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COMPETITION IN HEALTH CARE MARKETS
AND VERTICAL RESTRAINTS

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Competition in Health Care Markets and Vertical Restraints

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Abstract

This paper studies competition between Managed Care Organizations (MCOs) and "*Conventional Insurers*". Most of the time, MCOs sign exclusive contracts with providers and these vertical restrictions associated to differentiation in the providers' market imply a risk segmentation. Taking into account this phenomenon, we show that vertical restrictions in the health insurance sector can paradoxically create an "*anti-raise rivals' cost effect*" in which MCOs' penetration allows to decrease conventional insurers' premiums.

Keywoards: Vertical Restraints, Managed Care, Competition Policy.

Jel Classification: L42, I11 and G22.

1 Introduction

The number of Managed Care Organizations (MCOs) has dramatically increased during the last two decades and groups "*an alphabet soup*" of insurance plans (Gaynor and

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Haas-Wilson, 1999). The more common forms of managed care organizations are Health Maintenance Organizations (HMOs) and Preferred Provider Organizations (PPOs), both kinds of insurers implying restrictions in the choice of providers. The consequences of MCOs' penetration are still unclear. This phenomenon is often presented as an efficient solution to reduce or contain the growing health care costs. Several reasons are given in the health economics literature to explain this point of view (See Gaynor and Vogt, 1999): vertical integration helps to decrease providers' moral hazard (Wholey et *al,* 1998), to increase competition in the health insurance sector (Baker and Corts, 1996), to reduce the transaction costs and it allows MCOs to negotiate lower prices from providers. Indeed, Cutler, McClellan and Newhouse (2000) have shown that a consistent part of their lower expenditure is explained by lower unit prices.[1] In more general terms, the welfare implications of vertical restraints are still in debate.[2] The "*Chicago School*" explains that there is no anticompetitive impact from vertical restraints[3] whereas other analyses find that they can be anticompetitive (Krattenmaker and Salop, 1986).[4] As in the other sectors, the answer concerning the impacts of vertical restraints in the health care system depends on the characteristics of the market structure. One main specificity of the health insurance sector is certainly the risk segmentation associated to vertical restraints. Indeed, the low level of health expenditure generated by policy holders that belong to MCOs may be caused by a favorable risk segmentation. The low risk people often prefer to pay lower premiums even though they have a restricted choice of providers when they fall ill. At the opposite, high risk people prefer to select freely their providers and to pay higher premiums. The latter are more sensitive to the diversity offered by conventional insurers rather than by premium reductions. It is difficult to estimate precisely if the MCOs' lower costs are caused by risk segmentation or by the preceding positive arguments. Baker and Corts (1996) have estimated the relationship between market share and premiums and find a convex relationship between conventional insurance premiums and MCOs' penetration, "*suggesting that the market segmentation effect becomes relatively more important as penetration increases*". From a normative point of view, if MCOs lower premiums imply

[1] See also Melnick et *al* (1992) for an older evidence of this result.

[2] To be convinced, the readers can consult the Agenda for Joint FTC/DOJ Hearings on Health Care and Competition Law and Policy.

[3] Posner (1976).

[4] See for some other contributions: Salinger (1988) and Hart and Tirole (1990).

higher premiums for conventional insurers, it is difficult to assess the consequences of the MCOs' penetration on welfare.The goal of this paper is to understand the relationship between MCOs' market share and the variation of the conventional insurance premiums and to identify if a "*raise rivals' cost effect*" caused by vertical restraints is relevant in the health insurance sector. Salinger's framework[5] is used to model competition between MCOs and conventional insurers by introducing an endogenous risk segmentation effect. As Salinger, we consider a given market structure in order to focus on the relation between concentrations of hospitals on respectively health insurance and providers markets and premiums levels thanks to static comparative analysis. Following Gal-Or (1997) and Ma (1997), we assume that providers are differentiated, differentiation at the upstream market reflecting specialization in treating different diseases. This assumption means that each hospital can treat all disease even though each of them is specialised in treating a specific disease. This assumption seems reasonable in the sense that if there was no differentiation among health care producers everybody would choose MCOs in order to pay lower premiums. We show that the consequences of MCOs penetration on premiums crucially depend on the nature of contracts, exclusive or not, between MCOs and their providers. Besides, in the exclusive case, we prove that MCOs penetration can reduce premiums of conventional insurers without taking into account the potential competitive effect often associated to MCOs penetration described by Baker and Corts (1996). In the next section, we develop a theoretical model which enables us to examine this question and we conclude in the last section.

2 The Model

In the first paragraph, we give the main assumptions of the model. In the second, we study the case where contracts between providers and insurers are non-exclusive in the sense that the providers belonging to MCOs can sell some care to other insurers. The third paragraph analyzes the case where the contracts between providers and insurers are bilaterally exclusive.

[5] Salinger (1988).

2.1 Framework

We distinguish consumers according to two dimensions. The first one is the probability of disease, noted θ which, in our model, corresponds to the probability of health care consumption. We assume that θ belongs to $[0,1]$ and that policy holders are uniformly distributed on this interval. Following Gal-Or (1997, 1999), the second dimension is the *ex post* distribution which captures the type of disease of the policy holders. This assumption implies that policy holders view the providers as being differentiated, the differentiation being captured thanks to the Salop's circular location model. The *ex post* address of the policy holders is noted x and we assume that the providers are uniformly distributed on the circle. The transportation cost of the policy holders is linear and noted t. We assume that policy holders can obtain health care when they fall ill only by purchasing a health insurance contract. We consider here two kinds of insurance suppliers: conventional insurers and managed care organizations. Policy holders who buy a health insurance contract to a conventional insurer will be able to choose among different providers whereas MCOs restrict the choice of providers. For simplicity, we consider that policy holders who choose a MCO are forced to go to one specific provider even though the suitability of the selected provider for treating their disease, given by their *ex post* address, is not the best compared to some other provider. This effect of *ex post* differentiation described by Gal-Or captures the following idea: when policy holders choose their insurer, integrated or not, they don't know in advance the kind of disease they will suffer if they fall ill.[6] The number of MCOs and the number of conventional insurers are respectively n and $N-n$. The assumption that a MCO contracts with only one provider implies that we have n providers which belong to MCOs whereas $J-n$ providers are free. Following Salinger (1988), the difference between MCOs and conventional insurers is that the latter pay care to providers at a wholesale price R whereas the former, thanks to their vertical structure, obtain care at marginal cost. The preferences of the policy holders are represented by the following utility function

$$U = 2\theta y \int_0^{1/2y} (v - tx)dx - P \tag{1}$$

[6]This provider can be interpreted as a group of providers. This assumption implies no loss of generality if we suppose at the same time that the size of the diversity in each group of providers is the same.

with y describing the number of available providers for the policy holders. The parameter v represents the gross benefit of the health care diminished by the transportation cost tx taken in expectation, minus the premium paid P. We can observe that the expected transportation cost is equal to $\frac{\theta t}{4y}$, so it is decreasing in the number of providers that a policy holder is free to select. In a MCO, y is equal to 1, so the expected transportation cost level is maximum.We study in the next paragraph the case where the providers who belong to a MCO can supply some care to policy holders who choose conventional insurers.

2.2 Non-exclusive contracts

We distinguish policy holders according to the kind of insurers they choose. We use the subscript I for policy holders who choose integrated insurers and NI for non-integrated insurers. The expected utility level of a policy holder when he chooses respectively a conventional insurer ($y = J$) or a MCO ($y = 1$) is

$$U_{NI} = 2\theta J \int_0^{1/2J} (v - tx)dx - P_{NI} \tag{2}$$

And,

$$U_I = 2\theta \int_0^{1/2} (v - tx)dx - P_I \tag{3}$$

A policy holder, characterized by a probability θ, prefers to buy a health insurance contract to a conventional insurer rather than to a MCO if

$$U_{NI}(\theta) \geq U_I(\theta) \tag{4}$$

Under the assumption that *ex ante* policy holders do not know their *ex post* address, consider the marginal policy holder $\tilde{\theta}$ who is indifferent between MCOs and conventional insurers. Then, the last inequality holds if and only if

$$\theta \geq \tilde{\theta}(J) = \frac{(P_{NI} - P_I) 4J}{t(J-1)} \tag{5}$$

This definition of the marginal policy holder enables us to understand the trade-off between the difference of the premiums paid to each kind of insurers and the diversity of providers offered by the conventional insurers, weighted by the transportation cost. A policy holder characterized by a high probability of disease will prefer to choose freely his provider if he falls ill and to pay a higher premium. We can observe that $\tilde{\theta}(J)$ decreases with J which implies that, all other things equal, conventional insurers become more attractive thanks to the increasing diversity of providers.We use the traditional timing applied in the vertical relations literature and solve the market game in two steps. First, we derive the equilibrium at the downstream level (here the insurance sector) and second, we determine the wholesale price to characterize the equilibrium at the upstream level.At the downstream level, we assume that insurers compete *à la Bertrand* in each submarket of the insurance sector (MCOs and conventional insurers submarkets) with no differentiation among conventional insurers.[7] We choose to focus on the risk segmentation effect rather than on the potential competition effect due to MCOs' penetration described by Baker and Corts (1996). We assume no-loading factors in the health insurance market, therefore premiums P_{NI} will be equal to their marginal cost. Then,

$$P_{NI} = (\frac{1+\tilde{\theta}}{2})R \tag{6}$$

where $(1+\tilde{\theta})/2$ is the average probability of disease of the policy holders who choose conventional insurers and R is the price paid by insurers to providers. *Ex ante* policy holders do not know their *ex post* address, hence when they choose their health insurance contract, they have no preferences for a particular provider. Behind the veil of ignorance, there is no differentiation effect on the MCOs' submarket either even though the "*good*" sold is different from an *ex post* perspective. The differentiation is actually *ex post* but competition between MCOs is *ex ante*. Therefore, the premiums paid by the policy holders who choose MCOs are still equal to the MCOs' marginal cost, here the average probability of the policy holders multiplied by the cost c:

$$P_I = \frac{\tilde{\theta}}{2}c \tag{7}$$

The equilibrium in the sub-game at the downstream level can be derived directly from the marginal policy holder definition and the premiums. For a given price R, the health insurance sector equilibrium is

$$\begin{aligned} P_{NI} &= \frac{1}{2}R\left(1+\frac{2JR}{2cJ-2JR+(J-1)t}\right) \\ P_I &= \frac{cJR}{2cJ-2JR+(J-1)t} \\ \tilde{\theta} &= \frac{2JR}{2cJ-2JR+(J-1)t} \end{aligned}$$

[7] See Ma (1997) for a similar assumption.

Before analyzing the providers' behavior, we can make two remarks. First, in the non exclusive case, since health insurance markets are perfectly competitive, the health insurance equilibrium only depends on the number of providers J and does not depend on the respective numbers N and n. Second, providers which belong to MCOs have incentives to sell care to conventional insurers. Perfect competition in the health insurance sector implies that MCOs premiums are equal to their marginal cost. Thus, the only way for them to make profits is to sell care to conventional insurers.Only a fraction $(1-\tilde{\theta})$ of policy holders can freely choose their providers. Then, according to the *ex post* uniform distribution address, when contracts between insurers and providers are non-exclusive, each provider is actually in a monopoly situation[8] so he/she is confronted to a demand $\frac{1-\tilde{\theta}}{J}$. Therefore, each provider j seeks to maximize[9]

$$\underset{R_j}{Max}\,(R_j - c)\left(\frac{1-\tilde{\theta}(R_j, R_{-j})}{J}\right)$$

where R_{-j} is the vector of prices chosen by the other providers. The first-order condition gives

$$\frac{\partial\tilde{\theta}(R_j, R_{-j})}{\partial R_j}(R_j - c) = 1 - \tilde{\theta}(R_j, R_{-j})$$

Differentiating with respect to R_j and then setting $R_j = R$ yields[10]

$$R\,(J) = \frac{1}{8J^2}\left((1+3J)(2cJ+(J-1)t) - \sqrt{-1+J}\sqrt{A}\right) \tag{8}$$

where $\sqrt{A} = \sqrt{(2cJ+(J-1)t)(t+J(2c(J-1)+(6+J)t))}$

Proposition 1 *In equilibrium, the price of care is increasing with the number of providers.*

Proof: see Appendix 1This result may be interpreted as an induced demand effect by providers when their control variable is price and not quantity.[11] When the number of providers increases, the diversity supplied by conventional insurers increases too. All other things equal, their demand function shifts upwards, so the number of policy holders who

[8] Here, policy holders do not pay copayment and are characterized by a specific *ex post* adress when they fall ill.

[9] We show easily that the second-order conditions are satisfied.

[10] We focus on symmetric equilibrium.

[11] See Rice and Label (1989) for an explanation of the induced demand effect.

can choose freely their provider is more important, allowing providers to increase their mark-up.[12] The equilibrium of the game is then determined by the following system of equations

$$\begin{cases} P_{NI} = \frac{1}{2}R\left(1 + \frac{2JR}{2cJ-2JR+(J-1)t}\right) \\ P_I = \frac{cJR}{2cJ-2JR+(J-1)t} \\ \tilde{\theta} = \frac{2JR}{2cJ-2JR+(J-1)t} \\ R = \frac{1}{8J^2}\left((1+3J)(2cJ+(J-1)t) - \sqrt{-1+J}\sqrt{A}\right) \end{cases}$$

by substituting the price $R(J,c,t)$ in the value of $\tilde{\theta}$, P_{NI} and P_I. Consider now the following lemma.[13]

Lemma 1 *If the proportion of policy holders who choose MCOs increases, both premiums P_I and P_{NI} also increase.*

We can easily remark that the senses of variation of the premium P_I and the proportion $\tilde{\theta}$ are identical. Besides, the premium P_{NI} is both increasing with the wholesale price R and the proportion $\tilde{\theta}$. Thus, according to the result of proposition 1, the increasing share of policy holders who choose MCOs is a sufficient condition to insure that both premiums (P_{NI} and P_I) increase too. In order to give some comparative static results with respect to the number of providers, consider the elasticity

$$\epsilon(J) = \frac{\partial R(J)}{\partial J}\frac{J}{R(J)} \tag{9}$$

which describes the sensitivity of the wholesale price variations to the number of providers. Note that when providers compete in prices, this elasticity can be interpreted as an estimation of the induced demand.

Proposition 2 *For $\epsilon(J) \geq \frac{t}{2cJ+(J-1)t}$, the share of policy holders who choose MCOs is increasing with the numbers of providers.*

[12]Computations for providers' profit function is unfortunetly too complicated. But, it is worth noticing that providers may suffer from the *prisonner's dilemma* because none of them internalizes the consequences of his decision on the conventional insurers demand and has incentive to supply care at a lower price in order to increase $1-\tilde{\theta}$.

[13]In this paper, the market structure is given and we consider that the two kinds of insurers are present at equilibrium. We give in appendix 2 the conditions to ensure that $\tilde{\theta}$ belongs to $]0,1[$.

Proof: Appendix 2. Proposition 2 can appear in contradiction with the preceding remarks. It implies that the more the conventional insurers offer diversity through the number of providers, the more the share of policy holders who choose them is reduced. This result can actually be better understood if we take the derivative of $\tilde{\theta}$ with respect to J.

$$\frac{d\tilde{\theta}}{dJ} = \frac{\partial\tilde{\theta}}{\partial J} + \frac{\partial\tilde{\theta}}{\partial R}\frac{\partial R}{\partial J} > 0 \tag{10}$$

The first term is the *negative direct effect* that we have described whereas the second one is a *positive indirect effect* according to proposition 1. All other things equal, policy holders prefer more diversity because of differentiation costs (direct effect). Nevertheless, the wholesale price increases with the diversity supplied by conventional insurers (proposition 1) and the share $\tilde{\theta}$ is increasing with the wholesale price R. Proposition 2 implies that the indirect effect dominates the direct when the wholesale price is very sensitive to the number of providers.

Corollary 1 *If the condition of proposition 2 holds, the premiums P_I and P_{NI} are increasing with the number of providers at the upstream market.*

As we will be able to remark in the next paragraph, this comparative statics result with respect to J obtained in the non-exclusivity case will be important to understand the effect of vertical restrictions on premiums levels.

2.3 Exclusive contracts between MCOs and providers

When MCOs and providers sign exclusivity contracts, providers who belong to MCOs cannot supply health care to policy holders of conventional insurers. For a given number of providers, the prevalence of such contracts reduces the diversity of providers available for policy holders who opt for conventional insurers. In the exclusivity contracts case, providers who work with MCOs do not belong to the 'circle' of the providers available for policy holders who choose conventional insurers. Besides, the uniform distribution assumed in the Salop's model[14] implies a maximal differentiation.[15] Then,the exclusion of some providers from the circle implies a reallocation of the other providers to respect this

[14]Salop (1979).

[15]Aspremont et *al* (1979).

condition of uniform distribution. This phenomenon can actually be understood from a long term perspective. If a hospital is specialised and decides to join to a MCO, the other providers will react by improving their technologies in the specialization of the hospital that leaves the care market. The marginal policy holder becomes:

$$\tilde{\theta} = \frac{(P_{NI} - P_I)\, 4(J-n)}{t\,(J-n-1)} \tag{11}$$

It is easy to remark that we have exactly the same equilibrium than in the non-exclusive case but with an opposite effect. Indeed, in both cases, we have an equilibrium in K, with $K = J$ in the non-exclusive case and with $K = J - n$ in the exclusive case. In this latter case, we can remark that the probability of disease of the marginal policy holder is an increasing function of the number of MCOs. For a given number of providers, all other things equal, the number of "*free providers*" is reduced and the expected cost differentiation in the conventional insurers market increases. The equilibrium only depends on the numbers of providers and MCOs. The symmetry with the non-exclusive case enables us to write directly the following proposition.

Proposition 3 *In equilibrium, the price of care supplied by free providers is a decreasing function of the MCOs' number.*

(Proof: Straightforward thanks to the fact that $\frac{\partial K}{\partial J} = -\frac{\partial K}{\partial n}$)Some additional MCOs

imply that the number of free providers is reduced. If the price of care increases with the number of free providers, it decreases with the number of MCOs. The proposition 3 reveals the trade-off in the case of exclusive contracts between transportation costs due to MCOs and the fact that providers' mark-up decreases with the number of MCOs. Actually, competition between MCOs and conventional insurers creates two inefficiencies: a wholesale price above the marginal cost and transportation cost.In the literature dealing

with vertical restraints, the main question analyzed is the "*raise rivals' cost*" effect. Vertical restraints reduce the number of suppliers, and as a result the wholesale price being an increasing function of the conventional insurers costs at the downstream market, usually increases. In our differentiation framework, the nature of the link between vertical restraints and "*rivals' cost*" is different. Vertical restraints reduce the number of providers, therefore all other things equal, they decrease the diversity offered by conventional insurers. Nevertheless, the reduction in diversity decreases the wholesale price, which is in turn increasing with the conventional insurers' costs. Thus, if we isolate this wholesale price effect, our result is exactly the opposite of the famous "*raise rivals' cost*" effect. The more numerous vertical restrictions are, the more the wholesale price decreases.

Proposition 4 *For* $\epsilon(J) \geq \frac{t}{2c(J-n)+(J-n-1)t}$, *in the case of exclusivity contracts, MCOs penetration may decrease both premiums.*

Most of the time, negative correlation between conventional insurers premiums and MCOs penetration is explained by the increasing competition in the health insurance sector.[16] Here, we do no capture this effect but our result indicates that premiums of conventional insurers decrease with the number of MCOs when they sign exclusive contracts with providers. This result is explained by the fact that the wholesale price effect is exactly the opposite of the traditional "*raise rivals' cost effect*" revealed by the literature of vertical restraints. Besides, the wholesale price effect may be important enough to insure that the market share of policy holders who opt for conventional insurers increases. It is worth noticing that MCOs have incentive to sign non-exclusive contracts with their providers. In the model, we make the assumption of no differentiation on the downstream markets. Then, the only way for MCOs to make profits is to sell care to conventional insurers. Actually, there are some HMOs with exclusive contracts and other kinds of MCOs such as PPOs which sign non exclusive contracts. Our results can explain the recent increasing market share of PPOs compared to HMOs staff model (Gaynor and Haas-Wilson, 1999). Historically, most HMOs signed exclusive contracts, therefore their market was not perfectly competitive and they could make positive profits. After the improvement of their market share and the increase in competition among HMOs, the only way for them to make some profits is to obtain care at marginal cost and to sell it to conventional insurers. The emergence of PPOs can be explained thanks to the increasing competition on the MCOs' market.

[16] See for example Baker and Corts (1996).

3 Conclusion

This model allows to analyze the impact of vertical restrictions in the health insurance sector when there exists competition between conventional insurers and MCOs. We show that there is an "*anti-raise rivals' cost effect*" caused by vertical restrictions: the wholesale price on the care market decreases when the number of MCOs increases. The premiums of conventional insurers can decrease with the number of MCOs. From a positive point of view, the model can also explain the increasing share of PPOs among the MCOs' sector. We have observed that the nature of contracts between insurers and providers is more relevant than the vertical structure to explain the premiums levels variations. We have seen that vertical structures have no impact on premium levels without exclusivity. This result can be useful to highlight the opened debate on competition policy in the health insurance sector. More precisely, we have shown that the premiums variations depend on the price elasticity in the health care market with respect to providers' density.>From a normative point of view, it would be interesting to study the optimal size of MCOs (in terms of number providers) in a "two-sided markets" framework (Rochet and Tirole, 2003). Actually, we can see MCOs as platforms where two networks effects are relevant: on one side with the policy holders risk segmentation, on the other side some network effects between providers belonging to the same MCO.

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Appendix 1: Proof of the proposition 1 Differentiation of the price R with respect to J yields

$$\frac{\partial R}{\partial J} = \frac{\begin{pmatrix} 2c^2J^2 - 2c^2J^3 - 3cJt - 2cJ^2t + cJ^3t + t^2 + 3Jt^2 - 5J^2t^2 + J^3t^2 + \\ (\sqrt{J} - 1)(-cJ + T + Jt)\sqrt{A} \end{pmatrix}}{4\sqrt{-1+J}J^3\sqrt{A}}$$

The denominator is strictly positive, so the sign of the derivative depends on the sign of the numerator. After computations, the numerator N can be written:

$$N = \frac{4cJ\left(\sqrt{J-1}\sqrt{\frac{c^2J^2(J+1)^2}{J-1}}(3+J) + cJ(-3 + (-4+J)J)\right)}{J-1}$$

which is positive. **Appendix 2:** At equilibrium of the insurance market, the probability of the marginal policy holder is:

$$\tilde{\theta}(R) = \frac{2JR}{2cJ - 2JR + (J-1)t}$$

with $R(J) = \frac{1}{8J^2}\left((1+3J)(2cJ + (J-1)t) - \sqrt{-1+J}\sqrt{A}\right)$ and $A = (2cJ + (J-1)t)(t + J(2c(J-1) + (6+J)t))$ As $\tilde{\theta}(R) > 0$, the coexistence of MCOs and conventional insurers needs $\tilde{\theta}(R) < 1$ which is satisfied only if

$$\begin{aligned} 2JR &< 2cJ - 2JR + (J-1)t \\ \Leftrightarrow \quad R(J) &< \frac{2cJ + Jt - t}{4J} \end{aligned}$$

By substituting $R(J)$, the condition rewrites:

$$g(t) = 4c^2J^2 - 4t^2J^2 + 2t^2J - t^2 < 0$$

We have $g(t) = 0$ for $t_1 = \dfrac{2cJ}{\sqrt{4J^2 - 2J + 1}} > 0$ and $t_2 = \dfrac{-2cJ}{\sqrt{4J^2 - 2J + 1}} < 0$ Then $\tilde{\theta}(R) < 1$ for $t > t_1$. In the following, this condition will be more useful under the form:

$$c < \overline{c} = \frac{t\sqrt{4J^2 - 2J + 1}}{2J}$$

Appendix 3: Proof of the Proposition 2 The goal of this proof is to find that under the conditions given in the proposition 3, we have $\dfrac{\partial \theta}{\partial J} \geq 0$. We know that

$$\tilde{\vartheta} = \frac{2JR}{2cJ - 2JR + (J-1)t}$$

with $R(J) = \dfrac{(1+3J)(2cJ + (J-1)t) - \sqrt{J-1}\sqrt{A}}{8J^2}$ By substituting R in function of J, we can write θ only in function of J. Then, we have $\theta(J) = \theta(J, R(J))$. Differentiation of

$\theta(J)$ with respect to J gives

$$\frac{\partial \theta}{\partial J} = \frac{d\theta}{dJ} + \frac{d\theta}{dR}\frac{dR}{dJ}$$

Then,

$$\begin{aligned} \frac{d\theta}{dJ} + \frac{d\theta}{dR}\frac{dR}{dJ} &\geq 0 \\ \Leftrightarrow \quad \frac{R'(J)J}{R} &\geq \frac{t}{2cJ + tJ - t} \end{aligned}$$

In order to study this condition, consider the following function $f(R, c, t, J)$ such that

$$f(R, c, t, J) = \frac{R'(J)J}{R} - \frac{t}{2cJ + tJ - t}$$

The previous condition can be written more succintly by $f(R, c, t, J) \geq 0$. By substituting $R'(J)$ in function of R, we obtain:

$$f(R, c, t, J) = \frac{3t^2J^2c + t^3J^2 - 2t^3J - ct^2J - 4c^3J^2 + 6c^2Jt - 2ct^2 + t^3 + 4RJ^2c^2 - 8RJ^2ct - 8RJct + 3}{R(2cJ + tJ - t)A}$$

The denominator of $f(R, c, t, J)$ is strictly positive, then the sign of this function only depends on the sign of the numerator, noted $N(R, c, tJ)$, with

$$\begin{aligned} N(R, c, t, J) &= \left[8tJ^2\right] R^2 + \left[4c^2J^2 - 8ctJ^2 - 8ctJ + 3t^2 - 5t^2J^2 + 2t^2J\right] R \\ &\quad + \left[3t^2J^2c + t^3J^2 - 2t^3J - ct^2J - 4c^3J^2 + 6c^2Jt - 2ct^2 + t^3\right] \end{aligned}$$

Taking into account that R depends on J, we have:

$$N(R(J, A(J), c, t, J) = N(J, c, t)$$

Consider $H = \sqrt{J-1}\sqrt{A}$. N becomes $N(H, J, c, t)$. We note H^* the value of H which verifies $N(H^* J, c, t) = 0$. We find

$$H^* = \frac{[4c^2J^3 - 4ctJ^3 - 3t^2J^3 - 4c^2J^2 + 8ctJ^2 5t^2J^2 - t^2 + 4ctJ - t^2J]}{2cJ + tJ - t}$$

Consider the following function: $h(c) = H^* - H$ The first derivative is:

$$h\prime(c) = 3\left(8\,J^2 + 8\,J^4 - 16\,J^3\right)c^2 + 2\left(-4\,tJ^2 - 8\,tJ + 4\,tJ^4\right)c + 4\,t^2J + 12\,t^2J^3 + 2\,t^2 - 16\,t^2J^2 - 2\,t^2J^4$$

We note respectively c_1 and c_2 the solutions of $h(c) = 0$

$$c_1 = \frac{\left(4\,J + 8 - 4\,J^3 + 4\sqrt{34\,J^2 + 4\,J + 61\,J^4 + 1 - 76\,J^3 + 4\,J^6 - 24\,J^5}\right)t}{2\,(12 + 12\,J^2 - 24\,J)\,J}$$

And,

$$c_2 = \frac{\left(4\,J + 8 - 4\,J^3 - 4\sqrt{34\,J^2 + 4\,J + 61\,J^4 + 1 - 76\,J^3 + 4\,J^6 - 24\,J^5}\right)t}{2\,(12 + 12\,J^2 - 24\,J)\,J}$$

We can remark that $c_2 < 0$ because $4\,J + 8 - 4\,J^3 < 0$ for $J > 2$. Besides, $h'(0) = -2t^2(J^2 - 4J - 1)(J-1)^2 < 0$ for $J > 3$. Then, we have $h'(c) \leq 0$ if $c_2 \leq c \leq c_1$ with $c_2 < 0$ and $c_1 > 0$, and $h'(c) > 0$ for $c > c_1$. Tedious but straightforward computations allow to remark that $c_1 < \overline{c} = \dfrac{t\sqrt{4J^2 - 2J + 1}}{2J}$ For $c = 0$, we have $h(0) = -t^3(J-1)^4 < 0$. Besides, $h(\infty) = \infty$ for $J > 1$ Then $h'(c) < 0$ for $0 < c < c_1$ and $h(0) < 0$, so $h(c_1) < 0$ Computations on $h(\overline{c})$ give $h(\overline{c}) = \frac{t^3}{J}\left[(3J^2 + 2 + 2J)\,(J-1)^2\sqrt{4J^2 - 2J + 1} - 9J^3 - 2J^2 + 2J - 2 + 3J^5 + 2J^4\right] > 0$ for $J > 1$ To sum-up, we have: $h(0) < 0$, $h(c_1) < 0$, $h(\overline{c}) > 0$ and $h(\infty) = \infty$. Then, there is a threshold value $\widetilde{c}$ with $c_1 < \widetilde{c} < \overline{c}$ such that $h(\widetilde{c}) = 0$ If $c > \widetilde{c}$ then $h(c) > 0$, so $f(R, c, t, J) < 0 \Leftrightarrow \dfrac{\partial\theta}{\partial J} < 0$ If $c < \widetilde{c}$ (or $t < t_1$), then $h(c) < 0$ so $f(R, c, t, J) > 0 \Leftrightarrow \dfrac{\partial\theta}{\partial J} > 0$

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