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ABSTRACT

Who Integrates?*

We examine vertical backward integration in oligopoly. Analysing a standard linear Cournot model, we find that for wide parameter ranges (i) some firms integrate, while others remain separated, and (ii) efficient firms are more likely to integrate vertically. Adopting a reduced-form approach, we identify a wholesale price effect and demand/mark-up complementarities as the driving forces for our results. We show that our results generalize beyond the Cournot example under fairly natural assumptions.

JEL Classification: L13, L22, L40 and L82
Keywords: efficiency, foreclosure, vertical integration and vertically-related oligopolies

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1 Introduction

In many industries, some firms are vertically integrated, whereas others remain separated. A prominent example is the petroleum refining industry, which processes crude oil to manufacture products such as gasoline and lubricants. In the U.S., for instance, in 1995 many large refining firms were integrated backward into the exploration and extraction of crude oil or forward into the marketing and distribution of finished products. At the same time, there were smaller independent refining firms which were vertically separated both from crude oil production and retailing.[1]

Another interesting example is the UK package holidays industry, where tour operators assemble holiday packages by contracting with suppliers of transport and accommodation services. In 1998, the market for foreign package holidays comprised a small number of large and fully integrated tour operators that used their own airlines and distributed packages through their own travel agencies. These large integrated tour operators competed with numerous smaller independent firms on each layer of the industry.[2,3]

In the present paper, we examine how such asymmetries in vertical structure come about. In particular, we provide an explanation of the apparent empirical relation between firm size (or market share), and vertical integration. The received literature suggests that one may address endogenous vertical integration from the transaction cost perspective[4] or the product market competition perspective,[5] respectively. We shall adopt the latter ap-

[1] See Aydemir and Buehler (2002) for a more detailed discussion of the vertical structure of the U.S. petroleum refining industry. Bindemann (1999) provides a survey of vertical integration in the oil industry.

[2] The structure of the market for foreign package holidays is well-documented in two recent reports by the Monopolies and Mergers Commission (1997) and the European Commission (1999).

[3] Asymmetric vertical structures are also documented for the beer industry in the UK (Slade 1999a) and the retail gasoline market in Vancouver in 1991 (Slade 1999b).

[4] Prominent contributions include Williamson (1985), Grossman and Hart (1986), and Hart and Moore (1990), which analyze bilateral relationships and thus are not directly applicable to the analysis of endogenous asymmetries in oligopolies. In a more recent paper, Grossman and Helpman (2002) combine incomplete contracting with industry and general equilibrium. In contrast to these authors, we allow for cost-reducing investments of firms.

[5] Standard references are Bonanno and Vickers (1988) and Gal-Or (1990); see Perry

proach, since it is better suited to study strategic integration incentives in oligopoly, which are the focus of our analysis.

We proceed in two steps: In a first step, we consider a linear Cournot duopoly where potentially asymmetric firms decide about incurring a fixed cost to set up an upstream unit for the production of an essential intermediate input. Firms that decide to remain separated buy the input at the wholesale price set by an upstream monopolist. In this setting, we derive the following results:

(i) For suitable levels of setup costs, an equilibrium exists where one firm integrates and the other stays separated, even if firms are identical ex ante. In other words, vertical integration of one firm may act as a barrier to integration for the other.

(ii) When firms differ with respect to their initial cost structures, efficient firms are more likely to integrate vertically. As efficiency tends to coincide with high market share, this result fits nicely with the observation that we typically have large integrated and small separated firms.

In a second step, we adopt a reduced-form analysis to show that these results generalize beyond the linear Cournot example under fairly natural assumptions.

To identify the driving forces behind these results, it is necessary to analyze how integration decisions affect the production costs of downstream firms. For the integrating firm i, costs decrease as it no longer has to buy from the wholesale monopolist; this is the direct *efficiency effect* of vertical integration. For the separated competitor $j \neq i$ costs also fall. Intuitively, firm i's integration decision reduces demand for the intermediate input on the wholesale market, and the input price thus falls; this is the indirect *wholesale price effect* of vertical integration.[6]

For result (i) to hold, it is clearly important that integration decisions should be strategic substitutes, that is, integration is more profitable if the

(1989) for an early survey of the vertical integration literature. More recent contributions include Abiru et al. (1998) and Jansen (2003).

[6] In section 4.3, we modify our setting so that wholesale prices might increase if a firm integrates—that is, we allow for foreclosure effects.

competitor does not integrate. There are two reasons why vertical integration decisions are likely to be strategic substitutes. First, because of the wholesale price effect (the competitor's integration reduces the wholesale price), less is to be gained from avoiding to pay this price by own integration. Second, as long as the direct efficiency effect of integration dominates over the indirect wholesale price effect, integration leads to higher equilibrium demand and mark-up (price minus cost) and thus higher own product market profit. Vertical integration of a competitor, in turn, reduces a firm's demand, mark-up and product market profit. Thus, the mark-up increase resulting from integration is more valuable if the competitor is not integrated, as it applies to a greater output level. That is, there is a *demand/mark-up complementarity* that supports the strategic substitutes property of integration decisions.

The demand/mark-up complementarity also helps to explain why efficient firms are more likely to integrate. Firms that are efficient initially have high demand and mark-up and thus benefit more from the increase of demand and mark-up brought about by vertical integration.

Finally, we discuss a number of extensions and limitations of our analysis. First, we show that our results generalize quite naturally to the case with more than two downstream firms. Second, we consider the case where integrated downstream firms are also active as suppliers in the upstream market. We find that the incentives to integrate may actually be smaller for low-cost firms. Third, we examine the case where firms integrate backward by acquiring suppliers rather than setting up an upstream unit. While the basic demand/mark-up complementarity carries over to this setting, the wholesale price effect may be reversed: By integrating backward, downstream firms typically reduce both supply and demand—so that wholesale prices may rise rather than fall.[7] As a consequence, vertical integration decisions *may* be strategic complements rather than substitutes.

The paper adds to the vertical integration literature in several ways. First, we identify two driving forces of equilibrium vertical market structure that

[7]If wholesale prices rise with vertical integration, own integration increases (separated) rivals' costs (see section 4.3). The notion of "raising rivals' costs" (Salop and Scheffman 1983, 1987) lies at the heart of the literature on vertical foreclosure, which is a controversial topic in industrial organization. See Rey and Tirole (forthcoming) for a survey.

have hitherto received little or no attention: the demand/mark-up complementarity in product market competition, and the wholesale price effect of vertical integration. Second, we show that differences in the firms' efficiencies play a crucial role for explaining vertical market structure: in equilibrium, efficient firms are more likely to integrate vertically. This aspect has largely been ignored in the vertical integration literature.[8] Third, our reduced-form analysis indicates that asymmetric vertical market structure may be more common than the earlier literature suggests: it may occur for very general types of product market competition, and it does not rely on the existence of a foreclosure effect of vertical integration (i.e. there may be an asymmetric market structure even if the wholesale price decreases with vertical integration).[9]

The remainder of the paper is organized as follows. Section 2 uses a standard Cournot model to motivate the assumptions of our more general reduced-form model. Section 3 introduces our assumptions on downstream product market competition and develops the main results of the paper, suggesting in particular that efficient firms are more likely to integrate. Section 4 explains why the assumptions of section 3 are plausible in many contexts. Section 4 points to possible countereffects. Section 5 concludes and discusses possible extensions.

2 An Introductory Example

To motivate our reduced-form analysis below, we consider a linear Cournot duopoly as an example. The inverse demand function for the final product is given by $P(Q) = a - Q$, with q_i denoting the quantity of firm i, $Q = q_1 + q_2$, and $a > 0$.

To produce one unit of the final product (the downstream good), firms require one unit of an intermediate product (the upstream good). Suppose that the marginal cost of producing the intermediate product is constant

[8] Recent papers by Abiru et al. (1998) and Jansen (2003) have focused on vertical integration in Cournot models with symmetric firms.

[9] For instance, Ordover et al. (1990) show that asymmetric integration equilibria can arise when there is foreclosure.

and normalized to zero. A vertically integrated firm produces this input in-house. A vertically separated firm obtains the intermediate product from a monopolistic upstream supplier. Let w_i denote firm i's cost of obtaining the intermediate product. We then immediately have that $w_i = 0$ for integrated firms. For separated firms, w_i will be the monopoly price set by the upstream supplier.

Further, we assume that transforming the intermediate product into the final good adds t_i to marginal costs. Transformation costs t_i may differ across firms. It will be convenient to write firm i's transformation cost as $t_i = \bar{t} - Y_i$, where $\bar{t} \equiv \max(t_1, t_2)$. Here, Y_i can be interpreted as firm i's efficiency level. Thus, firm i's marginal cost is given by

$$c_i = w_i + \bar{t} - Y_i, \quad i = 1, 2.$$

Finally, let V_i reflect firm i's state of vertical integration such that

$$V_i = \begin{cases} 0, & \text{if } i \text{ is vertically separated,} \\ 1 & \text{if } i \text{ is vertically integrated,} \end{cases} \qquad i = 1, 2.$$

As usual, for linear Cournot competition, equilibrium downstream quantities, mark-ups (price minus cost) and product market profits are functions of marginal costs:

$$\begin{array}{ll} q_1 = m_1 = \frac{a-2c_1+c_2}{3}, & \pi_1 = \frac{(a-2c_1+c_2)^2}{9}; \\ q_2 = m_2 = \frac{a-2c_2+c_1}{3}, & \pi_2 = \frac{(a-2c_2+c_1)^2}{9}. \end{array}$$

As marginal costs will turn out to depend on the vertical structure $\mathbf{V} = (V_1, V_2)$ and the firms' efficiency levels $\mathbf{Y} = (Y_1, Y_2)$, it will often be convenient to use the following notation:

Notation 1 *For $i = 1, 2$, $j \neq i$, equilibrium product market profits Π_i, mark-ups M_i and outputs Q_i as functions of $\mathbf{V}$ and $\mathbf{Y}$ are written as*

$$\begin{aligned} \Pi_i(\mathbf{V}; \mathbf{Y}) &= \pi_i(c_1(\mathbf{V}; \mathbf{Y}), c_2(\mathbf{V}; \mathbf{Y})); \\ M_i(\mathbf{V}, \mathbf{Y}) &= m_i(c_1(\mathbf{V}; \mathbf{Y}), c_2(\mathbf{V}; \mathbf{Y})); \\ Q_i(\mathbf{V}, \mathbf{Y}) &= q_i(c_1(\mathbf{V}; \mathbf{Y}), c_2(\mathbf{V}; \mathbf{Y})). \end{aligned} \tag{1}$$

We now proceed to solve a vertical integration game where, in a first stage, firms simultaneously decide whether to set up their own upstream production unit before, in a second stage, the wholesale price is determined and, finally, product market competition takes place.

2.1 Product Market Competition

In the following, both the cost of obtaining the intermediate product w_i and equilibrium profits Π_i will depend on $\mathbf{V}$ and $\mathbf{Y}$. We start by deriving these specific functions $w_i(\mathbf{V}, \mathbf{Y})$ and $\Pi_i(\mathbf{V}, \mathbf{Y})$. To this end, we analyze each conceivable vertical industry structure $\mathbf{V} = (V_1, V_2)$, in turn. In each case, we assume that the market size $\alpha \equiv a - \bar{t}$ is sufficiently large and the efficiency differences between firms are small so as to avoid boundary solutions.[10]

Case 1 *Full Integration* ($\mathbf{V} = (1, 1)$)*:*

If both firms are integrated, then, by assumption, for both firms the cost of obtaining the intermediate product is

$$w_i(1, 1; \mathbf{Y}) = 0. \tag{2}$$

Firm i's marginal cost is thus $c_i = t_i = \bar{t} - Y_i$. Hence, in equilibrium downstream profits are

$$\Pi_i(1, 1; \mathbf{Y}) = \frac{(\alpha + 2Y_i - Y_j)^2}{9}, \quad i, j = 1, 2, i \neq j. \tag{3}$$

Case 2 *Partial Vertical Integration* ($\mathbf{V} = (1, 0)$)*:*

Suppose that firm 1 is vertically integrated, whereas firm 2 is vertically separated ($\mathbf{V} = (1, 0)$). Further, assume that the integrated firm is not active in the upstream market.[11] Suppose that the separated upstream firm sets

[10] More specifically, we require that $\alpha > \max\{2.5Y_i - 3.5Y_j\}, i, j = 1, 2, i \neq j$.

[11] The more general case where integrated firms may be active in the upstream market is discussed in section 4.2.

the wholesale price before downstream firms engage in quantity competition. The costs of obtaining the intermediate product are thus

$$w_1(\mathbf{V}, \mathbf{Y}) = w_1(1, 0; \mathbf{Y}) = 0 \tag{4}$$

and $w_2(\mathbf{V}, \mathbf{Y}) = w_2(1, 0; \mathbf{Y}) > 0$, respectively. Given the marginal costs implied by w_1 and w_2, downstream firms $i = 1, 2$ choose their profit maximizing quantity $q_i^*(w_1, w_2; \mathbf{Y})$. Thus, the upstream monopolist determines the wholesale price by maximizing $\Pi^U = w_2 \cdot q_2^*(w_1, w_2; \mathbf{Y})$. Straightforward calculations yield

$$w_2(1, 0; \mathbf{Y}) = \frac{1}{4}(\alpha - Y_1 + 2Y_2). \tag{5}$$

Using (5), downstream profits are given by

$$\Pi_1(1, 0; \mathbf{Y}) = \frac{(5\alpha + 7Y_1 - 2Y_2)^2}{144}; \quad \Pi_2(1, 0; \mathbf{Y}) = \frac{(2\alpha - 2Y_1 + 4Y_2)^2}{144}. \tag{6}$$

Case 3 *Full Vertical Separation* ($\mathbf{V} = (0, 0)$)*:*

Finally, suppose that both downstream firms are vertically separated from upstream operations, facing identical wholesale prices $w_1 = w_2 \equiv w$. Downstream firms then choose Cournot quantities $q_i^*(w, \mathbf{Y})$. The upstream monopolist then chooses w so as to maximize $\Pi^U = w \cdot (q_1^*(w, \mathbf{Y}) + q_2^*(w, \mathbf{Y}))$.

Straightforward calculations yield

$$w_i(0, 0; \mathbf{Y}) = \frac{1}{4}(2\alpha + Y_1 + Y_2), \quad i = 1, 2. \tag{7}$$

Comparison of (7) and (5) indicates that firm 2's wholesale price w_2 is smaller if firm 1 is integrated ($w_2(1, 0; \mathbf{Y}) < w_2(0, 0; \mathbf{Y})$). This wholesale price effect of vertical integration will be crucial in the reduced-form analysis below.

Using (7), downstream profits are given by

$$\Pi_i(0, 0; \mathbf{Y}) = \frac{(0.5\alpha + 1.75Y_i - 1.25Y_j)^2}{9}, \quad i, j = 1, 2, i \neq j. \tag{8}$$

2.2 Integration Decisions

We now study how non-integrated firms simultaneously decide about becoming vertically integrated before product market decisions are made. We assume that, by incurring a fixed cost of F, each firm can set up its own upstream unit.[12] Henceforth, we use the following notation to characterize firm i's incentive to integrate vertically:

Notation 2 *For $i = 1, 2$, $j \neq i$, let $\Delta_i (V_j; \mathbf{Y})$ denote firm i's profit increase from vertical integration, given the values of all other variables, i.e.*

$$\begin{aligned} \Delta_1 (V_2; \mathbf{Y}) &\equiv \Pi_1 (1, V_2; \mathbf{Y}) - \Pi_1 (0, V_2; \mathbf{Y}); \\ \Delta_2 (V_1; \mathbf{Y}) &\equiv \Pi_2 (V_1, 1; \mathbf{Y}) - \Pi_2 (V_1, 0; \mathbf{Y}). \end{aligned}$$

First, suppose both downstream firms are identical initially, so that $Y_1 = Y_2 = 0$. We can then write firm i's incentive to integrate as $\Delta_i (V_j; \mathbf{Y}) = \Delta_i (V_j; \mathbf{0})$, where $\mathbf{Y} = (0, 0) = \mathbf{0}$. The above results then imply that firm i's profit differentials associated with vertical integration are given by

$$\begin{aligned} \Delta_i (0; \mathbf{0}) &= \frac{25}{144}\alpha^2 - \frac{1}{36}\alpha^2 \approx 0.146\alpha^2; \\ \Delta_i (1; \mathbf{0}) &= \frac{1}{9}\alpha^2 - \frac{4}{144}\alpha^2 \approx 0.083\alpha^2. \end{aligned}$$

Our first observation then follows immediately.

Observation 1 *Suppose that $\mathbf{Y} = \mathbf{0}$. Then, if the costs of setting up an upstream unit satisfy $0.146\alpha^2 > F > 0.083\alpha^2$, we have*

$$\Delta_i (0; \mathbf{0}) > F > \Delta_i (1; \mathbf{0}), \tag{9}$$

i.e. there will be an asymmetric equilibrium where only one firm integrates.

Observation 1 indicates that the equilibrium market structure may turn out to be asymmetric even if firms are perfectly symmetric to start with.

[12] That is, F may be interpreted as the cost of setting up an upstream plant of minimum efficient scale, net of any resale value.

This happens since vertical integration decisions are *strategic substitutes* if condition (9) is satisfied.[13] In other words, integration by one firm makes integration less attractive for the other firm. In section 3, we shall generalize this result and clarify the economic intuition behind the strategic substitutes property.

Next, allow efficiency levels to differ. Assume w.l.o.g. that firm 2 is more efficient than firm 1, i.e. $Y_1 > Y_2$. We try to make sense of the intuition that efficient firms are more likely to integrate vertically than inefficient firms. A strong version of this statement would be that $Y_1 > Y_2$ implies $V_1 \geq V_2$ in any equilibrium of the integration game. Observation 1 immediately clarifies why such a result cannot be expected to hold: If $Y_1 = Y_2$, then asymmetric equilibria may well exist, because by condition (9) the integration incentive is *strictly* greater for a firm that faces a non-integrated competitor. In particular, there may be a strict equilibrium with firm 2 integrating, but not firm 1. By continuity, such an equilibrium still exists when firm 2 is slightly less efficient than firm 1.

However, a weaker version of the statement that efficient firms are more likely to integrate does hold: Whenever there is an equilibrium where only the inefficient firm integrates, there is also an equilibrium where only the efficient firm does. To see this, note that an equilibrium where only the inefficient firm integrates requires that, for $H > L$,

$$\Delta_2 (0; H, L) > F > \Delta_1 (1; H, L) . \tag{10}$$

The equilibrium where only the efficient firm integrates requires

$$\Delta_1 (0; H, L) > F > \Delta_2 (1; H, L) . \tag{11}$$

Clearly, (10) implies (11), provided

$$\Delta_1 (0; H, L) > \Delta_2 (0; H, L) \tag{12}$$

[13] Note in passing that for (9) to be satisfied, the market must be of intermediate size: For a given level of fixed costs F, none (both) of the firms will find it profitable to integrate if α is very large (small).

and

$$\Delta_1(1; H, L) > \Delta_2(1; H, L). \tag{13}$$

Straightforward calculations show that (12) and (13) indeed hold in the Cournot example for reasonable levels of cost reduction. We summarize this finding in our second observation:

Observation 2 *Suppose that $Y_1 > Y_2$. Then, firm 1 is more likely to integrate vertically than firm 2 in the following sense: Whenever there is an equilibrium where only the inefficient firm integrates, there is also an equilibrium where only the efficient firm integrates.*

As will be shown in the next section, observation 2 relies on the existence of a demand/mark-up complementarity, which essentially requires that the mark-up increase associated with vertical integration is more valuable when demand is high due to high efficiency. This demand/mark-up complementarity is naturally satisfied in the linear Cournot model.

3 A More General Model

We now show that observations 1 and 2 hold more generally. A reduced-form analysis clarifies the intuition of the results obtained for the Cournot example, as well as some limitations. We develop our main results in a duopoly framework. In section 4.1, we pursue the question how these results might be affected when there are more firms.

3.1 Assumptions

Our framework is similar to that in section 2, with the following exceptions: First, we do not impose any restrictions on the number of upstream firms. Second, we neither derive input prices w_i nor profits Π_i explicitly. Rather, generalizing the above example, we assume that w_i as well as equilibrium downstream demands Q_i, mark-ups M_i, and profits Π_i are functions of both $\mathbf{V}$ and $\mathbf{Y}$ with suitable properties. We therefore write firm i's marginal cost function as

$$c_i(\mathbf{V}; \mathbf{Y}) = w_i(\mathbf{V}, \mathbf{Y}) + \bar{t} - Y_i.$$

The following assumption generalizes conditions (2), (4), (5) and (7) from the linear Cournot example.

Assumption 1 *The* ***input price*** *satisfies the following conditions:*

$$w_1(1, V_2; \mathbf{Y}) = w_2(V_1, 1; \mathbf{Y}) = 0, \quad V_1, V_2 \in \{0, 1\}; \tag{14}$$

$$\begin{gathered}\text{For arbitrary } V', V'' \in \{0,1\} \text{ and } Y', Y'' \in [0, \infty) \\ w_1(V', V''; Y', Y'') = w_2(V'', V', Y'', Y');\end{gathered} \tag{15}$$

$$w_1(0, 0; \mathbf{Y}) > w_1(0, 1; \mathbf{Y}); \quad w_2(0, 0; \mathbf{Y}) > w_2(1, 0; \mathbf{Y}); \tag{16}$$

$$w_i(\mathbf{V}, \mathbf{Y}) \text{ is increasing in } Y_i \text{ and } Y_j \text{ if } V_i = 0. \tag{17}$$

Condition (14) restates the assumption that an integrated firm obtains the intermediate product at zero marginal cost. (15) is a symmetry condition which requires that under comparable market conditions, downstream firms pay the same price for acquiring the intermediate product. (16) reflects the wholesale price effect of integration on demand for the intermediate product: If a competitor becomes integrated, demand on the wholesale market falls, which reduces the wholesale price. (17) holds because more efficient firms have greater demand for the intermediate input, which drives up wholesale prices.

To model product market competition in reduced-form, we further impose the following assumption:

Assumption 2 *For every vector* $\mathbf{c} = (c_1, c_2)$ *of marginal costs, there exists a unique* ***product market equilibrium*** *resulting in downstream outputs* $q_i(\mathbf{c})$, *mark-ups* $m_i(\mathbf{c})$ *and profits* $\pi_i(\mathbf{c})$, *respectively, such that*

$$\pi_i(\mathbf{c}) = q_i(\mathbf{c}) \cdot m_i(\mathbf{c}),$$

where q_i *and* m_i *are both decreasing in* c_i *and increasing in* c_j *for* $j \neq i$.

Using assumption 2, we can write product market profits Π_i as well as mark-ups M_i and outputs Q_i directly as a function of the industry's vertical structure and the firms' efficiency levels. For simplicity, we assume that all these functions are differentiable in $\mathbf{Y}$. Finally, we require that product market profits satisfy the following symmetry condition.

Assumption 3 *Product market profits are* ***exchangeable****, i.e. for all* $V', V'' \in \{0, 1\}$ *and* $Y', Y'' \in [0, \infty)$,

$$\Pi_1(V', V''; Y', Y'') = \Pi_2(V'', V', Y'', Y').$$

3.2 Analyzing Integration Decisions

Generalizing section 2.2, we now characterize the equilibria of a vertical integration game where firms may choose to integrate vertically by setting up an upstream unit. Assume w.l.o.g. that firms are ordered such that

$$Y_1 \geq Y_2. \tag{18}$$

We suppose that non-integrated firms ($\mathbf{V}^0 = \mathbf{0}$) with efficiency levels $\mathbf{Y}$ simultaneously choose v_i, where $v_i = 1$ if firm i decides to integrate and $v_i = 0$ if it remains separated. As in the Cournot example, we suppose that the costs of setting up an upstream unit are given by a constant $F > 0$.[14] With $\mathbf{v} = (v_1, v_2)$ and $\mathbf{V} = \mathbf{V}^0 + \mathbf{v} = \mathbf{v}$, objective functions are given by

$$\Pi_i(\mathbf{V}, \mathbf{Y}) - F \cdot v_i.$$

Hence, we abstract from the possibility that integrated firms might also obtain profits from supplying intermediate goods to downstream competitors.[15] We use the notation $\mathbf{v} = \mathbf{1}$ and $\mathbf{v} = \mathbf{0}$ to denote situations where both firms integrate ($v_i = 1, i = 1, 2$) or stay separated ($v_i = 0, i = 1, 2$), respectively.

First, generalizing observation 1, we show that even if firms start out identically and face the same exogenous integration costs, the equilibrium may have one firm integrating, whereas the other remains separated.

[14] In section 4.3, we relax this assumption.

[15] The role of upstream sales is discussed in section 4.2.

Proposition 1 *Consider the vertical integration game with $Y_1 = Y_2$. Suppose that, for $i = 1, 2$,*

$$\Delta_i(0; \mathbf{Y}) \geq F \geq \Delta_i(1; \mathbf{Y}). \tag{19}$$

(i) There is an asymmetric equilibrium where exactly one firm integrates.

(ii) If (19) holds with inequality, all pure strategy equilibria must be asymmetric.

(iii) If (19) does not hold, then no asymmetric equilibrium exists.[16]

Proof. See Appendix. ∎

Proposition 1 states that there are asymmetric equilibria for suitable levels of integration costs if vertical integration decisions are *strategic substitutes.* More specifically, $\Delta_i(0; \mathbf{Y}) > \Delta_i(1; \mathbf{Y})$ requires that firm i's integration incentives are higher if firm j does not integrate than if it does. In contrast, if integration decisions were strategic complements, vertical integration by firm j would render vertical integration more profitable for firm i. As a result, only symmetric equilibria could exist: Either both firms would integrate or none.

Proposition 1 relates to the familiar Chicago school claim that strategic vertical integration cannot generate competitive harm, because non-integrated firms can always counter by vertically integrating themselves so as to assure input supply at competitive prices (see e.g. Bork 1978). Our proposition demonstrates that countering vertical integration by own integration—sometimes called "bandwagoning"—might turn out to be unprofitable even when the circumstances appear to be most favorable, i.e. when firms are symmetric initially and integration costs are the same for all firms. That is, vertical integration might effectively preempt vertical integration by other firms.

Note that proposition 1 differs from related results derived by Ordover et al. (1990) and Jansen (2003). Ordover et al. (1990) show that an asymmet-

[16] Proposition 1 can be extended to sequential integration decisions. For instance, if (19) holds, any subgame perfect equilibrium of a sequential vertical integration game must be asymmetric.

ric market structure may emerge endogenously if vertical integration raises wholesale prices, i.e. if there is a foreclosure effect. Proposition 1 clarifies that a foreclosure effect is not necessary for an asymmetric market structure to emerge.[17] Jansen (2003) fully abstracts from vertical externalities (such as double mark-ups or vertical foreclosure) to derive conditions under which asymmetric vertical market structures may endogenously emerge in Cournot equilibrium. Proposition 1, in contrast, allows both for vertical externalities and various forms of product market competition.

Next, we generalize our observation 2 from section 2, which states that efficient firms are more likely to integrate vertically than inefficient firms.

Proposition 2 *Suppose that* $\Pi_i(\mathbf{V}, \mathbf{Y})$ *satisfies the following condition:*

$$\frac{\partial \Pi_i}{\partial Y_i} - \frac{\partial \Pi_i}{\partial Y_j} \text{ is increasing in } V_i \text{ for } i = 1, 2, \ j \neq i. \tag{20}$$

(i) If $Y_1 > Y_2$ *and there is a pure strategy equilibrium with* $V_1^* < V_2^*$*, there also is a pure strategy equilibrium with* $V_1^* > V_2^*$*.*

(ii) If $\Delta_1(0; \mathbf{Y}) > F > \Delta_1(1; \mathbf{Y})$ *holds, there exists an asymmetric equilibrium where* $V_1^* = 1$ *and* $V_2^* = 0$*.*

Proof. See Appendix. ■

Result (i) states that, if condition (20) holds, and there is an equilibrium where the inefficient firm integrates and the efficient firm does not, then there is also an equilibrium where the efficient firm integrates and the inefficient firm does not. In this sense efficient firms are more likely to integrate. Result (ii) gives a sufficient condition under which an asymmetric equilibrium where only the efficient firm integrates actually exists.

Note that proposition 2 does not rule out the existence of an equilibrium where the inefficient firm integrates and the efficient firm does not (i.e. $Y_2 < Y_1$ and $V_2^* > V_1^*$): Though (20) works against such an equilibrium, it might still arise as one of several equilibria if the strategic substitutes condition (19) holds: An inefficient firm's decision to integrate may reduce the incentives of

[17] In fact, the presence of a foreclosure effect may make the strategic substitutes condition (19) more difficult to satisfy (see section 4.3).

an efficient firm to integrate (even though, in principle, integration is more attractive for efficient firms).

3.3 Interpretation

We have already seen that conditions (19) and (20) are satisfied in the Cournot example. We now explain intuitively why this is true, and we argue that these conditions are likely to hold for other models of vertically-related oligopolies. More specifically, we show that if two plausible conditions on equilibrium mark-up and demand hold ((22) and (23) below) and, in addition, the wholesale price effect is accounted for (by (24) below), the strategic substitutes condition (19) holds. Similar arguments will show that condition (20) is satisfied.

The strategic substitutes condition (19) implies that $\Delta_i(V_j, \mathbf{Y})$ should be decreasing in V_j. To see why this requirement is natural, decompose equilibrium product market profits into mark-ups and outputs:

$$\Pi_i(\mathbf{V}, \mathbf{Y}) = Q_i(\mathbf{V}, \mathbf{Y}) \cdot M_i(\mathbf{V}, \mathbf{Y}).$$

Now, w.l.o.g., consider firm 1's incentive to integrate, $\Delta_1(V_2, \mathbf{Y})$. Rewriting this profit differential yields

$$\begin{aligned} \Delta_1(V_2, \mathbf{Y}) &= Q_1(1, V_2; \mathbf{Y})[M_1(1, V_2; \mathbf{Y}) - M_1(0, V_2; \mathbf{Y})] \\ &\quad + M_1(0, V_2; \mathbf{Y})[Q_1(1, V_2; \mathbf{Y}) - Q_1(0, V_2; \mathbf{Y})]. \end{aligned} \tag{21}$$

It is plausible to require that the terms in brackets are positive, i.e.,

$$Q_i \text{ and } M_i \text{ are increasing in } V_i. \tag{22}$$

Intuitively, an increase in V_i affects Q_i and M_i via c_i and c_j. The efficiency effect implies that c_i falls; by the wholesale price effect, the same is true for c_j. (22) states that the former effect dominates. Another plausible requirement is:

$$Q_i \text{ and } M_i \text{ are non-increasing in } V_j \text{ for } j \neq i. \tag{23}$$

Recall that an increase in V_j affects Q_i and M_i via c_i and c_j. If the efficiency effect holds, then integration of firm j reduces c_j and thus Q_i and M_i. On the other hand, using (16), integration of firm j also reduces w_i and thus c_i for separated firms, which would tend to increase Q_i and M_i. In principle, (23) might therefore be violated.[18] Like (22), (23) will hold when the efficiency effect is strong relative to the wholesale price effect.

If (22) holds, the terms in square brackets in (21) are both positive, and if (23) holds, the terms before the brackets are both non-increasing in V_2. Thus, the mark-up increase associated with own integration is worth more when the competitor is non-integrated, since demand is higher. Conversely, the demand increase associated with own integration is worth more when the competitor is non-integrated, since the mark-up is higher. This would suggest that vertical integration is more valuable when the competitor is not integrated.

However, an additional effect might arise because the terms in brackets in (21) themselves depend on the competitor's integration decision. More specifically, the effect of an increase in V_i (own integration) on own demand and mark-up is likely to be smaller if $V_j = 1$. For instance, the following condition is likely to be satisfied for demand:

$$Q_1(1,1;\mathbf{Y}) - Q_1(0,1;\mathbf{Y}) \leq Q_1(1,0;\mathbf{Y}) - Q_1(0,0;\mathbf{Y}).$$

To understand why, reformulate this inequality as

$$Q_1(0,0;\mathbf{Y}) - Q_1(0,1;\mathbf{Y}) \leq Q_1(1,0;\mathbf{Y}) - Q_1(1,1;\mathbf{Y}). \tag{24}$$

Note that the l.h.s. of this inequality is the effect of firm 2's integration on firm 1's demand when firm 1 is separated, whereas the r.h.s. is the corresponding effect when firm 1 is integrated. Both terms are positive by (23), reflecting the adverse effect of lower costs of the integrated competitor on own demand. However, this adverse effect is less pronounced when firm 1 is separated: firm 2's integration also reduces the wholesale price, which tends to reduce the l.h.s. of (24). Thus, while the competitor's integration is purely negative for

[18] In the example from section 2, $Q_1(1,0;\mathbf{Y}) = M_1(1,0;\mathbf{Y}) > Q_1(1,1;\mathbf{Y}) = M_1(1,1;\mathbf{Y})$, and $Q_1(0,0;\mathbf{Y}) = M_1(0,0;\mathbf{Y}) = Q_1(0,1;\mathbf{Y}) = M_1(0,1;\mathbf{Y})$.

an integrated firm, it has a positive aspect for a separated firm, so that the l.h.s. of (24) is relatively small.[19]

To sum up, there are two reasons why vertical integration decisions satisfy the strategic substitutes condition (19): (i) Demand/mark-up complementarities, and (ii) the wholesale price effect of the competitor's integration highlighted in (24).

Next, we argue that condition (20) in proposition 2 can be justified in a similar way, that is, by reference to demand/mark-up complementarities following from (22) and (23). Clearly, (20) will hold if

$$\frac{\partial \Pi_i}{\partial Y_i} \text{ is increasing in } V_i \text{, and } \frac{\partial \Pi_i}{\partial Y_j} \text{ is decreasing in } V_i \text{ for } i \neq j.$$

To understand these requirements, first note that

$$\frac{\partial \Pi_i}{\partial Y_i} = \frac{\partial Q_i}{\partial Y_i} M_i + \frac{\partial M_i}{\partial Y_i} Q_i. \tag{25}$$

By definition, $Q_i, M_i, \partial Q_i/\partial Y_i$ and $\partial M_i/\partial Y_i$ are all positive. Clearly, then $\partial \Pi_i/\partial Y_i$ will be increasing in V_i if condition (22) holds, and $\partial Q_i/\partial Y_i$ and $\partial M_i/\partial Y_i$ are non-decreasing in V_i.[20] The role of (22) is to ensure that there are demand/mark-up complementarities: The positive effect of higher downstream efficiency on output ($\partial Q_i/\partial Y_i$) is more valuable when the mark-up M_i is higher because of own integration, and similarly, the positive effect of higher downstream efficiency on the mark-up ($\partial M_i/\partial Y_i$) is more valuable when output Q_i is higher. The additional requirement that $\partial Q_i/\partial Y_i$ and $\partial M_i/\partial Y_i$ must be non-decreasing in V_i is also fairly natural: For separated firms, an increase in efficiency has the undesirable side-effect that the resulting demand increase drives up wholesale prices, which reduces investment incentives. This effect is absent for integrated firms.

The requirement that $\partial \Pi_i/\partial Y_j$ is decreasing in V_i is quite natural as well. By analogous arguments, this condition follows from $\partial Q_i/\partial Y_j < 0$ and $\partial M_i/\partial Y_j < 0$ if (22), and (23) are satisfied, and $\partial Q_i/\partial Y_j$ and $\partial M_i/\partial Y_j$ are

[19] In the Cournot example, condition (24) is satisfied, since $Q_1(0,0;\mathbf{Y}) = Q_1(0,1;\mathbf{Y})$ and $Q_1(1,0;\mathbf{Y}) > Q_1(1,1;\mathbf{Y})$.

[20] In the Cournot example, both requirements are fulfilled.

non-decreasing in V_i. Higher efficiency of a competitor has a direct negative effect on own demand- and mark-up by assumption 2, which reduces the returns from integration. However, the greater efficiency of the competitor also increases its demand, leading to an increase in wholesale prices by (17). Thus, there is a reason why $\partial Q_i/\partial Y_j$ might be decreasing in V_i, that is, $|\partial Q_i/\partial Y_j|$ might be higher for $V_i = 0$ than for $V_i = 1$: For a separated firm ($V_i = 0$), an increase of Y_j drives up the wholesale price w_i, which reinforces the direct negative effect of higher competitor efficiency. For a vertically integrated firm ($V_i = 0$), the latter effect is clearly absent. Nevertheless, even if this last effect is strong enough such that $\partial \Pi_i/\partial Y_j$ in increasing in V_i (rather than decreasing), (34) will still hold provided that $\partial \Pi_i/\partial Y_i$ increases strongly with V_i.

Summing up, our crucial conditions (19) and (20) are naturally satisfied when there are demand/mark-up complementarities.

4 Generalizations and Limitations

As argued above, the assumptions underlying propositions 1 and 2 arise naturally in a duopoly model, when firms integrate by setting up their own upstream units and integrated firms do not engage in wholesale activity. We now discuss the plausibility of our results without these restrictions.

4.1 Large Numbers of Firms

With more than two downstream firms, results that are analogous to propositions 1 and 2 can still be shown to hold. The generalization of proposition 1 is straightforward. Proposition 2 requires a natural extension of our exchangeability assumption. More specifically, assumption 3 has to be generalized by requiring that, for arbitrary firms i and $j, j \neq i, \Pi_i(\mathbf{V}, \mathbf{Y}) = \Pi_j(\mathbf{V}^T, \mathbf{Y}^T)$ if $\mathbf{V}^T$ and $\mathbf{Y}^T$ are obtained from $\mathbf{V}$ and $\mathbf{Y}$ by permutation of i and j. Furthermore, simultaneous permutations of V_j and V_k and Y_j and Y_k for $j \neq k$ ($j, k \neq i$) do not affect firm i's profits. Thus, different competitors have symmetric impacts on firm i. With this extension, the proof of proposition 2 can be generalized to arbitrary numbers of downstream firms. The justification of conditions (19) and (20) follows the lines of section 3.3.

4.2 Upstream Sales

To model the possibility of upstream sales, we continue to work with the reduced-form profit function $\Pi_i(\mathbf{V}, \mathbf{Y})$. However, we now suppose that Π_i also contains profits from upstream activities, $\Pi_i^U(\mathbf{V}, \mathbf{Y})$.[21] Using $Q_i^U(\mathbf{V}, \mathbf{Y})$ and $M_i^U(\mathbf{V}, \mathbf{Y})$ to denote equilibrium wholesale demands and mark-ups, respectively, we obtain

$$\Pi_i^U(\mathbf{V}, \mathbf{Y}) = Q_i^U(\mathbf{V}, \mathbf{Y}) \cdot M_i^U(\mathbf{V}, \mathbf{Y}). \tag{26}$$

Denoting downstream demands and mark-up as $Q_i^D(\mathbf{V}, \mathbf{Y})$ and $M_i^D(\mathbf{V}, \mathbf{Y})$, respectively, the objective function of firm i is given by

$$\Pi_i(\mathbf{V}, \mathbf{Y}) = Q_i^D(\mathbf{V}, \mathbf{Y}) \cdot M_i^D(\mathbf{V}, \mathbf{Y}) + Q_i^U(\mathbf{V}, \mathbf{Y}) \cdot M_i^U(\mathbf{V}, \mathbf{Y}). \tag{27}$$

To assess the robustness of the comparative statics results in the presence of positive upstream profits, we need to explore more thoroughly the characteristics of the functions Q_i^U and M_i^U.

To start with, consider the effects of V_i and Y_i on upstream demands, mark-ups, and profits. Since separated downstream firms ($V_i = 0$) do not sell anything on the wholesale market, we have $Q_i^U = 0$ by definition. For vertically integrated firms ($V_i = 1$), however, we have $Q_i^U \geq 0$ and $M_i^U \geq 0$. Hence, we immediately obtain that

$$Q_i^U \text{ and } \Pi_i^U \text{ are non-decreasing functions of } V_i. \tag{28}$$

With respect to Y_i, the following properties appear plausible:

$$Q_i^U,\ M_i^U \text{ and thus } \Pi_i^U \text{ are non-increasing in } Y_i. \tag{29}$$

Intuitively, if an integrated firm reduces its costs, its downstream demand will

[21] Whether it is reasonable for integrated firms to supply competitors depends on the specific setting, which is unmodeled here (such as the intensity of competition).

be higher and its competitor will face lower demand. Thus, the competitor will require less inputs on the wholesale market, which decreases firm i's wholesale demand. As a result, both Q_i^U and M_i^U should decrease.

Next, consider the effect of V_j on Q_i^U. It is hardly controversial that, to avoid double marginalization, the downstream unit of firm j will demand less from the wholesale market after integration, which should be expected to affect firm i's wholesale demand negatively. Thus, we suppose

$$Q_i^U, M_i^U \text{ and thus } \Pi_i^U \text{ are non-increasing in } V_j. \tag{30}$$

Finally consider the effect of increasing Y_j on Q_i^U: Such an increase will increase firm j's downstream demand Q_j^D, so that additional intermediate inputs will be required to satisfy downstream demand. Thus, an increase in Y_j should have a positive effect on Q_i^U and M_i^U.[22]

Table 1 summarizes the likely comparative statics properties of upstream demand and mark-up.[23]

Table 1: Properties of upstream demand and mark-up

	Strategic Choice Variables			
	Vertical Integration		Downstream Investment	
	V_i	V_j	Y_i	Y_j
Q_i^U	$+$	$-$	$-$	$+$
M_i^U		$-$	$-$	$+$

These considerations indicate that the assumptions required for propositions 1 and 2 might be violated. Take for instance, condition (20). We argued above that this condition is plausible because of demand/mark-up complementarities: In particular, it would seem natural that $\partial\Pi_i^D/\partial Y_i$ is non-decreasing in V_i. However, for Π_i^U, this is less plausible: Using the decomposition (26) and assuming for simplicity that Q_i^U and M_i^U are linear

[22] For more than two downstream and upstream firms, this is less clear, as an increase in Y_j should reduce the demands of other downstream competitors $k \neq i, j$, with negative effects on the upstream demand of firm i.

[23] In the case of vertical separation, the upstream mark-up M_i^U is not well-defined as $Q_i^U = 0$. We therefore do not indicate the effect of V_i on M_i^U in table 1.

functions, we obtain

$$\frac{\partial \Pi_i^U}{\partial Y_i} \text{ is non-increasing in } V_i. \tag{31}$$

Condition (31) holds because $\partial \Pi_i^U / \partial Y_i = 0$ for $V_i = 0$ and $\partial \Pi_i^U / \partial Y_i \leq 0$ for $V_i = 1$ by (29). Intuitively, compared with a separated firm, the incentive for an integrated firm i to increase its efficiency level is reduced because the *business-stealing* effect of higher downstream efficiency also means that downstream competitors reduce their input demand from the upstream unit of integrated firm i.[24] Of course, (20) might still hold because of the complementarity of Y_i and V_i in raising downstream profits. Nevertheless, the case for the results that rely on (20) is somewhat weakened.

Another important assumption was that integration decisions are strategic substitutes (19). To see whether V_i and V_j are likely to be strategic substitutes in Π_i^U, first note that $\Pi_i^U = 0$ if $V_i = 0$. Therefore, we simply need to check whether the upstream profit $\Pi_i^U = Q_i^U \cdot M_i^U$ of a vertically integrated firm ($V_i = 1$), is non-increasing in V_j. As both Q_i^U and M_i^U are non-increasing in V_j, the following observation is immediate:

$$\Pi_i^U \text{ satisfies strategic substitutes with respect to } V_i \text{ and } V_j. \tag{32}$$

Thus, the strategic substitutes property remains plausible with upstream sales in the duopoly setting. We should note, however, that with $I > 2$ downstream and $J \geq I$ upstream firms, additional countereffects could arise.[25]

4.3 Integration by Acquisition

So far, we have assumed that firms become integrated by setting up an upstream unit. Alternatively, firms could acquire upstream suppliers.[26] Most of the insights of the paper generalize to such a setting, even though coun-

[24] Chen (2001) called this reduction of firm i's incentive to invest into cost reduction the "collusion effect" of vertical integration.

[25] See Buehler and Schmutzler (2003a) for details.

[26] To allow for the possibility that all firms integrate by acquisition, there must be at least as many upstream firms as downstream firms.

tereffects may arise. We shall now sketch the main ideas.

First, suppose for simplicity that acquisition costs are an exogenous constant. Then, the only substantial complication arises from the fact that (16) is not necessarily plausible in the new setting. An acquisition of an upstream firm by a competitor not only reduces upstream demand, it may also reduce upstream supply, as a potential supplier is integrated into the competitor. Depending on the relative strength of the two effects, foreclosure might arise, that is, the wholesale price may increase if a firm integrates. This modification does not affect the results derived in section 3. However, the intuition for the conditions underlying propositions 1 and 2 has to be modified.

First, consider the strategic substitutes condition (19). To recall, the argument relied on demand/mark-up complementarities and the wholesale price effect. The argument for the demand/mark-up complementarities is still the same. A demand increase of given size is worth more the greater the mark-up, and vice versa. However, there are now clear reasons why the size of the demand and mark-up increase associated with own integration could be increasing (rather than decreasing) as a competitor integrates: The competitor's integration *may* increase the wholesale price, which increases the beneficial effect of own integration. Thus, the existence of a foreclosure effect may make the strategic substitutes condition (19) more difficult to satisfy.

Second, observe that the possibility of foreclosure has ambiguous effects on condition (20). On the one hand, the demand/mark-up complementarities become more pronounced: If wholesale prices increase when competitors integrate, it is even more likely that own integration increases own demand and mark-up—which is crucial. On the other hand, the size of the mark-up and demand effects may now increase if competitors become integrated: If their integration increases wholesale prices, own integration has a stronger effect on marginal costs.

The analysis becomes more complex when acquisition costs are modeled in a more realistic way. To this end, suppose that for downstream firm i, the cost of acquiring an independent upstream firm is given by $F_i(V_j, \mathbf{Y}), i \neq j$. That is, acquisition costs depend on the vertical structure and the firms' efficiency levels. Using the idea that acquisition costs reflect the opportunity costs of the firms that are being taken over, the following properties are plausible:

$$F_i \text{ is non-decreasing in } Y_i \text{ and } Y_j. \tag{33}$$

Intuitively, equilibrium downstream demand increases when downstream firms reduce their processing costs. Thus, the input demand increases, which raises the profits of upstream firms. Since the costs of acquiring an upstream firm approximately correspond to the profits of that firm in the absence of a merger, acquisition costs should be expected to increase in cost reductions.

Condition (33) suggests another reason why more efficient firms are not necessarily more likely to integrate: Even though demand/mark-up complementarities increase their incentives to do so, they also face higher acquisition costs. Therefore (20) need not hold.[27]

5 Conclusions

This paper provides two main results on the strategic behavior of firms in vertically-related oligopolies. First, even in a symmetric setting it is possible that some firms integrate vertically, and others do not. Second, when downstream firms differ with respect to their initial efficiency levels, efficient firms are more likely to integrate, even though some countereffects may arise.

The first result cautions against the notion that asymmetric vertical integration is unlikely to arise endogenously, as non-integrated firms can always counter by integrating with a non-integrated supplier (bandwagoning): Even when the conditions for this are favorable—i.e. when firms are equally efficient and face the same costs of setting up an upstream unit or acquiring an upstream firm—, the integration of a competitor may reduce the incentives for vertical integration to an extent that separated competitors find bandwagoning unprofitable.

[27] It is also possible that endogenous acquisition costs work against the strategic substitutes property of vertical integration decisions: This would happen if acquisition costs were decreasing in V_j. A force in this direction would be that firm j disappears as a demander on the wholesale market. However, firm j might also disappear as a supplier on the wholesale market, with ambiguous net effects on the remaining upstream firm's profit.

The second result is consistent with the observation that, in many vertically-related industries, the large firms tend to be the integrated ones: Efficiency works towards a high market share, and, as our analysis shows, it also works towards vertical integration.

While this paper is concerned with the effects of efficiency differences on integration decisions, the converse question is also interesting: How do incentives for efficiency improvements for integrated firms differ from those for separated firms? In Buehler and Schmutzler (2003b), we explore this issue in more detail.

6 Appendix

6.1 Proof of Proposition 1

Result (i) is straightforward to prove: First, $\Delta_i(0;\mathbf{Y}) \geq F$ ensures that, if firm j does not integrate, it will be a best response for firm i to do so. Second, $\Delta_i(1;\mathbf{Y}) \leq F$ guarantees that if firm j integrates, it is a best response for firm i to remain separated. (19) also implies that vertical integration will always be profitable for exactly one firm. The argument for (ii) is similar. Result (iii) simply states that there cannot be an asymmetric equilibrium if firm i is not willing to integrate when firm j does not integrate ($\Delta_i(0;\mathbf{Y}) < F$) or when firm i is willing to integrate when firm j does $(F < \Delta_i(1;\mathbf{Y}))$.

6.2 Proof of Proposition 2

(i) The proof follows the logic given in section 2: We have to show that with $Y_1 = H > L = Y_2$, equilibrium condition (10) for $\mathbf{v} = (0,1)$ implies condition (11) for $\mathbf{v} = (1,0)$. As argued in section 2, it therefore suffices to show that (12) and (13) hold. Using exchangeability, (12) and (13) both hold if, for $v_2 = 0$ and $v_2 = 1$

$$\Pi_1(1,v_2;L,H) - \Pi_1(0,v_2;L,H) \leq \Pi_1(1,v_2;H,L) - \Pi_1(0,v_2;H,L). \quad (34)$$

We now prove that (34) holds. For $y \in [0, H-L]$ define

$$f(y) \equiv \Pi_1(1, v_2; L+y, H-y) - \Pi_1(0, v_2; L+y, H-y).$$

Condition (34) is equivalent to

$$f(H-L) - f(0) = \int_0^{H-L} f'(y) dy \geq 0.$$

Note that

$$\begin{aligned} f'(y) = \frac{\partial \Pi_1}{\partial Y_1}(1, v_2, L+y, H-y) - \frac{\partial \Pi_1}{\partial Y_2}(1, v_2, L+y, H-y) \\ - \frac{\partial \Pi_1}{\partial Y_1}(0, v_2, L+y, H-y) + \frac{\partial \Pi_1}{\partial Y_2}(0, v_2, L+y, H-y). \end{aligned}$$

Condition (20) implies that $f'(y)$ is everywhere positive. Thus, (34) holds.

(ii) The result follows because exchangeability implies

$$\Delta_2(1; Y_1, Y_2) = \Delta_1(1; Y_2, Y_1).$$

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