Churn vs. Diversion in Antiturst: An Illustrative Model

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Abstract. An important question in horizontal merger analysis is what share of a firm's lost output from a unilateral price increase will divert to its merger partner. This "diversion ratio" is often estimated using data on customer switching from a firm to its rivals ("churn"). We use a tractable oligopoly model to investigate the potential biases of such estimates, depending on what caused the churn: shifts in quality or marginal cost of the firm or of a rival; or demand-side shifts due to changed circumstances or learning about product attributes. With demand-side shifts, churn can be greater between more distant competitors.

Keywords: diversion ratios, churn, horizontal mergers

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1. INTRODUCTION

In evaluating the likely competitive effects of mergers between sellers of differentiated substitute products, a central question is the strength or "closeness" of competition between those products relative to alternatives. A commonly used measure of the importance of, say, product 2 as a competitor to product 1 is the *diversion ratio* from 1 to 2: the fraction of unit sales lost by product 1 due to an increase in its price that would be diverted to product 2.[1] In a discrete choice context, if firm 1's price increase would cause it to lose 200 customers and firm 2 to gain 100 of them while firm 3 gains 50 and another 50 drop out, the diversion ratios to firms 2 and 3 are 50% and 25%, respectively, and it is natural to identify firm 2 as the closest competitor to firm 1.

Diversion ratios are also used for computing Upward Pricing Pressure (UPP) from a horizontal merger. If single-product firms 1 and 2 merge, the UPP on product 1's price is the increased profit earned on product 2 per unit reduction in the sales of 1. This constitutes an opportunity cost of selling product 1 that will be internalized by the merged firm but was ignored by firm 1 initially, thereby providing a post-merger incnetive to raise the price of product 1 (and similalry for product 2). UPP has been proposed as a screen for anti-competitive mergers in differentiated product industries (Farrell and Shapiro, 2010; see also Moresi, 2010). Diversion ratios and UPP have been adopted in various jurisdictions, including the UK and European Union (OECD, 2011; Oldale and Padilla, 2013), and have been incorporated into the

[1] As originally noted by Willig (1991), the diversion ratio from product j to product k equals (i) the cross-price elasticity of demand for k with respect to $j's$ price multiplied by $k's$ initial quanity, divided by (ii) $j's$ own price elasticity multiplied by $j's$ initial quantity. Shapiro (1996) introduced diversion ratios as a tool in horizontal merger analysis. Werden (1998) discusses, among other things, the relative merits of cross elasticities and diversion ratios for measuring "closeness" of substitutes.

revised U.S. Horizontal Merger Guidelines (2010).[2]

Observe that comparing diversion ratios based on unit sales does not provide a meaningful ranking of relative substitutability when competitors' outputs are in different units.[3] However, recall that diversion ratios are used in merger review not only as stand-alone measures of substitution but also to compute Upward Pricing Pressure from a merger—and can serve that purpose also when the products are in different units.[4] Finally, diversion ratios have relevance beyond horizontal mergers, e.g. for analyzing tax incidence under differentiated Bertrand competition, again regardless of the units in which products are measured (Weyl and Fabinger, 2013).

Estimating diversion ratios, however, is not straighforward. Diversion ratios from a given firm refer to the consumer switching patterns following a unilateral price increase by that firm, while product characteristics, demand conditions, and rivals' prices are held constant. This ideal experiment is rarely available, and in practice agencies often use as an indicator the observed *churn ratios*: of the customers that left a particular firm for whatever reason, what fraction switched to each of its competitors.

It is widely recognized, of course, that churn and diversion ratios can differ depending on the specific reasons for churn, as the Court in *H&R Block* perceptively

[2] "Diversion ratios between products sold by one merging firm and products sold by the other merging firm can be very informative for assessing unilateral price effects. ... The Agencies rely much more on the value of diverted sales than on the level of the HHI [Herfindahl-Hirschman Index] for diagnosing unilateral price effects in markets with differentiated products." (*Id.*, section 6.1.)

[3] Hypothetically, consider sellers of substitute forms of entertainment: movies, sports events, and concerts. The units problem further implies that outside of discrete choice settings diversion ratios can exceed 100%, a point sometimes overlooked. For further discussion of the units issue see Chen and Schwartz (2015, section 5). The model used in this paper will sidestep such issues by assuming unit demands.

[4] The UPP on firm 1's product due to a merger with firm 2 is given by $UPP_1 = d_{12}(p_2 - c_2)$, where $p_2 - c_2$ is the dollar margin beween 2's price and marginal cost. Because the diversion ratio d_{12} expresses additional output sold of product 2 per unit lost by 1, and $p_2 - c_2$ is in dollars per unit of product 2, UPP_1 measures dollars gained on product 2 per unit lost of product 1. Using Monte Carlo experiments Miller, Remer, Ryan and Sheu (2016) find that UPP predicts the price effects from mergers under several demand systems fairly well compared to full-blown merger simulations with misspecified functional forms or errors in estimating demand elasticties.

noted.[5] The OECD (2011, p.255) explicitly cautions: "However, it is then important to understand as much as possible the reasons for these customer switches. Indeed, analyzing win/loss data without relating them to price changes may not provide an accurate assessment of the degree of substitution between brands for a given price increase." Nevertheless, and understandably, churn data are often used, based on an intuition that they provide a (possibly rough) proxy for diversion.[6] Ineed, the *Block* Court itself added: "The plaintiff's expert argues, however, that the IRS switching data can provide at least some estimate of diversion. While this approach is not without its limitations, ... the Court finds that the switching data is at least somewhat indicative of likely diversion ratios." (*Id.*, p. 36.)

In this paper we go beyond the general observation that churn can differ from diversion, and address two questions. Depending on the reason for churn, what are the biases in estimating diversion ratios from churn data? And when do churn ratios, even if biased, rank a firm's rivals correctly in order of competitive importance? We address these questions in a tractable oligopoly model, a variant on the spokes model of Chen and Riordan (2007).[7] In practice, outside observers often have some knowledge of the exogenous shock(s) that directly or indirectly induced the churn, so our results may provide useful guidance in such cases.

[5] "The IRS data, however, provides little direct insight about *why* any given taxpayer switched methods of preparation. The switch could have been for reasons of price, convenience, changes in the consumer's personal situation, an increase or decrease in tax complexity, a loss of confidence in prior method of preparation, or any other reason. As opposed to switching, diversion refers to a consumer's response to a measured increase in the price of a product." (U.S. vs. H&R Block et al., 2011, p. 35.) We will discuss this case further in Section 4.

[6] For example, the US Department of Justice's expert used churn data in U.S. v. H&R Block, Inc., et al. (2011). The European Commission (2012 and 2014) estimated diversion ratios between mobile network operators based data on customers who switched between operators and kept their phone numbers, as has the US Federal Communications Commission (FCC, *see* Kwerel, Lafontaine and Schwartz, 2012). We will discuss these and other cases further in Sections 4 and 5.

[7] Recent applications that use variants of the spokes model include, for example, Caminal (2010), Caminal and Granero (2012), Germanoa and Meier (2013), Rhodes (2011), and Reggiani (2014). Our formulation here is more closely related to the static version of the dynamic model in Somaini and Einav (2013).

Section 2 presents the model. Each firm competes with two rivals and each pair are connected by a Hotelling line to form a triangle. Consumers are located (only) on the three line segments, and a segment's competitive importance depends on both the number of consumers located on it and the degree of product differentiation, the "transport cost" along that line. These parameters determine diversion ratios. We also discuss the relationship in our model between diversion ratios and market shares, a metric that is sometimes used instead of churn as a proxy for diversion ratios.

In Section 3 we consider churn from firm 1 (say) due to supply-side shocks, such as a decrease in its product quality. In our model this is formally equivalent to a price increase, so the churn ratios from firm 1 to its rivals will, by definition, equal the diversion ratios if rivals' prices remain constant. Instead, if churn occurs at the *new equilibrium prices*, we show that churn ratios will typically yield biased estimates of diversion ratios, but nevertheless will correctly identify the closer competitor (Proposition 1). These results apply equally when the exogenous shock is an increase in firm 1's marginal cost instead of a decrease in quality. We then consider churn away from firm 1 due to an increase in the product quality of a rival, say firm 2. If all prices remain constant, then churn from firm 1 to firm 2 obviously will overstate the diversion ratio (because firm 1 becomes less attractive only relative to firm 2, unlike for a price increase by firm 1); but we are able to show that this bias persists even after prices adjust to the new equilibrium (Proposition 2). This result applies also for a decrease in firm 2's marginal cost instead of an increase in its quality.

In Section 4, we analyze churn due to changing preferences, broadly interpreted to include a change in a consumer's circumstances that alters the relative appeal of various products, or learning from experience that the chosen product failed to match expectations. We provide analytic conditions under which the churn ratio between a pair of firms overstates or understates the corresponding diversion ratio (Proposition 3). Relatedly, we show that the churn ratio from firm 1 to, say, firm 2 can be higher than to firm 3 even though firm 3 is the closer competitor to firm 1 (Proposition 4), and discuss scenarios where this wrong ranking may arise in practice.

Section 5 discusses several merger cases where churn data were used as an indicator of diversion ratios, and approaches taken to reduce potential biases. We also briefly discusss limitations of our model and potential extensions.

2. THE MODEL

Consider a simple extension of the Hotelling model: three firms, $1, 2$, and 3, are pairwise connected by three Hotelling lines of unit length forming a triangle. Consumers are uniformly distributed on the lines connecting the three firms, l_{12}, l_{13}, and l_{23}, but the mass of consumers can differ across these segments. A consumer located on l_{12} at distance $x_{12} \in [0,1]$ to firm 1 is denoted as consumer x_{12}, and similarly $x_{13} \in [0,1]$ and $x_{23} \in [0,1]$ denote consumers on l_{13} and l_{23}. Each consumer desires at most one unit, and values firm j's product at V_j minus "transport costs," where j indexes each of the two firms on the relevant segment. Transport costs are proportional to the consumer's distance from the relevant firm; the transport cost parameter represents the degree of product differentiation between the two firms on that segment.

This simple model, adapted from Chen and Riordan's (2007) spokes model, has several notable features. First, it describes a form of discrete choice demand where each consumer only has a first and a second preferred choice, and effectively chooses between these two alternatives in market equilibrium. The model is thus especially convenient to analyze, and can be easily extended to incorporate more firms.[8] As suggested by Somaini and Einav (2013), the model and its extensions can also provide a useful framework for empirical analysis.

[8] For instance, with four firms there would be a network of six Hotelling lines connecting the firms. With only three firms, our model is equivalent to the Hotelling circle model with equidistant firms, but the equivalence does not extend beyond three firms.

Second, it is a spatial model of product differentiation with non-localized competition, where each firm competes with every other firm in the market, but for different sets of consumers. The competitive importance of a particular market segment increases with the mass of consumers located on that segment and decreases with the the transport cost—the proxy for product differentiation in this setting.

Let $m_{ab} \equiv m_{ba}$ denote the mass of consumers on the segment connecting firms a and b, and $t_{ab} \equiv t_{ba}$ denote the transport cost. Without loss of generality we analyze competition from the standpoint of firm 1 against its rivals firms 2 and 3, and define

$$\mu \equiv \frac{m_{12}}{m_{13}} \quad \text{and} \quad \tau \equiv \frac{t_{12}}{t_{13}}, \tag{1}$$

where μ is the market size of segment l_{12} relative to l_{13} and τ is the relative product differentiation. The market structure is illustrated in Figure 1.

Insert Figure 1 here

Suppose for now that firms compete in the above setting for only one period, choosing prices p_1, p_2, and p_3 independently and simultaneously. We make the standard assumption that each firm sets a uniform price to all consumers. Thus, each firm's equilibrium price will depend on competitive conditions in its two directly connected segments *and* in the third segment, because the latter affects rivals' prices. The equilibrium prices have closed form solutions, but their expressions are complex and are shown in the Appendix. We proceed here with demand functions and diversion ratios, which do not require deriving equilibrium prices.

A consumer located between firms 1 and 2, say, obtains net surplus

$$U(x_{12}, p_1, p_2) = \begin{cases} (V_1 - p_1) - t_{12}x_{12} & if \;\; \text{buys product 1} \\ (V_2 - p_2) - t_{12}(1 - x_{12}) & if \;\; \text{buys product 2} \end{cases} \tag{2}$$

and similarly for consumers located on the other two segments. Let V_j denote firm $j's$ "product quality." Since all potential consumers of product j would obtain the same surplus $V_j - p_j$ before subtracting transport costs, we have the following property:

Remark 1 *In our model, a decrease of size Δ in firm $j's$ product quality V_j has the same effect on consumer demands as an increase of size Δ in firm j's price.*

Using the standard Hotelling logic, demand functions are obtained by first identifying the consumer who is indifferent between the two firms on the relevant line segment. Denote the indifferent consumers on the segments l_{12}, l_{13}, and l_{23}, by $\hat{x}_{12}$, $\hat{x}_{13}$, and $\hat{x}_{23}$ respectively. Unless stated otherwise, we assume $V_j = V$ for $j = 1, 2, 3$, with V large enough that the market is fully covered in equilibrium. Then

$$\hat{x}_{12} = \frac{1}{2} + \frac{p_2 - p_1}{2t_{12}}; \qquad \hat{x}_{13} = \frac{1}{2} + \frac{p_3 - p_1}{2t_{13}}; \qquad \hat{x}_{23} = \frac{1}{2} + \frac{p_3 - p_2}{2t_{23}}. \tag{3}$$

The demand functions for firms 1, 2, and 3 are respectively

$$Q_1 = m_{12}\hat{x}_{12} + m_{13}\hat{x}_{13}, \quad Q_2 = m_{12}(1 - \hat{x}_{12}) + m_{23}\hat{x}_{23}; \quad Q_3 = m_{13}(1 - \hat{x}_{13}) + m_{23}(1 - \hat{x}_{23}). \tag{4}$$

The diversion ratio from firm i to firm j is $d_{ij} \equiv -(\partial Q_j/\partial p_i)/(\partial Q_i/\partial p_i)$.[9] Holding rivals' prices constant, if a price increase by firm i causes all its departing customers to switch to the two rivals rather than drop out of the market—as in our Hotelling setting with the market always covered—the diversion ratio is given by

$$d_{ij} = \frac{\partial Q_j/\partial p_i}{\partial Q_j/\partial p_i + \partial Q_k/\partial p_i}.$$

[9] In our model the derivatives of demand functions are constant over all price ranges that yield each firm positive sales on both its market segments; hence the value of d_{ij} will apply not only for a marginal change in p_i but for any change that maintains such positive sales.

In the case of a price change by firm 1,

$$\frac{\partial Q_2}{\partial p_1} = \frac{m_{12}}{2t_{12}}; \qquad \frac{\partial Q_3}{\partial p_1} = \frac{m_{13}}{2t_{13}}. \tag{5}$$

It will be helpful, especially for Section 4, to define the diversion ratios from firm 1 as

$$d \equiv d_{12} \quad \text{hence} \quad d_{13} = (1 - d). \tag{6}$$

Using (1) and (5) yields

$$d = \frac{\mu}{\mu + \tau}. \tag{7}$$

The diversion ratio from firm 1 to firm 2 increases if the mass of consumers on segment l_{12} relative to l_{13} (μ) increases or if the relative product differentiation on these segments (τ) decreases. Firm 2 is the more important competitor to firm 1, i.e. $d > 1/2$, if $\mu > \tau$.

Competition agencies typically lack sufficient information to adequately estimate demand parameters, and they often construct indicators of diversion ratios using data on customer switching ("churn") or on firms' market shares. Before turning to our main focus in the rest of the paper—biases in estimating diversion ratios from churn data—we will discuss briefly the relationship between diversion ratios and market shares in our model.

Diversion Ratios and Market Shares

Willig (1991) showed, *inter alia*, that with logit demand, diversion ratios are proportional to market shares, e.g. if firm 2's market share is twice as large as firm 3's, then a unilateral price increase by firm 1 will cause twice as much diversion to firm 2 as to firm 3. He cautioned, however, that this proportionality need not hold for other demand systems, and it generally does not hold in our model.

As a simple example, assume that all segments have equal masses of consumers and equal transport costs, and that firms 1 and 3 are symmetric but firm 2 has lower marginal cost or higher quality. Then firm 2's equilibrium market share will be larger than 3's, whereas the diversion ratios from firm 1 are equal. Here, the market share advantage (of firm 2) overstates that firm's relative importance as a competitor.

The opposite bias can also arise. Let all firms have equal marginal costs and qualities. Suppose all market segments exhibit equal product differentiation ($t_{ab} = t$ for all ab) but potentially unequal masses of consumers. Then among firm 1's rivals: their aggregate market shares, s_2 and s_3, will track the ranking of diversion ratios from firm 1; but the diversion ratio to the larger rival will be disproportionately greater than its market share: if $s_2 > s_3$ then $d_{12}/d_{13} > s_2/s_3$ (unlike the equality for logit demand). Here, the larger rival's market share *understates* its relative importance as a competitor to firm 1. The proof of this result is in the Appendix (Proposition 5), along with all other proofs, but the intuition runs as follows.

Given $t_{ab} = t$ for all ab, the disparity in diversion ratios d_{12} and d_{13} comes solely from unequal m_{12} and m_{13}, consumer masses on segments l_{12} and l_{13}. Now consider market shares. With symmetric firms, for any segment l_{ab} the two firms' *preferred* price depends only on the differentiation parameter t_{ab}; when $t_{ab} = t$, the preferred prices are equal across segments, hence all firms charge equal equilibrium prices, $p_1^* = p_2^* = p_3^*$, and obtain equal segment shares. Thus, any disparity in the aggregate market shares s_2 and s_3 also arises solely from unequal consumer masses on segments l_{12} and l_{13}, implying the same ranking as for diversion ratios. However, s_2 and s_3 reflect also segment l_{23}, where customers are split equally, which dilutes the discrepancy in market shares compared to diversion ratios.

Thus, when market shares are unequal, they often will yield biased estimates of diversion ratios in our model. Notice from (4) that our model gives rise to a system of linear demands. This suggests that some of our results—such as the lack of proportionality between diversion ratios and market shares illustrated above, and

Propositions 1 and 2 in Section 3—should extend, under suitable parameter restrictions, to linear demands derived from alternative models such as a representative consumer with quadratic utility.

3. CHURN DUE TO SUPPLY-SIDE SHOCKS

The (outbound) churn ratio from firm i to firm j is defined as

$$c_{ij} = \frac{\text{\# of consumers switching from } i \text{ to } j}{\text{Total \# of consumers switching away from } i}, \tag{8}$$

and we will compare this observed churn ratio to the corresponding diversion ratio d_{ij}. We will consider shocks to a firm's marginal cost or product quality.

Remark 2 *In our model, an exogenous change of size Δ in firm j's marginal cost c_j will have identical effects on equilibrium quantities demanded and, hence, on churn ratios, as a change $-\Delta$ in firm j's quality V_j.*

To see the equivalence, consider without loss of generality firm 1, and write its demand and profit functions as

$$Q_1 = D_1(p_1 - V_1, p_2 - V_2, p_3 - V_3)$$

$$\Pi_1 = (p_1 - c_1)D_1(p_1 - V_1, p_2 - V_2, p_3 - V_3).$$

Define firm j's "dollar margin," as $\gamma_j \equiv p_j - c_j$, and firm j's "quality-adjusted marginal cost" as $z_j \equiv c_j - V_j$. We can then rewrite firm 1's profit function as

$$\Pi_1 = \gamma_1 D_1(\gamma_1 + z_1, \gamma_2 + z_2, \gamma_3 + z_3).$$

Thus, our model where firms are described by two parameters (c_j and V_j) and choose prices (p_j) is identical to a model where firms are described by a single parameter

($z_j \equiv c_j - V_j$) and choose margins ($\gamma_j \equiv p_j - c_j$). Therefore, an increase in firm 1's marginal cost from c_1 to $c_1 + \Delta$ is equivalent to a decrease in firm 1's quality from V_1 to $V_1 - \Delta$. Either shock has the same effect on z_1 and, hence, on equilibrium margins and quality-adjusted prices $p_j^* - V_j$ $(= \gamma_j^* + z_j)$, which determine consumer demands.

Given the equivalence, it suffices to analyze shocks to product quality, and we will simplify henceforth by normalizing marginal costs to zero.

3.1 Decrease in Product 1's Quality

Suppose firm 1's product quality V_1 falls by $\Delta > 0$. From Remark 1, the effect on consumer demands is equivalent to an increase by Δ in firm 1's price, implying:

Remark 3 *If churn is caused only by a decrease in firm 1's quality and prices remain constant, then firm 1's churn ratios will equal the diversion ratios:* $c_{1j} = d_{1j}$.

Thus, churn patterns caused by a quality decrease with all prices held constant will give exact measures of diversion ratios—as would an increase in that firm's marginal cost that led to an increase in its price while holding all else constant.[10] Though straightforward, this observation is useful because it helps identify additional natural experiments where churn may provide a good estimate of diversion. Empirically, a quality reduction could reflect shocks such as deterioration in firm 1's customer service or, in the context of video distribution, a dispute between a video provider and a programmer that causes the provider to lose some programming ("blackout"). Such a quality reduction will provide a closer approximation to the effect of an exogenous (cost-induced) price increase by firm 1 the more uniform is its impact on all consumers, in particular, when it does not alter the relative appeal of products 2 and 3 as alternatives to product 1.

[10] If rivals' prices remain constant, churn induced by a fall in firm 1's quality V_1 will yield an exact measure of the diversion ratios even if firm 1's price adjusts downwards, as long as $V_1 - p_1$ still falls.

Suppose, however, that all prices adjust to their new equilibrium levels and the observed churn occurs at these new equilibrium prices. We address two questions: (i) When will the churn ratio c_{12} yields a biased measure of the diversion ratio d_{12} and what determines the direction of the bias? (ii) If there is a bias, do the churn ratios c_{12} and c_{13} nevertheless track the ranking of the diversion ratios d_{12} and d_{13}, and thereby still correctly identify which of firm 1's rival is its "closer" competitor?

Proposition 1 *If churn from firm 1 is caused by a decrease in firm 1's product quality and occurs at the new equilibrium prices, then:*
(i) (Bias) $c_{12} = d_{12}$ *if* $d_{12} = d_{13}$, $c_{12} > d_{12}$ *if* $d_{12} < d_{13}$, *and* $c_{12} < d_{12}$ *if* $d_{12} > d_{13}$.
(ii) (Ranking) $c_{12} = c_{13}$ *if* $d_{12} = d_{13}$, $c_{12} > c_{13}$ *if* $d_{12} > d_{13}$, *and* $c_{12} < c_{13}$ *if* $d_{12} < d_{13}$

Part (i) of the Proposition says that the observed churn ratio from firm 1 to firm 2 (c_{12}) will equal the corresponding diversion ratio (d_{12}) if firms 2 and 3 are equally important competitors to firm 1 ($d_{12} = d_{13}$), will overstate d_{12} if firm 2 is the less important competitor ($d_{12} < d_{13}$), and understate d_{12} if firm 2 is more important. To understand the biases, consider the case $d_{12} < d_{13}$. The reduction in firm 1's quality will shift demand to firms 2 and 3 (even after firm 1's price reduction) and lead them to raise prices. If segment l_{12} is competitively less important than l_{13}, as required for $d_{12} < d_{13}$, then firm 2's price increase will be smaller than firm 3's, so firm 2 will attract a larger share of firm 1's departing customers than if rivals' prices had stayed constant, as assumed in defining d_{12}. Thus, $c_{12} > d_{12}$ in this case.

Part (ii) states that, notwithstanding the possible biases, churn ratios will correctly identify the stronger competitor to firm 1. That is, although c_{12} may over– or underestimate d_{12}, the ranking of c_{12} and c_{13} will always mirror that of d_{12} and d_{13}.

Remark 2 implies that Proposition 1 will apply equally if the exogenous shock is an increase in firm 1's constant marginal cost instead of a decrease in its product quality, again measuring churn at the new equilibrium prices.

3.2 Increase in a Rival's Product Quality

Now consider the switching patterns from firm 1 after an exogenous improvement in the offering of one rival, say firm 2, represented by an increase by $\Delta > 0$ in firm 2's product quality. Since this is equivalent to a *decrease* in 2's price by Δ, if prices remain constant at their initial levels, p_1, p_2, and p_3, then—using (3)—the marginal consumers on the three segments become

$$\hat{x}_{12} = \frac{1}{2} + \frac{p_2 - p_1 - \Delta}{2t_{12}}; \qquad \hat{x}_{13} = \frac{1}{2} + \frac{p_3 - p_1}{2t_{13}}; \qquad \hat{x}_{23} = \frac{1}{2} + \frac{p_3 - p_2 + \Delta}{2t_{23}}, \tag{9}$$

with the demands Q_1, Q_2, and Q_3 again given by (4). Thus, at the original prices, some consumers would switch from 1 to 2 but none from 1 to 3, implying $c_{12} = 1 > d_{12}$: the churn ratio from firm 1 to firm 2 will overstate the diversion ratio. This is obvious, since a quality increase for firm 2 at constant prices will reduce the appeal of firm 1 only relative to firm 2, whereas a unilateral price increase by firm 1 and holding everything else constant—the experiment underlying d_{12}—will reduce firm 1's appeal also relative to firm 3.

Suppose, instead, that churn occurs after all prices adjust to the new equilibrium following firm 2's quality increase? If the equilibrium price differential $p_3 - p_1$ declines, firm 1 will lose some consumers also to firm 3, reducing the churn ratio c_{12} below 1. When would this occur, and could c_{12} then potentially exceed the diversion ratio d_{12}?

Proposition 2 *If churn from firm 1 is caused by an increase in firm 2's product quality and occurs at the new equilibrium prices, then:*
(i) $c_{12} = 1$ $(> d_{12})$ *if* $d_{21} \geq d_{23}$.
(ii) $c_{12} < 1$ *if* $d_{21} < d_{23}$, *but still* $c_{12} > d_{12}$.

The role of $d_{21} \geq d_{23}$ versus $d_{21} < d_{23}$ is understood as follows (a similar argument explained the bias conditions in Proposition 1). Following the increase in firm 2's quality, firm 1 will experience some churn also to firm 3, causing $c_{12} < 1$, if and only if the equilibrium price differential $p_3^* - p_1^*$ falls. An increase in firm 2's quality will indeed trigger a larger price cut by firm 3 than by firm 1 if and only if segment l_{23} is competitively more important to firm 3 than is l_{21} to firm 1 (in the sense of $d_{23} > d_{21}$), because conditions have not changed on the segment l_{23} between firms 2 and 3.

Turning to part (*ii*), even when the price differential $p_3^* - p_1^*$ falls after an improvement in firm 2's quality, so that firm 1 loses customers also to firm 3, the churn ratio to firm 2 still overstates the diversion ratio. One might have conjectured that if segment l_{21} were sufficiently unimportant relative to l_{23}, then the differential price responses to firm 2's quality increase could reduce $p_3^* - p_1^*$ sufficiently to drive c_{12} below d_{12}. However, the factors that makes l_{21} competitively less important relative to l_{23}—fewer consumers or greater differentiation—will also reduce the diversion ratio d_{12}, ensuring $c_{12} > d_{12}$.

Finally, note that Proposition 2 would apply equally if the exogenous shock were a decrease in firm 2's marginal cost rather than an increase in its quality (Remark 2).

4. CHURN DUE TO CHANGING PREFERENCES

Next, consider customer switching driven not by a change in prices or product attributes but by an exogenous "change in preferences." This can reflect a *change in circumstances* that alters the relative appeal of various products, or *learning* from experience that the chosen product performed worse than expected.

We represent such churn using a two-period extension of the static model, again comparing churn and diversion ratios from firm 1. In each period firms play the same static pricing game, but for some consumers their first and second preferred choices reverse between periods. A simple way of modeling this is to assume that in the second period, a portion of consumers $\alpha_{1j}/2$ on segment l_{1j}, $j = 2, 3$, switch locations from $x_{1j} < 1/2$ to $x_{12} > 1/2$, and $\alpha_{1j}/2$ switch in the other direction. (For our purposes, we do not need to specify the switching pattern on l_{23}.) The consumer populations remain uniformly distributed on all market segments. Therefore, equilibrium prices and market shares in both periods are the same as in the static model.[11]

The portion of consumers that will actually switch between firms is determined as follows. Let $\hat{x}^*_{1j}$, given explicitly in (16) and (17) in the Appendix, denote firm 1's equilibrium share of the market segment l_{1j} between firm 1 and firm j, $j = 2, 3$. Recall that $\hat{x}^*_{1j}$ is also the location of the consumer who is indifferent between firms 1 and j. To switch from firm 1 to firm j, a consumer's preferences (i.e., location) must satisfy two conditions: (i) in the first period, $x_{1j} \in [0,\, \hat{x}^*_{1j})$, so this consumer bought from firm 1; and (ii) in the second period, $x_{1j} \in (\hat{x}^*_{1j}, 1]$, so this consumer will buy from firm j. The portion of all consumers whose preferences change from $x_{1j} < 1/2$ to $x_{1j} > 1/2$ and, hence, who *potentially* will switch, is $\alpha_{1j}/2$. The portion that will actually switch from firm 1 to firm j is therefore given by[12]

$$\lambda_{1j} = \alpha_{1j} \min\left\{\hat{x}^*_{1j},\ 1 - \hat{x}^*_{1j}\right\},\ \text{for } j = 2, 3. \tag{10}$$

One can view λ_{1j} as the portion of consumers whose preferences change from 1 to j, adjusted by firm 1's share of consumers on the market segment l_{1j} (hereafter, "segment share"). With equal shares, $\hat{x}^*_{1j} = 1/2$, implying $\lambda_{1j} = \alpha_{1j}/2$.[13] With unequal shares, $\lambda_{1j} < \alpha_{1j}/2$. The *mass* of consumers who will switch from firm 1 to firm 2 and firm 3 is $m_{12}\lambda_{12}$ and $m_{13}\lambda_{13}$, respectively.

[11] Our reduced-form modeling of "changes in preferences" (here, locations) is obviously coarse and restrictive. The model can be extended to asymmetric changes in preferences between two firms, but retaining symmetry will greatly simplify the analysis, enabling us to focus on the relevant issues.

[12] If $\hat{x}^*_{1j} \leq \frac{1}{2}$, the portion that switch is $\frac{1}{2}\alpha_{1j}(\frac{\hat{x}^*_{1j}}{1/2}) = \alpha_{1j}\hat{x}^*_{1j}$, where $\frac{\hat{x}^*_{1j}}{1/2}$ is the fraction of potential switchers that initially bought from firm 1, since consumers are uniformly distributed on $[0, 1]$. If $\hat{x}^*_{1j} > \frac{1}{2}$, the portion that switch is $\frac{1}{2}\alpha_{1j}(\frac{1-\hat{x}^*_{1j}}{1/2}) = \alpha_{1j}(1 - \hat{x}^*_{1j})$, where $\frac{1-\hat{x}^*_{1j}}{1/2}$ is the fraction of potential switchers that will buy from firm j.

[13] It is easily verified that segment shares will be equal, i.e. $\hat{x}^*_{12} = \hat{x}^*_{13} = \frac{1}{2}$, if $t_{ab} = t$ for all ab, while this may not be true if $m_{ab} = m$ for all m but t_{ab} can differ for different ab.

Define the churn ratios from firm 1 as

$$c \equiv c_{12} \quad \text{hence } c_{13} = (1 - c) \tag{11}$$

and define

$$\lambda \equiv \frac{\lambda_{12}}{\lambda_{13}} \tag{12}$$

as the relative preference reversal on firm 1's market segments. The churn ratio from firm 1 to 2 caused by changing preferences is $c_\lambda = \frac{m_{12}\lambda_{12}}{m_{12}\lambda_{12}+m_{13}\lambda_{13}}$ or

$$c_\lambda = \frac{\mu}{\mu + \lambda^{-1}}, \tag{13}$$

while, from (7), the diversion ratio from firm 1 to firm 2 is

$$d = \frac{\mu}{\mu + \tau},$$

where $\mu \equiv \frac{m_{12}}{m_{13}}$ and $\tau \equiv \frac{t_{12}}{t_{13}}$ were defined in (1) as the market size of segment l_{12} relative to l_{13}, and the relative product differentiation.

The churn and diversion ratios, therefore, are positively correlated through the relative market size μ, but this term does not directly affect their ranking. The ranking depends on λ relative to τ. If $\lambda = \tau$, then $c_\lambda = d$, and otherwise the churn ratio yields a biased measure of the diversion ratio.

Proposition 3 *Suppose churn is caused only by preference reversals. Then the churn ratio will overestimate the diversion ratio, $c_\lambda > d$, if $\lambda > \tau^{-1}$, i.e. if the preference reversal on segment l_{12} relative to l_{13} is greater than the inverse of relative product differentiation, and will underestimate when the inequality is reversed.*

Three illustrative cases are shown next, with $\alpha \equiv \frac{\alpha_{12}}{\alpha_{13}}$:

(i) Suppose $t_{ab} = t$: equal product differentiation on all market segments. Then all firms charge the same equilibrium prices and obtain equal segment market shares of 1/2, hence, using (10), the proportion who switch from firm 1 to rival j is $\lambda_{1j} = \frac{\alpha_{1j}}{2}$. Therefore, $c_\lambda > d$ if $\lambda = \alpha > 1$, i.e. if a higher proportion of consumers reverse their preferences between firms 1 and 2 than between 1 and 3.

(ii) Suppose $m_{ab} = m$: equal masses of consumers. Assume further $t_{12} = t_{23} = 1$ while $t_{13} = t$. Then, from (18) in the Appendix, $\hat{x}_{12}^* = \frac{1}{2}\frac{2t+3}{3t+2}$, $\lambda_{12} = \frac{1}{2}\frac{4t+1}{3t+2}\alpha_{12}$, $\lambda_{13} = \alpha_{13}/2$, and c_{12} over-estimates d_{12} if

$$\alpha = \frac{\alpha_{12}}{\alpha_{13}} > \frac{3t+2}{4t+1}t,$$

which, for $t \leq 1$, holds if $\alpha > 1$, or $\alpha_{12} > \alpha_{13}$.

(iii) Suppose $\lambda \geq 1$: the preference reversal rate is weakly higher between firms 1 and 2 than between 1 and 3. Then $c_\lambda > d$ if $\tau < 1$, i.e. if the relative product differentiation is weaker between firms 1 and 2.

In a subset of the cases where churn from firm 1 to firm 2 overstates the diversion ratio ($c_\lambda > d$), comparing churn ratios will wrongly identify firm 1's major competitor. Using (6) and (7), firm 2 is the less important competitor if

$$d < \frac{1}{2} \Leftrightarrow \mu < \tau.$$

Using (13), the churn ratio will be greater to firm 2 if

$$c_\lambda > \frac{1}{2} \Leftrightarrow \mu > \lambda^{-1}.$$

Therefore:

Proposition 4 *Suppose churn is caused only by preference reversals. If* $\lambda^{-1} < \mu < \tau$, *then: (i) firm 2 is firm 1's less important competitor* ($d < \frac{1}{2}$), *yet (ii) churn from firm 1 is greater to firm 2* ($c_\lambda > \frac{1}{2}$).

The logic is straightforward. From Proposition 3, churn overstates diversion ($c_\lambda > d$) if $\lambda > \tau^{-1}$ or, as used below, $\lambda^{-1} < \tau$, which is independent of the relative mass of consumers μ on segment l_{12} versus l_{13}. Diversion ratios depend only on μ and the relative differentiation τ, and $d < \frac{1}{2}$ will hold if $\mu < \tau$. Churn ratios, on the other hand, depend only on μ and the relative preference reversal λ, and $c_\lambda > \frac{1}{2}$ will hold if $\mu > \lambda^{-1}$. Thus, for $\mu \in (\lambda^{-1}, \tau)$ we will have both $d < \frac{1}{2}$ and $c_\lambda > \frac{1}{2}$.[14]

Suggestive Examples

By "changing preferences" we have in mind at least two scenarios that may lead to substantial switching between relatively distant substitutes.[15] One involves changes in personal circumstances. A sports car driver with young children may well switch to a mini van rather than another sports car, and switch back to a sports car when the children are grown; consumers whose incomes rise over the life cycle often migrate from lower-quality versions of a product to higher-quality versions instead of switching among lower-quality versions. A second scenario involves learning about product attributes. A driver who discovers that the sports car's low ride is more terrifying than expected on highways, or that the cargo room is simply too small, is more likely to switch to a different car segment than to another sports car.

Consider competition among US video distributors: two firms that use satellite transmission (DBS) nationally, and local providers that use "wireline" transmission (typically the cable company, and in some areas also the phone company). One expects the DBS firms to compete more closely with each other than with wireline providers, because the performance characteristics of DBS and wireline technologies can differ, and because DBS firms predominantly sell video on a stand-alone basis whereas wireline providers predominantly sell video bundled with broadband Internet

[14] Given $\lambda^{-1} < \tau$ (yielding the bias $c_\lambda > d$), if μ lies outside the interval (λ^{-1}, τ), the ranking of churn ratios and diversion ratios will coincide. When $\mu < \lambda^{-1}$, both d and $c_\lambda < \frac{1}{2}$; when $\mu > \tau$, then both d and $c_\lambda > \frac{1}{2}$.

[15] For further discussion see Chen and Schwartz (2015, Section 4).

access. However, if customer switching occurs over a period when product attributes and prices are stable, one could observe disproportionately large switching (relative to market shares) from a DBS firm to wireline rivals. The switching may reflect changing circumstances, such as a move to a home lacking satellite reception, or increased demand for broadband which makes the wireline bundled offer more attractive. It may also reflect disappointment with DBS technology, e.g. learning that signal reception in bad weather was worse than expected. Switching to a wireline provider is again likely: "you didn't like satellite, so try something different." Importantly, the pool of customers who switch due to such "changing preferences" is not representative of diversion—switching patterns caused by a unilateral price increase.[16]

A vivid illustration that the bias can be large comes from the proposed merger of TaxACT and H&R Block (2011). These firms and Intuit were the top three providers of digital do-it-yourself (DDIY) tax preparation software. The US Department of Justice (DOJ) sued to block the merger, claiming the relevant product market was DDIY services. The merging firms argued for a broader market that includes additional tax preparation methods: assisted preparation and do it yourself pen-and-paper. Internal Revenue Service (IRS) data showed considerable switching from all DDIY providers to those other methods (43% from HRB, 47% from TaxACT, and 61% from Intuit, for tax years 2007-08). Yet, in a thoughtful and detailed opinion, the Court accepted DDIY as the relevant market, based partly on evidence that switching from DDIY was substantially due to changes in tax complexity for those individuals. The IRS categorizes tax returns as Simple, Intermediate, or Complex. As expected, assisted

[16] A similar criticism, the "Silent Majority Fallacy," has been made of the Elzinga-Hogarty test for geographic market definition in antitrust. The test finds a given region overly narrow to qualify as an antitrust market—i.e. a hypothetical monopolist comprised of all the sellers of the relevant product in that region would not profitably raise price by a significant amount—if a sufficient fraction of all consumers residing in that region travel outside it to purchase the product (e.g. patients travelling to out-of-region hospitals). However, this argument presumes "that the non-traveling 'silent majority' is similar to the traveling (pre-merger) minority and is protected against a post-merger price increase by those patents poised to join those already willing to migrate." (Elzinga and Swisher, 2011.)

preparation is relatively more common for Complex than for Simple returns, while the reverse is true of pen-and-paper.[17] Consistent with this, taxpayers who switched from DDIY to pen-and-paper (for tax years 2008-09) on average experienced a decrease in tax complexity. Taxpayers who switched from DDIY to assisted preparation—the greater proportion—were twice as likely to have experienced an *increase* in complexity as those who stayed with DDIY.[18] Based on this and other evidence, the Court concluded that churn from DDIY greatly overestimated the diversion that would occur to other tax preparation methods due to a post merger DDIY price increase.

5. DISCUSSION AND CONCLUSION

Using a simple model, we identified potential biases in estimating diversion ratios from churn data depending on the specific reasons for churn. A key message is the need to recognize why customers switched, in particular, distinguish between supply-side shocks to prices or product attributes versus "changes in preferences." In the latter, switching patterns can be seriously misleading about relative substitutability. Sophisticated practitioners recognize the general problem; here, we note a few ways in which it has been addressed.

In mergers between mobile phone operators, switching data are available for customers who moved between operators and transferred ("ported") their phone number. Agencies obtain porting data as part of enforcing number portability rules and have used it to estimate diversion ratios, while recognizing that the switching need not be driven solely by exogenous changes in quality-adjusted prices. For instance, switch-

[17] Data presented by one of the economic experts showed the following shares: among Complex returns — assisted 70%, DDIY 23% (and the remaining 7% presumably pen-and–paper); among Simple returns — assisted 44%, DDIY 37% (and 19% presumably pen-and–paper).

[18] In addition, HRB documents suggested that more than half of switching from DDIY to assisted preparation is unrelated to pricing changes; and HRB's former CEO stated that research had shown the primary reason individuals switched between assisted preparation and DDIY was "life events" that changed their tax status.

ing between pre-paid and post-paid segments plausibly is often due to changes in personal circumstances such as income and, hence, may not be a good proxy for diversion among competing operators.[19] Accordingly, in its review of the Telefónica Deutschland/E-Plus merger the European Commission (2014) also presented alternative estimates of diversion ratios using switching only within segments. (¶¶ 107-8.)[20] Similarly, it used portability data only within the post-paid retail segment to assess diversion when reviewing the merger between Hutchison 3G Austria and Orange Austria (European Commission, 2012).

Within-segment switching patterns were taken as acceptable proxies for diversion in the above cases.[21] This default position may be reasonable if switching is deemed predominantly due to changes in prices or quality (perhaps based on company documents or other sources). But when information is available on supply-side shocks, it is valuable to examine switching patterns specifically around such events. The US FCC staff took this approach when analyzing the proposed AT&T/T-Mobile merger (FCC, 2011b). It identified several major price reductions and introductions of new handsets (such as the iPhone, akin to a quality improvement), and examined switching between AT&T and T-Mobile following such events. Based on these more granular analyses, staff concluded that "the substitution rates seen in the porting data generally, likely resulting from buyer substitution in response to a wide range of factors ... along

[19] In a similar vein, Israel (2013, ¶ 26) cautioned when analyzing substituability between AT&T and Leap (a lower-end wireless operator): "[P]orting data ... include people who switch for any reason. A likely effect ... is that porting data may capture those who switch because they are looking for something different in a new provider ... , whereas those who switch solely due to a price increase at their current provider [the diversion scenario] may be more apt to switch to another provider with a similar offering at a better price."

[20] It stated: "Following comments by the Notifying Party ... the Commission considers that observed switching across segments [pre-paid versus post-paid] in the MNP [Mobile Number Portability] data is less likely to be a good proxy for reactions by consumers to price changes." (p.11, fn. 5.)

[21] In *Telefónica*, the Commission considered "diversion ratios from MNP data within segment [pre- or post-paid] to be informative on price based switching between MNOs [Mobile Network Operators] within the same segment." (¶ 108) In *Hutchison*, it saw "no reason to expect it [MNP switching data] to be a poor or biased estimator of switching in the post-paid segment." (Annex I, ¶ 1.)

with price, do not mislead as to the rates of substitution that would be observed in response to changes in price." (*Id.,* ¶ 55, fn. 160.)

The FCC's "event study" approach potentially could be extended to other industries. For example, in estimating diversion ratios among video distributors, one might look for programming disputes that caused a loss of programming for a particular distributor and track where its departing subscribers went. In practice, however, it is often difficult to obtain solid information on the switching destination of departing customers outside of cases such as number portability (though competition agencies sometimes can construct such information by combining various data sources). A complementary approach is to use survey data, focusing on switching patterns among the subset of customers who switched due to exogenous changes in price or quality. For example, in the Comcast/NBCU merger, DIRECTV submitted estimates of diversion rates from DBS to cable based on a survey of subscribers who switched their video provider due to dissatisfaction with programming (FCC, 2011a, ¶ 15).

When little is known about the reason for switching, raw churn data deserves less weight, especially when the patterns conflict with information from other sources about relative competitive closeness. In the US Federal Trade Commission's challenge to a merger of two leading food wholesalers (FTC vs. Sysco, 2015), the FTC's economic expert cited bidding data as showing that the parties were close competitors while the parties' economic expert disputed this based on switching data. The Court ultimately found the bidding data more persuasive, commenting *inter alia* that "unlike an RFP [Request for Proposal] or bid situation, a switch does not necessarily equate to actual competition." (*Id*, pp. 86-87.)

Turning to some limitations of our analysis and potential extensions, our modeling of changing preferences was highly stylized. For example, the fraction of consumers who change their preferences (locations on the line) was symmetric and independent of product differentiation. More refined modeling could disaggregate "changing preferences" into changed circumstances or learning about product quality.

Second, and mainly for convenience, we assumed all market segments were covered. By ignoring leakage to outside goods following a price increase, this assumption overstates diversion ratios to competitors in "the market" and, hence, overstates the upward pricing pressure from a merger. Also, each consumer only chooses between two products. While this assumption is obviously unrealistic, it may not be overly problematic for purposes of estimating diversion ratios, because the pattern of switching in response to a firm's unilateral price increase will depend only on the second preference of each of its customers.

Another extension would be to allow more than three firms, as in the spokes model of Chen and Riordan (2007). We illustrated the biases in using switching data to estimate diversion ratios when switching from a firm is caused by supply-side shocks—a decrease in its quality or increase in its marginal cost (Proposition 1), or the opposite shocks to a rival (Proposition 2)—after incorporating the adjustment of equilibrium prices. In each case, the bias depended on comparing competitive conditions between a (different) pair of market segments. The extension to more than three firms will depend on the properties of the additional market segments, because equilibrium prices depend on all segments.

To conclude, our model was intended to be illustrative and we do not wish to overstate its direct empirical applicability. But we hope that it offered some insights and will stimulate further work on the issue.

APPENDIX

A1. Equilibrium Prices in the Model of Section 2

We normalize the production cost of all firms to zero. Thus, prices should be interpreted as markups. For any firm i, $i = 1, 2, 3$, its profit function is $\pi_i = p_i Q_i$, where the demand functions Q_i were given in (4):

$$\begin{aligned}
Q_1 &= m_{12}\left(\frac{1}{2}+\frac{p_2-p_1}{2t_{12}}\right)+m_{13}\left(\frac{1}{2}+\frac{p_3-p_1}{2t_{13}}\right),\\
Q_2 &= m_{12}\left(\frac{1}{2}+\frac{p_1-p_2}{2t_{12}}\right)+m_{23}\left(\frac{1}{2}+\frac{p_3-p_2}{2t_{23}}\right),\\
Q_3 &= m_{13}\left(\frac{1}{2}+\frac{p_1-p_3}{2t_{13}}\right)+m_{23}\left(\frac{1}{2}+\frac{p_2-p_3}{2t_{23}}\right).
\end{aligned}$$

Equilibrium prices are determined by the solutions to the three first-order conditions $\partial\pi_i/\partial p_i = Q_i + p_i \partial Q_i/\partial p_i = 0$ or

$$\begin{aligned}
m_{12}\left(\tfrac{1}{2}+\tfrac{p_2-p_1}{2t_{12}}\right)+m_{13}\left(\tfrac{1}{2}+\tfrac{p_3-p_1}{2t_{13}}\right)-p_1\left(\tfrac{m_{12}}{2t_{12}}+\tfrac{m_{13}}{2t_{13}}\right)&=0,\\
m_{12}\left(\tfrac{1}{2}+\tfrac{p_1-p_2}{2t_{12}}\right)+m_{23}\left(\tfrac{1}{2}+\tfrac{p_3-p_2}{2t_{23}}\right)-p_2\left(\tfrac{m_{12}}{2t_{12}}+\tfrac{m_{23}}{2t_{23}}\right)&=0,\\
m_{13}\left(\tfrac{1}{2}+\tfrac{p_1-p_3}{2t_{13}}\right)+m_{23}\left(\tfrac{1}{2}+\tfrac{p_2-p_3}{2t_{23}}\right)-p_3\left(\tfrac{m_{13}}{2t_{13}}+\tfrac{m_{23}}{2t_{23}}\right)&=0,
\end{aligned} \tag{14}$$

from which we obtain the following equilibrium prices:

$$p_1^* = \frac{1}{2}t_{12}t_{13}\frac{g_1}{f}; \quad p_2^* = \frac{1}{2}t_{12}t_{23}\frac{g_2}{f}; \quad p_3^* = \frac{1}{2}t_{13}t_{23}\frac{g_3}{f}, \tag{15}$$

where

$$\begin{aligned}
g_1 = \; & 2m_{12}m_{13}t_{23}^2\left(3m_{12}+3m_{13}+2m_{23}\right)+3m_{12}m_{23}^2t_{12}t_{13}+3m_{13}m_{23}^2t_{12}t_{13}+3m_{12}m_{23}^2t_{13}t_{23}\\
&+3m_{13}m_{23}^2t_{12}t_{23}+6m_{12}^2m_{23}t_{13}t_{23}+m_{13}m_{23}t_{23}\left(5m_{12}t_{12}+5m_{12}t_{13}+6m_{13}t_{12}\right),
\end{aligned}$$

$$g_2 = 2m_{12}m_{23}t_{13}^2\left(3m_{12}+2m_{13}+3m_{23}\right)+3m_{12}m_{13}^2t_{12}t_{23}+3m_{12}m_{13}^2t_{13}t_{23}+6m_{13}m_{23}^2t_{12}t_{13}$$
$$+6m_{12}^2m_{13}t_{13}t_{23}+3m_{13}^2m_{23}t_{12}t_{13}+m_{13}m_{23}\left(5m_{12}t_{12}t_{13}+5m_{12}t_{13}t_{23}+3m_{13}t_{12}t_{23}\right),$$

$$g_3 = 2m_{13}m_{23}t_{12}^2\left(2m_{12}+3m_{13}+3m_{23}\right)+3m_{12}t_{12}\left(2m_{13}^2t_{23}+2m_{23}^2t_{13}+m_{12}m_{13}t_{23}\right)$$
$$+3m_{12}^2t_{13}\left(m_{23}t_{12}+m_{13}t_{23}+m_{23}t_{23}\right)+5m_{12}m_{13}m_{23}t_{12}t_{13}+5m_{12}m_{13}m_{23}t_{12}t_{23},$$

$$f = 3m_{12}m_{13}^2t_{12}t_{23}^2+3m_{12}m_{23}^2t_{12}t_{13}^2+3m_{13}m_{23}^2t_{12}^2t_{13}+3m_{12}^2m_{13}t_{13}t_{23}^2$$
$$+3m_{12}^2m_{23}t_{13}^2t_{23}+3m_{13}^2m_{23}t_{12}^2t_{23}+7m_{12}m_{13}m_{23}t_{12}t_{13}t_{23}.$$

Furthermore, firm 1's equilibrium shares on the market segments l_{12} and l_{13} are respectively

$$\hat{x}_{12}^* = \frac{1}{2}+\frac{p_2^*-p_1^*}{2t_{12}}, \tag{16}$$

$$\hat{x}_{13}^* = \frac{1}{2}+\frac{p_3^*-p_1^*}{2t_{13}}. \tag{17}$$

We note that

$$\hat{x}_{12}^* = \hat{x}_{13}^* = \frac{1}{2} \text{ if } t_{ab}=t \text{ for all } ab.$$

But if $m_{ab}=m$ for all ab while transportation costs may differ across consumer segments, then the expressions for market shares are complex. In particular:

$$\hat{x}_{12}^* = \frac{1}{2}\frac{3t_{12}^2t_{13}+6t_{12}t_{23}^2+3t_{12}^2t_{23}+2t_{13}t_{23}^2+4t_{13}^2t_{23}+7t_{12}t_{13}t_{23}}{3t_{12}t_{13}^2+3t_{12}^2t_{13}+3t_{12}t_{23}^2+3t_{12}^2t_{23}+3t_{13}t_{23}^2+3t_{13}^2t_{23}+7t_{12}t_{13}t_{23}}. \tag{18}$$

A2. New Equilibrium After Decrease in Firm 1's Product Quality

Proof of Proposition 1.

After Firm 1's quality decreases by Δ, the new equilibrium prices, p_1^*, p_2^*, and p_3^*, solve the following first-order conditions

$$\begin{aligned} m_{12}\left(\frac{1}{2}+\frac{-\Delta+p_2-p_1}{2t_{12}}\right)+m_{13}\left(\frac{1}{2}+\frac{-\Delta+p_3-p_1}{2t_{13}}\right)-p_1\left(\frac{m_{12}}{2t_{12}}+\frac{m_{13}}{2t_{13}}\right) &= 0, \\ m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1-p_2}{2t_{12}}\right)+m_{23}\left(\frac{1}{2}+\frac{p_3-p_2}{2t_{23}}\right)-p_2\left(\frac{m_{12}}{2t_{12}}+\frac{m_{23}}{2t_{23}}\right) &= 0, \\ m_{13}\left(\frac{1}{2}+\frac{\Delta+p_1-p_3}{2t_{13}}\right)+m_{23}\left(\frac{1}{2}+\frac{p_2-p_3}{2t_{23}}\right)-p_3\left(\frac{m_{13}}{2t_{13}}+\frac{m_{23}}{2t_{23}}\right) &= 0. \end{aligned}$$

Substituting these prices into $m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1-p_2}{2t_{12}}\right)$ and $m_{13}\left(\frac{1}{2}+\frac{\Delta+p_1-p_3}{2t_{13}}\right)$, we obtain:

$$\begin{aligned} \frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_2^*}{2t_{12}}\right)\right]}{\partial\Delta} &= \frac{m_{12}(m_{12}t_{13}+m_{13}t_{12})(m_{13}t_{23}+m_{23}t_{13})(2m_{12}t_{23}+3m_{23}t_{12})}{4t_{12}f_1} \\ \frac{\partial\left[m_{13}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_3^*}{2t_{13}}\right)\right]}{\partial\Delta} &= \frac{m_{13}(m_{12}t_{13}+m_{13}t_{12})(m_{12}t_{23}+m_{23}t_{12})(2m_{13}t_{23}+3m_{23}t_{13})}{4t_{13}f_1} \end{aligned}, \qquad (19)$$

where

$$\begin{aligned} f_1 &= 3m_{12}m_{13}^2t_{12}t_{23}^2+3m_{12}m_{23}^2t_{12}t_{13}^2+3m_{13}m_{23}^2t_{12}^2t_{13}+3m_{12}^2m_{13}t_{13}t_{23}^2 \\ &\quad +3m_{12}^2m_{23}t_{13}^2t_{23}+3m_{13}^2m_{23}t_{12}^2t_{23}+7m_{12}m_{13}m_{23}t_{12}t_{13}t_{23}. \end{aligned}$$

The numbers of consumers switching from firm 1 to firms 2 and 3 are, respectively,

$$\frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_2^*}{2t_{12}}\right)\right]}{\partial\Delta}\Delta \quad \text{and} \quad \frac{\partial\left[m_{13}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_3^*}{2t_{13}}\right)\right]}{\partial\Delta}\Delta.$$

The churn ratio from firm 1 to 2 is thus

$$c_{12} = \frac{\frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_2^*}{2t_{12}}\right)\right]}{\partial\Delta}}{\frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_2^*}{2t_{12}}\right)\right]}{\partial\Delta}+\frac{\partial\left[m_{13}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_3^*}{2t_{13}}\right)\right]}{\partial\Delta}}.$$

After simplifications, we obtain

$$c_{12} = \frac{t_{13}m_{12}\left(m_{13}t_{23}+m_{23}t_{13}\right)\left(2m_{12}t_{23}+3m_{23}t_{12}\right)}{f_2}. \tag{20}$$

where

$$\begin{aligned} f_2 \;=\; & 2m_{12}m_{13}^2t_{12}t_{23}^2+3m_{12}m_{23}^2t_{12}t_{13}^2+3m_{13}m_{23}^2t_{12}^2t_{13}+2m_{12}^2m_{13}t_{13}t_{23}^2 \\ & +2m_{12}^2m_{23}t_{13}^2t_{23}+2m_{13}^2m_{23}t_{12}^2t_{23}+6m_{12}m_{13}m_{23}t_{12}t_{13}t_{23}. \end{aligned}$$

It follows that

$$c_{12}-d_{12} = \frac{\left(m_{13}t_{12}-m_{12}t_{13}\right)m_{12}m_{13}m_{23}t_{12}t_{13}t_{23}}{\left(m_{12}t_{13}+m_{13}t_{12}\right)f_2},$$

which takes the sign of $(m_{13}t_{12}-m_{12}t_{13})$, and since

$$d_{12}-d_{13} = \frac{\frac{m_{12}}{t_{12}}}{\frac{m_{12}}{t_{12}}+\frac{m_{13}}{t_{13}}} - \frac{\frac{m_{13}}{t_{13}}}{\frac{m_{12}}{t_{12}}+\frac{m_{13}}{t_{13}}} = \frac{m_{12}t_{13}-m_{13}t_{12}}{m_{12}t_{13}+m_{13}t_{12}},$$

we have

$$c_{12}-d_{12} \gtreqless 0 \Leftrightarrow d_{12}-d_{13} \lesseqgtr 0.$$

This proves part (i) of Proposition 1.

Turning to part (ii), from (19):

$$c_{13} = \frac{\frac{\partial\left[m_{13}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_3^*}{2t_{13}}\right)\right]}{\partial\Delta}}{\frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_2^*}{2t_{12}}\right)\right]}{\partial\Delta}+\frac{\partial\left[m_{13}\left(\frac{1}{2}+\frac{\Delta+p_1^*-p_3^*}{2t_{13}}\right)\right]}{\partial\Delta}}.$$

After simplifications, we have:

$$c_{13} = \frac{t_{12}m_{13}\left(m_{12}t_{23}+m_{23}t_{12}\right)\left(2m_{13}t_{23}+3m_{23}t_{13}\right)}{f_3}, \tag{21}$$

where

$$\begin{aligned} f_3 \;=\;& 2m_{12}m_{13}^2t_{12}t_{23}^2+3m_{12}m_{23}^2t_{12}t_{13}^2+3m_{13}m_{23}^2t_{12}^2t_{13}+2m_{12}^2m_{13}t_{13}t_{23}^2 \\ &+2m_{12}^2m_{23}t_{13}^2t_{23}+2m_{13}^2m_{23}t_{12}^2t_{23}+6m_{12}m_{13}m_{23}t_{12}t_{13}t_{23}. \end{aligned}$$

Thus, from (20) and (21):

$$c_{12}-c_{13} = \frac{\left(m_{12}t_{13}-m_{13}t_{12}\right)\left(2m_{12}m_{13}t_{23}^2+3m_{23}^2t_{12}t_{13}+2m_{12}m_{23}t_{13}t_{23}+2m_{13}m_{23}t_{12}t_{23}\right)}{f_3},$$

which takes the sign of $\left(m_{12}t_{13}-m_{13}t_{12}\right)$, the same sign as $d_{12}-d_{13}$. This proves part (ii) of Proposition 1.

A3. New Equilibrium after Increase in Firm 2's Product Quality

Proof of Proposition 2.

After Firm 2's quality increases by Δ, the new equilibrium prices p_1^*, p_2^*, and p_3^*

solve the first-order conditions

$$
\begin{aligned}
m_{12}\left(\frac{1}{2}+\frac{-\Delta+p_2-p_1}{2t_{12}}\right)+m_{13}\left(\frac{1}{2}+\frac{p_3-p_1}{2t_{13}}\right)-p_1\left(\frac{m_{12}}{2t_{12}}+\frac{m_{13}}{2t_{13}}\right) &= 0,\\
m_{12}\left(\frac{1}{2}+\frac{\Delta+p_1-p_2}{2t_{12}}\right)+m_{23}\left(\frac{1}{2}+\frac{\Delta+p_3-p_2}{2t_{23}}\right)-p_2\left(\frac{m_{12}}{2t_{12}}+\frac{m_{23}}{2t_{23}}\right) &= 0,\\
m_{13}\left(\frac{1}{2}+\frac{p_1-p_3}{2t_{13}}\right)+m_{23}\left(\frac{1}{2}+\frac{-\Delta+p_2-p_3}{2t_{23}}\right)-p_3\left(\frac{m_{13}}{2t_{13}}+\frac{m_{23}}{2t_{23}}\right) &= 0.
\end{aligned}
$$

Using these prices, we have, at the new equilibrium:

$$
\frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{-\Delta+p_2^*-p_1^*}{2t_{12}}\right)\right]}{\partial\Delta}=\frac{-\frac{1}{4}m_{12}(m_{12}t_{23}+m_{23}t_{12})(m_{13}t_{23}+m_{23}t_{13})(2m_{12}t_{13}+3m_{13}t_{12})}{t_{12}f_4},
$$

$$
\frac{\partial\left[m_{13}\left(\frac{1}{2}+\frac{p_3^*-p_1^*}{2t_{13}}\right)\right]}{\partial\Delta}=\frac{\frac{1}{4}m_{13}^2(m_{12}t_{23}-m_{23}t_{12})(m_{12}t_{23}+m_{23}t_{12})}{f_4}
$$

where

$$
\begin{aligned}
f_4 = {}& 3m_{12}m_{13}^2t_{12}t_{23}^2+3m_{12}m_{23}^2t_{12}t_{13}^2+3m_{13}m_{23}^2t_{12}^2t_{13}+3m_{12}^2m_{13}t_{13}t_{23}^2\\
&+3m_{12}^2m_{23}t_{13}^2t_{23}+3m_{13}^2m_{23}t_{12}^2t_{23}+7m_{12}m_{13}m_{23}t_{12}t_{13}t_{23}.
\end{aligned}
$$

The number of consumers switching from 1 to 3 due to Δ is 0 if $\frac{m_{12}}{m_{23}}\geq\frac{t_{12}}{t_{23}}$, in which case $c_{12}=1>d_{12}$. If $\frac{m_{12}}{m_{23}}<\frac{t_{12}}{t_{23}}$, then there are consumers switching from 1 to both 2 and 3, with

$$
\begin{aligned}
c_{12} &= \frac{\frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{-\Delta+p_2^*-p_1^*}{2t_{12}}\right)\right]}{\partial\Delta}}{\frac{\partial\left[m_{12}\left(\frac{1}{2}+\frac{-\Delta+p_2^*-p_1^*}{2t_{12}}\right)\right]}{\partial\Delta}+\frac{\partial\left[m_{13}\left(\frac{1}{2}+\frac{p_3^*-p_1^*}{2t_{13}}\right)\right]}{\partial\Delta}}\\
&= \frac{m_{12}\left(m_{13}t_{23}+m_{23}t_{13}\right)\left(2m_{12}t_{13}+3m_{13}t_{12}\right)}{\left(m_{12}t_{13}+m_{13}t_{12}\right)\left(2m_{12}m_{13}t_{23}+2m_{12}m_{23}t_{13}+m_{13}m_{23}t_{12}\right)}
\end{aligned}
$$

and

$$c_{12} - d_{12} = \frac{m_{12}m_{13}t_{12}\left(3m_{13}t_{23} + 2m_{23}t_{13}\right)}{\left(m_{12}t_{13} + m_{13}t_{12}\right)\left(2m_{12}m_{13}t_{23} + 2m_{12}m_{23}t_{13} + m_{13}m_{23}t_{12}\right)} > 0.$$

Finally, since

$$d_{21} - d_{23} = \frac{\frac{m_{12}}{2t_{12}}}{\frac{m_{12}}{2t_{12}} + \frac{m_{23}}{2t_{23}}} - \frac{\frac{m_{23}}{2t_{23}}}{\frac{m_{12}}{2t_{12}} + \frac{m_{23}}{2t_{23}}} = \frac{m_{12}t_{23} - m_{23}t_{12}}{m_{12}t_{23} + m_{23}t_{12}} \gtreqless 0 \Leftrightarrow \frac{m_{12}}{m_{23}} \gtreqless \frac{t_{12}}{t_{23}},$$

we have (i) $c_{12} = 1$ ($> d_{12}$) if $d_{21} \geq d_{23}$; (ii) $c_{12} < 1$ if $d_{21} < d_{23}$, but still $c_{12} > d_{12}$.

A4. Diversion Ratios and Market Shares

Proposition 5 *Assume that all market segments exhibit equal product differentiation ($t_{ab} = t$ for all ab). Then the ranking of diversion ratios from firm 1 to its rivals will track rivals' market shares, but the rival with the larger share will have disproportionately larger diversion from firm 1:*

$$\text{if } s_2 = s_3 \text{ then } d_{12} = d_{13}; \qquad \text{if } s_i > s_j \text{ then } \frac{d_{1i}}{d_{1j}} > \frac{s_i}{s_j} \text{ for } i \neq j = 2, 3. \tag{22}$$

Proof. Substituting p_1^*, p_2^*, p_3^* from (15) into the demand functions, with $t_{ab} = t$ for all ab, we obtain the equilibrium outputs for the three firms:

$$Q_1 = \frac{m_{12} + m_{13}}{2}; \qquad Q_2 = \frac{m_{12} + m_{23}}{2}; \qquad Q_3 = \frac{m_{13} + m_{23}}{2}.$$

The market shares of the three firms are respectively

$$
\begin{aligned}
s_1 &= \frac{\frac{m_{12}+m_{13}}{2}}{\frac{m_{12}+m_{13}}{2}+\frac{m_{12}+m_{23}}{2}+\frac{m_{13}+m_{23}}{2}} = \frac{1}{2}\frac{m_{12}+m_{13}}{m_{12}+m_{13}+m_{23}}, \\
s_2 &= \frac{\frac{m_{12}+m_{23}}{2}}{\frac{m_{12}+m_{13}}{2}+\frac{m_{12}+m_{23}}{2}+\frac{m_{13}+m_{23}}{2}} = \frac{1}{2}\frac{m_{12}+m_{23}}{m_{12}+m_{13}+m_{23}}, \\
s_3 &= \frac{\frac{m_{13}+m_{23}}{2}}{\frac{m_{12}+m_{13}}{2}+\frac{m_{12}+m_{23}}{2}+\frac{m_{13}+m_{23}}{2}} = \frac{1}{2}\frac{m_{13}+m_{23}}{m_{12}+m_{13}+m_{23}}.
\end{aligned}
$$

Thus, firm 2's market share relative to firm 3's share is given by

$$
\frac{s_2}{s_3} = \frac{\frac{1}{2}\frac{m_{12}+m_{23}}{m_{12}+m_{13}+m_{23}}}{\frac{1}{2}\frac{m_{13}+m_{23}}{m_{12}+m_{13}+m_{23}}} = \frac{m_{12}+m_{23}}{m_{13}+m_{23}} = \frac{\mu+\frac{m_{23}}{m_{13}}}{1+\frac{m_{23}}{m_{13}}}. \tag{23}
$$

The diversion ratios from firm 1 are related as follows

$$
\frac{d_{12}}{d_{13}} = \frac{\frac{\frac{m_{12}}{t}}{\frac{m_{12}}{t}+\frac{m_{13}}{t}}}{\frac{\frac{m_{13}}{t}}{\frac{m_{12}}{t}+\frac{m_{13}}{t}}} = \frac{m_{12}}{m_{13}} = \mu. \tag{24}
$$

Thus,

$$
s_2 = s_3 \Leftrightarrow \mu = 1 \Leftrightarrow d_{12} = d_{13},
$$

$$
s_2 \gtrless s_3 \Leftrightarrow \mu \gtrless 1 \Leftrightarrow \frac{s_2}{s_3} \lessgtr \mu = \frac{d_{12}}{d_{13}}.
$$

■

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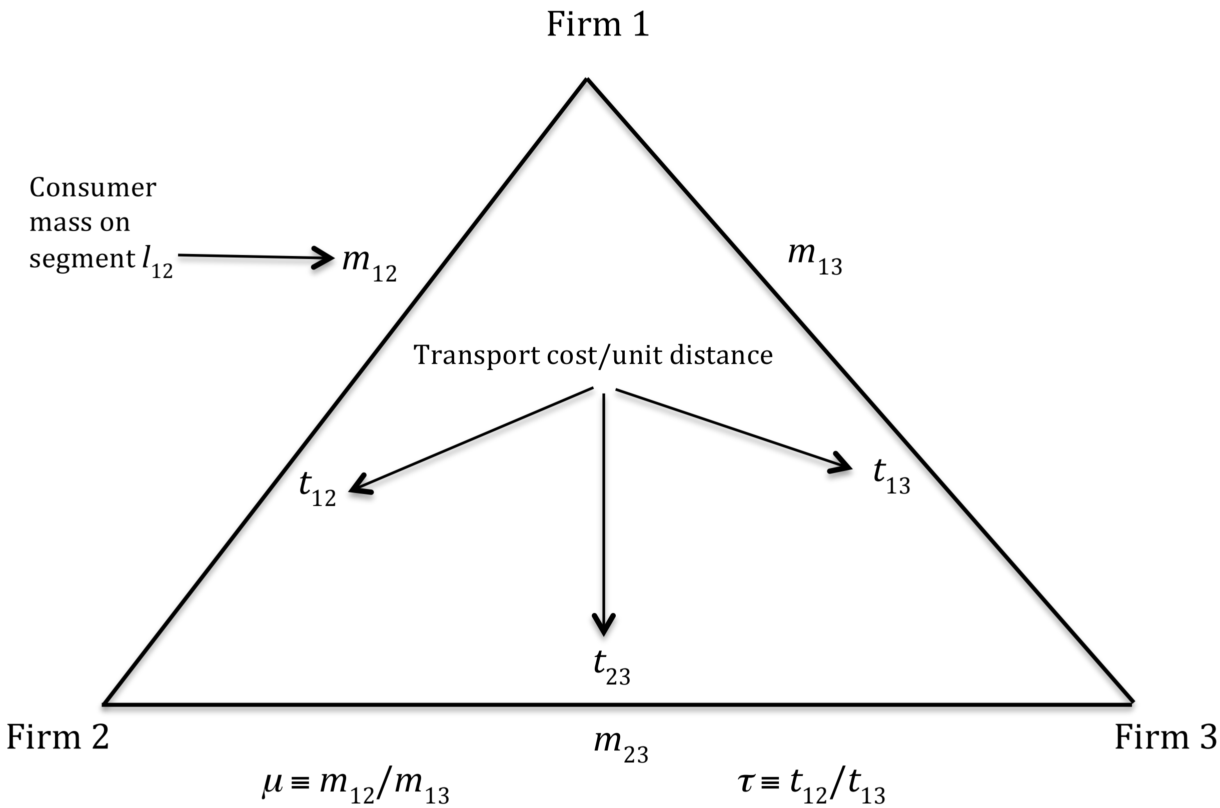
Figure 1



Firm 1
Consumer mass on segment l_{12}
m_{12}
m_{13}
Transport cost/unit distance
t_{12}
t_{13}
t_{23}
Firm 2
m_{23}
Firm 3
$\mu \equiv m_{12}/m_{13}$
$\tau \equiv t_{12}/t_{13}$