensively discussed in contract theory. See Hart and Moore (1988), Rogerson (1992), MacLeod and Malcomson (1993), Aghion, Dewatripont and Rey (1994) and Nöldeke and Schmidt (1995), *inter alia*.

[5]Lambertini (2014) nests into a large literature discussing the dynamics of brand equity and the use of two-part tariffs, from Jeuland and Shugan (1983) to Zaccour (2008).

efficient outcome engendered by the vertically integrated firm, the distortion induced by vertical separation is illustrated, to the effect that the sum of upstream and downstream R&D efforts do not match those taking place across divisions belonging to an integrated monopolist, and equilibrium quality consequently decreases. Then, it is shown that a two-part tariff consisting of an exogenously given fee combined with a wholesale price set at marginal cost creates a hold-up problem inducing the upstream firm not to invest at all in quality-increasing activities. As a consequence, the vertical channel falls short of the performance of the vertically integrated monopolist, which is instead attained modelling the fixed fee as an endogenous function of either (i) the R&D effort of the upstream firm, or (ii) the quality level itself. While being equally effective at first sight, these two alternative contractual designs may indeed be not entirely equivalent. This is because the quality level being developed along the supply chain may not be observable or verifiable along the chain itself (as well as by the final customer before purchasing), and therefore the alternative contract based on the R&D effort - which can be verified from the balance sheet of the upstream firm, unless fraudulent behaviour is adopted by the latter - appears more reliable an instrument to cope with the issue represented by the vertical externality.

The remainder of the paper is structured as follows. The setup and the analysis of the vertically integrated monopolist are in Section 2. The case of vertical separation with double marginalization is dealt with in Section 3, while Section 4 contains the analysis of the alternative contractual designs based on three different definitions of the two-part tariff. Concluding remarks are in Section 5.

2 Benchmark: the vertically integrated monopolist

The model is a variation on the setup introduced by Mussa and Rosen (1978) and Gabszewicz and Thisse (1979). We assume the market is supplied by a single-product monopoly selling a nondurable good of quality $q(t) > 0$ at price $p(t) > 0$ over continuous time $t \in [0, \infty)$. The population of consumers is characterised by a level of marginal willingness to pay for quality $\theta \in [\Theta - 1, \Theta]$, where $\Theta > 1$, and is distributed with a uniform density $d = 1$ over such interval. Hence, the total mass of consumers amounts to 1. Net consumer surplus is $u = \theta q(t) - p(t) \geq 0$, so that parameter θ can be interpreted as a proxy of income or wealth. At any time $t \in [0, \infty)$, partial market coverage is assumed. The marginal consumer is identified by the marginal willingness to pay $\widehat{\theta}$ solving $\widehat{\theta} q(t) - p(t) = 0$; hence, $\widehat{\theta} = p(t)/q(t)$ and - assuming $p(t)/q(t) > \Theta - 1$ always - market demand at any time t is $x(t) = \Theta - p(t)/q(t)$.

Production takes place at marginal cost c, which can be normalised to zero without further loss of generality. The firm consists of two vertically related divisions, U (for *upstream*) and D (for *downstream*), each investing in R&D aimed at improving the quality level of the product supplied to consumers. Define as $k_i(t)$ the instantaneous effort of division $i = D, U$. If R&D activity takes place at decreasing returns to scale, the total cost function borne by the firm is

$$C(t) = b\left[k_U^2(t) + k_D^2(t)\right] \tag{1}$$

where b is a positive parameter. One can imagine the present setup as describing a situation in which each division cares for an input or component whose quality is crucial in determining the overall quality level of the final consumption good. The state dynamics describing the evolution of the state variable $q(t)$ over time is

$$\frac{dq(t)}{dt} \equiv \dot{q} = z\left[k_U(t) + k_D(t)\right] - \delta q(t) \tag{2}$$

in which z is a positive constant and $\delta > 0$ is the decay rate of quality. The transfer price along the supply chain being nil, the vertically integrated monopolist's instantaneous profits are

$$\pi(t) = p(t)\left[\Theta - \frac{p(t)}{q(t)}\right] - b\left[k_U^2(t) + k_D^2(t)\right] \tag{3}$$

and the firm wants to maximise the discounted profit flow

$$\Pi(t) = \int_0^\infty \pi(t) e^{-\rho t} dt \tag{4}$$

w.r.t. controls $p(t)$, $k_U(t)$ and $k_D(t)$, under the constraints posed by the state equation (2), initial condition $q(0) = q_0 > 0$, and the appropriate transversality condition to be specified below. Profits are discounted at the constant rate $\rho > 0$.

The Bellman equation is

$$\rho V_{VI}(q(t)) = \max_{p(t),k_U(t),k_D(t)} \left\{\pi(t) + V_{VI}'(q(t)) \cdot \frac{dq(t)}{dt}\right\} \tag{5}$$

where subscript VI mnemonics for *vertical integration* and $V_{VI}'(q(t)) \equiv \partial V_{VI}(q(t))/\partial q(t)$. In the remainder, I pose $V_{VI}(q(t)) = \alpha q(t) + \beta$, so that $V_{VI}'(q(t)) = \alpha$. Taking the first order conditions (FOCs) on $\{p(t), k_u(t), k_d(t)\}$ and solving, one obtains the following triple of optimal feedback controls:

$$p^*(t) = \frac{\Theta q(t)}{2}\,;\; k_U^*(t) = \frac{zV_{VI}'(q(t))}{2b} = k_D^*(t) \tag{6}$$

Plugging (6) into (5) and simplifying, one obtains the following equation:

$$q(t)\left[b\left(\Theta^2 - 4\alpha(\delta + \rho)\right)\right] + 2\left(z^2\alpha^2 - 2b\beta\rho\right) = 0 \tag{7}$$

with the system of Riccati equations

$$\begin{aligned} b\Theta^2 - 4b\alpha(\delta+\rho) &= 0 \\ z^2\alpha^2 - 2b\beta\rho &= 0 \end{aligned} \tag{8}$$

being solved by $\alpha = \Theta^2/[4(\delta+\rho)]$ and $\beta = z^2\alpha^2/(2b\rho)$. Accordingly, optimal symmetric R&D controls can be rewritten as $k^* = z\Theta^2/[8b(\delta+\rho)]$, and the resulting steady state quality level is $q^* = z^2\Theta^2/[4b\delta(\delta+\rho)]$. The remaining equilibrium magnitudes are $p^* = z^2\Theta^3/[8b\delta(\delta+\rho)]$, $x^* = \Theta/2$ and $\pi^* = z^2\Theta^4(\delta+2\rho)/\left[32b\delta(\delta+\rho)^2\right]$.

3 Vertical separation: the effect of double marginalization

Now I illustrate the game in which U and D are independent firms playing noncooperatively, with the upstream firm endogenously setting a wholesale price $w(t)$ when selling each unit of its part or component to firm D, which then combines it with its own one and then sells the final good to consumers on the market. The two firms' instantaneous profit functions are (henceforth, the time argument is omitted for the sake of brevity):

$$\pi_U = wx - bk_U^2\,;\ \pi_D = (p-w)\,x - bk_D^2 \tag{9}$$

Firm U controls w and k_U; firm D controls p and k_D. Their respective Bellman equations are:

$$\rho V_U(q) = \max_{w,k_U}\left\{\pi_U + V_U'(q)\cdot\frac{dq}{dt}\right\} \tag{10}$$

$$\rho V_D(q) = \max_{p,k_D}\left\{\pi_D + V_D'(q)\cdot\frac{dq}{dt}\right\} \tag{11}$$

Proceeding by backward induction, I take w and k_U as given and solve firm D's optimum problem. The relevant FOCs on controls p and k_D yield:

$$p^{VS} = \frac{\Theta q + w}{2} \,;\; k_D^{VS} = \frac{zV_D'(q)}{2b} \tag{12}$$

where superscript VS stands for *vertical separation*. Controls (12) can be substituted into (10) together with $V_D(q) = \gamma q(t) + \varepsilon$ and $V_D'(q) = \gamma$, in such a way that (10) can be rewritten as follows:

$$\rho V_U(q) = \max_{w, k_U(t)} \left\{ \frac{(\Theta q - w)\, w}{2q} - bk_U^2 + \frac{V_U'(q)\left[z^2\gamma + 2b\left(zk_U - \delta q\right)\right]}{2b} \right\} \tag{13}$$

This generates the following FOCs:

$$\begin{gathered} \frac{\Theta}{2} - \frac{w}{q} = 0 \\ zV_U'(q) - 2bk_U = 0 \end{gathered} \tag{14}$$

which deliver $w^{VS} = \Theta q/2$ and $k_U^{VS} = zV_U'(q)/(2b)$. Then, posing $V_U(q) = \zeta q + \eta$, so that $V_U'(q) = \zeta$, the two Bellman equations simplify as follows:

$$\frac{bq\left[8(\delta + \rho)\zeta - \Theta^2\right] + 8b\eta\rho - 2z^2\zeta(2\gamma + \zeta)}{8b} = 0 \tag{15}$$

for firm U, and

$$\frac{bq\left[16(\delta + \rho)\gamma - \Theta^2\right] + 16b\varepsilon\rho - 4z^2\gamma(\gamma + 2\zeta)}{16b} = 0 \tag{16}$$

for firm D. The unique solution of the system of four Riccati equations associated with (15-16) is

$$\gamma = \frac{\Theta^2}{16(\delta + \rho)} \,;\, \zeta = \frac{\Theta^2}{8(\delta + \rho)} \,;\; \varepsilon = \frac{5z^2\Theta^4}{1024b(\delta + \rho)\rho} \,;\, \eta = \frac{z^2\Theta^4}{128b(\delta + \rho)\rho} \tag{17}$$

and the equilibrium levels of R&D efforts and product quality are, respectively:

$$k_U^{VS} = \frac{z\Theta^2}{16b(\delta + \rho)} \,;\, k_D^{VS} = \frac{z\Theta^2}{32b(\delta + \rho)} \,;\, q^{VS} = \frac{3z^2\Theta^2}{32b\delta(\delta + \rho)} \tag{18}$$

with $k_U^{VS} + k_D^{VS} < 2k^*$ and consequently also $q^{VS} < q^*$. Additionally, output $x^{VS} = \Theta/4 = x^*/2$. As a result, equilibrium channel profits

$$\pi^{VS} = \frac{z^2\Theta^4 (12\delta + 18\rho)}{1024b\delta (\delta + \rho)^2} \tag{19}$$

are lower than π^*. The analysis carried out in this section entails the following:

Proposition 1 *The double marginalization associated with vertical separation brings about a reduction in R&D efforts, quality level and channel profits as compared to the vertically integrated solution.*

However, it is also worth noting that, although a hold-up effect is indeed operating because $k_i^{VS} < k^*$, $i = U, D$, it is nonetheless true that $k_U^{VS} = 2k_D^{VS}$, a property which is spelled out in

Corollary 2 *Vertical separation and double marginalization lead the upstream firm to invest twice as much as the downstream firm.*

The reason driving this result lies in the fact that firm U has an incentive to increase quality to keep output unaltered while at the same time driving upward the input price w^{VS}, both variables influencing positively its revenues.

4 Two-part tariffs

A subset of the extant literature on supply chains where product quality is explicitly treated as a relevant feature of the channel's performance (see Economides, 1999; Bacchiega and Bonroy, 2015, *inter alia*) relies on the adoption of a Nash bargaining solution to design the allocation of profits along the channel itself, showing that this route fails to deliver the same total profits as the vertically integrated solution.

Here I rely on alternative definitions of a contract based on two-part tariffs to illustrate a twofold result:

- the traditional two-part tariff consisting of a fixed fee associated with a wholesale price does not allow the vertically separated firms to reproduce the performance of the vertically integrated monopolist. Instead, this can be achieved by adopting, alternatively,

- a control-linear two-part tariff (where the control at stake is firm U's R&D effort).

In both cases, the fee is accompanied by a wholesale price set at marginal production cost. As mentioned above, the second result is relevant in that the quality level may not be immediately observable or verifiable by the downstream firm, which would therefore be subject to the risk associated with opportunistic behaviour in the form of underinvestment on the part of the upstream firm. To complement the analysis, I also show that the replication of the vertically integrated outcome can indeed be attained by setting the fixed part of the tariff as a linear function of quality - in which case the aforementioned caveat should be kept in mind.

4.1 The exogenous two-part tariff

Here I consider the case in which the vertical relation between separated firms U and D takes the form of a 'classical' two-part tariff $T = wx + F$. The resulting instantaneous objective functions are therefore the following:

$$\pi_U = wx + F - bk_U^2 \, ; \, \pi_D = (p - w)\, x - F - bk_D^2 \tag{20}$$

where the fixed component F of the TPT is an exogenous parameter, accompanied by a wholesale price equal to marginal production cost, $w = 0$.

The FOCs pertaining to firm D yield the same controls as in (12). Now, posing $w = 0$, $V_D(q) = \gamma q + \varepsilon$ and $V_D'(q) = \gamma$ and proceeding as in the previous section, it is easily verified that, since $\pi_U = F - bk_U^2$, the optimal R&D

effort by firm U solving its first order condition is again $k_U^F = zV_U'(q)/(2b)$, superscript F indicating the adoption of a TPT with an exogenous fee.

The partial derivative of the downstream firm's value function is again $V_U'(q) = \zeta$. However, firm U's Bellman equations simplifies as follows:

$$\frac{z^2\zeta\left[\Theta^2 + 2\zeta(\delta+\rho)\right] - 8b(\delta+\rho)\left[\eta\rho + \zeta q(\delta+\rho) - F\right]}{8b(\delta+\rho)} = 0 \tag{21}$$

whereby one of the two Riccati equation generated by (21) is

$$8b\zeta q(\delta+\rho)^2 = 0 \tag{22}$$

which implies $\zeta = 0$, so that $V_U'(q) = 0$ and therefore also $k_U^F = 0$. This shows that the exogeneity of the fixed fee appearing in the tariff altogether eliminates any R&D incentive upstream. It is also worth stressing that, typically, F should be posed equal to

$$p^*x^* = \frac{z^2\Theta^4}{16b\delta(\delta+\rho)} \tag{23}$$

in order for the upstream firm to appropriate the revenues generated by sales, but this of course wouldn't do the job of restoring R&D incentives upstream either.

Accordingly, we may claim:

Proposition 3 *The adoption of a classical TPT of the form $T = wx + F$ altogether eliminates the upstream firm's incentive to invest in product quality improvement.*

That is, here the classical hold-up problem emerges upstream in its entirety, being clearly generated by the presence of a fixed fee transferring upwards the whole of firm D's revenues. Firm D's investment being $k_D^F = k^*$, the resulting steady state quality level is $q^F = z^2\Theta^2/\left[8b\delta(\delta+\rho)\right] = q^*/2$.

4.2 The control-linear two-part tariff

The definition of the two-part tariff is the same as in the previous case. Therefore, the instantaneous profit functions are as in (20). In this case, however, I will pose $F = \phi + \psi k_U$. Hence, all of the relevant variables and profits will be identified by a superscript k_U revealing that the TPT specified in the contract is a function of the upstream firm's R&D control. Setting $w = 0$, the optimal controls of firm D are $p_{VS} = \Theta q/2$ and $k_D^{k_U} = zV_D'(q)/(2b)$. Specifying the upstream firm's value function as $V_D(q) = \gamma q + \varepsilon$ and solving the resulting system w.r.t. γ and ε, we obtain:

$$\gamma = \frac{\Theta^2}{4(\delta+\rho)}\,;\, \varepsilon = \frac{z^2\Theta^4 + 16b(\delta+\rho)\left[zk_U\Theta^2 - 4F(\delta+\rho)\right]}{64b\rho(\delta+\rho)^2} \tag{24}$$

Now define $F = \phi + \psi k_U$ and proceed backward to the Bellman equation of the upstream firm, to take the FOC on k_U, which delivers $k_U^{k_U} = (zV_U'(q) + \psi)/(2b)$. Conjecturing $V_U(q) = \zeta q + \eta$, the resulting system of Riccati equations is solved by $\zeta = 0$ and $\eta = \left(4b\phi + \psi^2\right)/(4b\rho)$, and the state equation simplify as follows:

$$\dot{q} = \frac{z\left[z\Theta^2 + 4(\delta+\rho)\psi\right]}{8b(\delta+\rho)} - \delta q \tag{25}$$

whereby the equilibrium quality level is

$$q_U^{k_U} = \frac{z\left[z\Theta^2 + 4(\delta+\rho)\psi\right]}{8b\delta(\delta+\rho)} \tag{26}$$

It is then immediate to check that $k_U^{k_U} = \psi/(2b)$ and $k_D^{k_U} = k^*$. Hence, we have that $k_U^{k_U} = k^*$ and $\pi_U^{k_U} + \pi_D^{k_U} = \pi^*$ at $\psi = z\Theta^2/4(\delta+\rho)$. Firms' profits in steady state are:

$$\pi_U^{k_U} = \frac{z^2\Theta^4}{64b(\delta+\rho)^2} + \phi\,;\, \pi_D^{k_U} = \frac{z^2\Theta^4(\delta+4\rho)}{64b\delta(\delta+\rho)^2} - \phi \tag{27}$$

with

$$\pi_D^{k_U} \geq 0\,\forall\,\phi \in \left[0, \frac{z^2\Theta^4(\delta+4\rho)}{64b\delta(\delta+\rho)^2}\right]$$

This analysis boils down to the following:

Proposition 4 *A two-part tariff* $TPT = wx + F$*, with* $F = \phi + \psi k_U$*,*

$$\phi \in \left[0, \frac{z^2\Theta^4(\delta+4\rho)}{64b\delta(\delta+\rho)^2}\right]$$

and $\psi = z\Theta^2/4(\delta+\rho)$ *allows the vertically separated industry to reproduce the same performance attained by the vertically integrated monopolist.*

4.3 The state-linear two-part tariff

A natural way out of the problem outlined above consists in defining the fee F as a linear function of the quality level, i.e., $F = \phi + \psi q$, coupled with $w = 0$.[6] Of course, this solution can be pursued as long as the quality level of the component or intermediate good supplied by U to D is observable by D. If not (or, if it is verifiable after a significant lag), then such a contract will not be, in general, a solution to the aforementioned hold-up problem. State and control variables, as well as output and profits will carry superscript q to recall that the TPT is a function of the quality level.

For the moment, I keep F as exogenous and just set $w = 0$. The maximum problem of firm D is solved by (12), with $w = 0$. Then, posing $V_D(q) = \gamma q(t) + \varepsilon$ and $V_D'(q) = \gamma$ and taking k_U as given, the Bellman equation of firm D is solved by the pair (γ, ε) solving the following system of Riccati equations:

$$\begin{gathered}\Theta^2 - 4\gamma(\delta+\rho) = 0 \\ z^2\gamma^2 - 4b(F - \gamma z k_U + \varepsilon\rho) = 0\end{gathered} \tag{28}$$

System (28) delivers

$$\varepsilon = \frac{\gamma(4\gamma z^2 + 4bk_U) - 4bF}{4b\rho}\,;\ \gamma = \frac{\Theta^2}{4(\delta+\rho)} \tag{29}$$

[6] This is the standard approach to obtain (degenerate) Markovian equilibria in Stackelberg differential games where the leader's policy is taken to be a linear function of the relevant state variable (see Dockner *et al.* 2000, pp. 134-41).

The downstream firm's profit simplifies as follows:

$$\pi_D^q = \frac{\Theta^2 q}{4} - \frac{z^2 \Theta^4}{64b(\delta+\rho)^2} - F \tag{30}$$

and it is nil in correspondence of

$$F = \frac{\Theta^2 q}{4} - \frac{z^2 \Theta^4}{64b(\delta+\rho)^2} \tag{31}$$

The expressions appearing in (29) and (31) can be substituted into the Bellman equation of the upstream firm, which generates a FOC w.r.t. k_U delivering the by now familiar result $k_U^q = zV_U'(q)/(2b)$. Assuming again $V_U(q) = \zeta q + \eta$, the Bellman equation of firm U produces the following system:

$$4\zeta(\delta+\rho) - \Theta^2 = 0 \tag{32}$$

$$64b\eta\rho(\delta+\rho)^2 - z^2\left[16\zeta^2\left(\delta^2+\rho^2\right) + 8\zeta\left(\Theta^2(\delta+\rho) + 4\zeta\rho\right) - \Theta^4\right] = 0 \tag{33}$$

whose unique solution is identified by the pair

$$\zeta = \frac{\Theta^2}{4(\delta+\rho)}\,;\ \eta = \frac{z^2\Theta^4}{32b\rho(\delta+\rho)^2} \tag{34}$$

At this point it is quickly checked that $q = q^*$, $k_U^q = k_D^q = k^*$, $x^q = x^*$ and $\pi_U^q + \pi_D^q = \pi^*$. Accordingly, I may formulate

Proposition 5 *If the fee appearing in the TPT is (i) linear in the quality level and (ii) extracts the full surplus from the pockets of the downstream firm, the equilibrium attained under vertical separation replicates the performance of the vertically integrated monopolist.*

Although apparently this type of contract produces the same equilibrium as the one based on a TPT linear in the upstream firm's control, the approach illustrated in this section is somewhat problematic as it leaves room to a moral hazard problem. If any given quality increase along the supply chain is verifiable (and therefore contractible), then the TPT incorporating (31) represents a feasible efficient solution to the hold-up problem. If not, (31) is a gamble the downstream firm should not be willing to accept as it exposes the same firm to an obvious opportunistic behaviour on the part of the upstream supplier.

5 Concluding remarks

I have investigated the efficient design of the contract based on a two-part tariff that should be adopted to lead a supply chain along which quality-improving investments take place to entirely replicate the performance of a vertically integrated firm. In particular, the foregoing analysis has shown that there exist two alternative specification of the TPT achieving this outcome: one contemplates a fee defined as a linear function of the upstream R&D endeavour, the other has the fee specified as a linear function of product quality. The latter might not be a feasible solution if quality improvements along the vertical relation are not immediately observable/verifiable, and therefore not contractible, while the adoption of the former hinges upon reliable financial reports on the part of the upstream OEM firm.

Several extensions of the above analysis can be envisaged. First of all, the setup can be extended to allow for oligopolistic competition to take place either downstream or upstream, or in both. Secondly, the presence of some other type of investment, e.g., in cost-reducing innovation, could also be accounted for, as in Lambertini and Orsini (2000; 2015). Thirdly, here I have confined my attention to nondurables; using the same approach to analysing contractual design based on TPT's for durables looks like a natural *addendum*. These tasks are left for future research.

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