Reimbursing Consumers' Switching Costs in Network and Non-network Industries*

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Abstract

To analyze how firms' policies to reimburse consumer switching costs affect prices, market structure, and welfare, we develop a dynamic duopoly model with network effects, switching costs, and switching cost reimbursement. We find that each firm's reimbursement strategy is nonmonotonic in its installed base. While nonmonotonic, the firm with the greater installed base always reimburses more of the switching cost than its smaller competitor, allowing the firm that obtains an early advantage to dominate the market. Consumers benefit from the reimbursement, while producers only benefit in network industries when network effects are large; otherwise, the reimbursement induces a prisoner's dilemma.

JEL: L13, L14. *Keywords*: behavior-based price discrimination, network goods, reimbursement, switching costs.

1 Introduction

Many modern industries, both network and non-network, such as financial services, computer hardware and software, dating platforms, healthcare services, and telecommunications are characterized by switching costs (Stango, 2002; Strombom et al., 2002; Chen and Hitt, 2006; Viard, 2007; Cullen and Shcherbakov, 2010; Barone et al., 2011; Park, 2011; Shcherbakov, 2016).[1] This paper develops a dynamic analysis of behavior-based price discrimination (Chen, 1997; Villas-Boas, 1999; Fudenberg and Tirole, 2000; Cabral, 2016) with and without network effects (Cabral, 2011; Chen, 2016).[2] We

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[1] The literature on switching costs can be traced back to von Weizsäcker (1984). Shortly thereafter, markets with switching costs were examined in Klemperer (1987a), Klemperer (1987b), and Klemperer (1987c). Since then, much headway has been made. A thorough summary through 2007 is given in Farrell and Klemperer (2007). For more recent surveys see Villas-Boas (2015) and the literature review in Cabral (2016).

[2] We incorporate network effects in the benchmark analysis.

investigate a common strategy employed by firms in network industries: reimbursing the switching costs (monetary and non-monetary) incurred by consumers switching from rivals. The model is motivated by recent policies where firms post a common price and a reimbursement that is explicitly tied to a switching cost.[3] The reimbursement may cover only a portion of the switching cost or its entirety, but often does not go beyond the switching cost.[4] We then use the model to highlight how the reimbursement affects both the demand- and supply-side of the market.

In addition to these pricing policies, our study is also motivated by the many implemented or proposed public policies aimed at reducing switching costs in network industries. For example, mobile phone number portability (XConnect, 2021), the limitation of early termination fees charged by wireless carriers considered by the US Federal Communications Commission (German, 2008), the proposal to provide switching facilities for retail banking and payment systems by the European Competition Authorities (ECAFSS, 2006), and the adoption of common open software standards by governments (Casson and Ryan, 2006).

We build an infinite-horizon duopoly model with network effects and switching costs using the Ericson and Pakes (1995) dynamic computational approach, expanding upon the model in Chen (2016).[5] There are two firms and a finite number of consumers. In each period, the two forward-looking firms simultaneously and independently make pricing and reimbursement decisions. Then, one randomly chosen consumer reevaluates their purchasing decision as in Cabral (2011). The consumer chooses to purchase from one of the two firms or selects an outside option (e.g., no purchase). Consumers are initially assumed myopic, but we show that the results are robust to forward-looking consumers in an extension. We solve for a symmetric Markov perfect equilibrium using numerical methods à la Doraszelski and Satterthwaite (2010) and identify the effects of the reimbursement by comparing the equilibrium to Chen (2016), where there is no reimbursement.[6]

The reimbursement strategy is unique relative to traditional models of behavior-based price discrimination (Chen, 1997; Villas-Boas, 1999; Shaffer and Zhang, 2000; Cabral, 2016; Colombo, 2016; De Nijs, 2017; Colombo, 2018).[7] The reimbursement is only offered to consumers switching from the competitor and not to those who previously chose the outside option. Many companies offer

[3]In 2015, Verizon Wireless covered up to \$350 to pay off early termination fees (Goldman, 2015) and, as of July 2023, offers up to \$650. The other major wireless carriers AT&T and T-Mobile offer similar reimbursement policies of up to \$800, as do cable providers such as Spectrum (Spectrum, 2021).

[4]For example, when a customer's phone breaks, that customer must decide to either switch to a new carrier or remain with their current carrier. When remaining, the consumer continues to pay the current monthly rate. When switching to a new carrier (while acquiring a new phone), the consumer pays the new carrier's rate, plus the net of switching costs that are not reimbursed. When a consumer moves to another state, the consumer must reevaluate their cable provider or choose an outside option (e.g., a streaming service).

[5]See Doraszelski and Pakes (2007) for a survey of the literature using this approach.

[6]Dynamic price competition with network effects and switching costs have been studied extensively. Without reimbursement, our framework corresponds to the models in Keller et al. (2010), Suleymanova and Wey (2011), Doganoglu and Grzybowski (2013), and Chen (2016).

[7]See also Fudenberg and Tirole (2000), Gehrig et al. (2011), and Bouckaert et al. (2012).

introductory prices, e.g., a discount for new customers.[8] From a modeling standpoint, these two pricing strategies are identical only if there is no outside option or the market is fully covered. Furthermore, the extent to which firms can price discriminate using the switching cost reimbursement channel changes when the magnitude of switching costs changes due to public policies or technological developments.

When switching costs cannot be reimbursed, increasing the switching cost relative to the magnitude of the network effect decreases market concentration (Chen, 2016), consistent with the existing switching cost literature for both non-network goods (Beggs and Klemperer, 1992; Chen and Rosenthal, 1996; Taylor, 2003) and network goods (Suleymanova and Wey, 2011; Doganoglu and Grzybowski, 2013; Chen, 2016).[9] Reimbursements break this pattern of "mean reversion" (Cabral, 2011) in contrast to much of the literature on switching costs, e.g., Beggs and Klemperer (1992), Chen and Rosenthal (1996), Taylor (2003), Farrell and Klemperer (2007), and Chen (2016).

The firm with the larger installed base always reimburses a greater share of the switching cost than their competitor, though the share of the switching cost reimbursed is not monotonic in either firm's installed base. *A priori*, this pattern is not obvious. With nonconvex network effects, a smaller firm has a (weakly) larger marginal benefit of attracting a new customer than a larger firm. The larger firm, *ceteris paribus*, is more valuable to a customer than the smaller firm and thus less enticing is necessary to induce switching. On the other hand, the larger firm, by attracting an additional customer, can increase its price to each customer when the network effects are strong. After intense competition to gain the early advantage in market shares, this difference in the two firms' reimbursement policies gives the winning firm an advantage in attracting switching consumers, in contrast to Gehrig et al. (2012), Mehra et al. (2012), and Esteves (2014). This pattern persists even absent network effects. Correspondingly, an increase in the switching cost – which increases the magnitude of reimbursement that's possible – leads to a higher market concentration.

Is the reimbursement channel, much like behavior-based price discrimination more generally, a prisoner's dilemma as suggested by much of the literature? When network effects are small (or absent), reimbursements lower producer surplus, which is consistent with much of the behavior-based price discrimination literature (Chen, 1997; Villas-Boas, 1999; Fudenberg and Tirole, 2000; Pazgal and Soberman, 2008; Esteves, 2010; Zhang, 2011; Choe et al., 2018). However, with large network effects, reimbursements break the prisoner's dilemma and instead increase producer surplus. While this is not the first paper to show that producer surplus can be increased through a

[8] Amazon, in a highly publicized case, had to publicly apologize and refund customers who had paid higher prices due to the outcry against Amazon's price discrimination that charged regular customers higher prices (Ramasastry, 2005).

[9] In the literature on endogenous market dominance, Budd et al. (1993) use a dynamic duopoly model to study whether the larger firm becomes increasingly dominant. They similarly suggest that switching costs make price cuts more costly for the larger firm than for the smaller firm and may overcome the gravitation towards asymmetric market shares and result in a "catch-up" equilibrium.

form of behavior-based price discrimination, it is the first to show that reimbursements can increase consumer surplus without ex ante asymmetries such as quality differences (Jing, 2017; Rhee and Thomadsen, 2017) or differences in loyal and price-sensitive consumers (Chen and Zhang, 2009).

Reimbursements uniformly increase consumer surplus for a given switching cost. The average price is higher when the network effect is significant; however, this increase in price is offset by the increase in consumer value from the larger network built through the reimbursements. This result is not obvious. Prices are not set independently of reimbursements and reimbursements are (potentially partially) financed by higher prices to locked-in consumers. Our results indicate that consumers' gains from both the increase in network size and the lower effective price paid by switching consumers outweigh the loss in surplus from the higher price paid by repeat customers. Hence, policies aimed at either reducing switching costs or preventing behavior-based price discrimination such as the FCC's proposal to limit early termination fees, the ECA's proposal to reduce switching costs in finance, or the mandating of common standards in hardware and software platforms can backfire and negatively impact consumers.

Our theory of switching cost reimbursement builds upon the dynamic network model with switching costs of Chen (2016). We add to it the endogenous reimbursement channel, and show that when firms have the option to reimburse consumers' switching costs, market dynamics and outcome change significantly. In particular, the endogenously determined asymmetry in the firms' reimbursement strategies counteracts the effects of switching costs, so that increases in switching costs no longer transform network industries from being dominated by one firm to being roughly evenly split between the firms. Furthermore, while Chen (2016) considers exclusively the case with myopic consumers, we study in an extension the case with forward-looking consumers, which shows our main findings are robust and generates additional insights.

This paper adds to the interrelated literatures on switching costs, price discrimination, and network effects. Dubé et al. (2009), Arie and Grieco (2014), Rhodes (2014), Fabra and García (2015), and Cabral (2016), study switching costs in infinite-horizon dynamic models of price competition. Except for Cabral (2016), those papers have focused on the case in which firms cannot distinguish between consumers. In recent years, a few papers have emerged that study network effects and switching costs jointly, including Keller et al. (2010), Suleymanova and Wey (2011), Doganoglu and Grzybowski (2013), and Chen (2016, 2018), though they do not consider switching cost reimbursement.

Chen (1997) and Shaffer and Zhang (2000) are among the first papers to study discriminatory pricing in the context of switching costs. Using a two-period model, Chen (1997) finds that firms play a "bargain-then-ripoff" strategy, where the prices in the first period are below marginal cost while prices in the second period are above marginal cost. When engaging in discriminatory pricing, firms are worse off and consumers are not necessarily better off, leading to deadweight loss. The discriminatory price is not a function of the firm's market share, which follows from the model having a finite time horizon. By considering an infinite-horizon model, we find that both the pricing and reimbursement decisions depend explicitly on market shares.[10]

Shaffer and Zhang (2000) study the properties of price discrimination in a static model with switching costs. They show that when demand is symmetric, a firm charges a lower price to its rival's consumers (paying to switch). However, when demand is asymmetric, a firm charges a lower price to its own consumers (paying to stay). By incorporating dynamic competition, we show that each firm reimburses a portion (potentially all) of consumers' switching costs, charging a lower price to its rival's consumers and a higher price to its own consumers.

Cabral (2016) studies the effects of switching costs in a dynamic competitive environment in which sellers can discriminate between locked-in and not locked-in consumers. He shows that if markets are very competitive to begin with, then switching costs make them even more competitive; whereas if markets are not very competitive to begin with, then switching costs make them even less competitive. We show that if firms have the option to reimburse consumers' switching costs, then switching costs make the market less competitive. In addition, we find that with switching cost reimbursements, when network effects are small, the U-shaped relationship between the average price and the switching cost found in Cabral (2016) persists, but with large network effects, we find that the average price is instead monotonically increasing in the switching cost.

Lastly, by studying the effects of public policies that alter switching costs or firms' ability to reimburse switching costs, this paper joins a growing literature that takes the computational dynamic oligopoly equilibrium approach to studying policy implications, such as Gowrisankaran and Town (1997), Benkard (2004), Tan (2006), Ching (2010), Filson (2012), and Chen (2018).

2 Model

This section develops a dynamic duopoly model employing the Ericson and Pakes (1995) dynamic computational approach. It builds on prior dynamic analyses of network effects and switching costs, particularly Chen (2016), by adding the endogenous reimbursement of switching costs and allowing for forward-looking consumers.[11]

[10]Prior studies that have emphasized the dynamic nature of network effects include Doganoglu (2003), Mitchell and Skrzypacz (2006), Markovich (2008), Markovich and Moenius (2009), Chen et al. (2009), and Cabral (2011), among others.

[11]We discuss forward-looking consumers in Section 5.

2.1 Supply Side

Time is discrete with an infinite horizon. There are two firms indexed by $j = 1, 2$, each producing a single *inside good*, and an *outside good* indexed by 0. Both the inside and outside goods are imperfectly durable.[12] The firms compete to sell to a sequence of M buyers with unit demands (described in Section 2.2). Firm j is described by its state: the installed base of its product at the beginning of a period $b_j \in \{0, 1, \ldots, M\}$, subject to $b_1 + b_2 \leq M$.[13] Denote by $b_0 = M - b_1 - b_2$ the outside good's installed base. The industry state space is $\Omega = \{(b_1, b_2) \mid 0 \leq b_j \leq M,\ j = 1, 2;\ b_1 + b_2 \leq M\}$ with $b \in \Omega$ denoting a specific industry state.

In each period, given b, the firms simultaneously set their prices and their respective shares of the switching cost to be reimbursed. Denote by $p_j \in \mathbb{R}$ the price for good j, by $p = (p_1, p_2)$ the vector of prices, and by $d_j \in [0, 1]$ the share of the switching cost reimbursed by firm j. Both the marginal cost of production and the outside good's price p_0 are normalized to zero.

2.2 Demand Side

In each period one random consumer's unit "dies" and she returns to the market to purchase one of the three (inside or outside) goods, i.e., there is exactly one buyer per period. This modeling approach follows prior dynamic models of network goods, such as Chen et al. (2009) and Cabral (2011). Whereas in those papers, in each period a random old consumer dies and is replaced with a new consumer, here we assume that the random consumer doesn't die but instead her product unit dies so we can model the switching costs. Formally, *product death* is any (random) event that prevents a consumer from continuing to use a durable good without repaying for it, e.g., physical breakdown, expiring subscription, moving to another state, etc.[14] A consumer is *attentive*, i.e., making a purchasing decision only when her product unit dies and otherwise remains *inattentive*.

Denote by $r \in \{0, 1, 2\}$ the good that the attentive consumer previously purchased. With stochastic product death, the probability that the attentive consumer previously purchased good j is

$$\Pr(r = j|b) = \frac{b_j}{M}. \tag{1}$$

By purchasing good j, a consumer who previously purchased good r receives utility

$$u_{rj} = v_j - p_j - \mathbf{1}(r \neq 0, j \neq 0, r \neq j)(1 - d_j)k + \mathbf{1}(j \neq 0)\theta g(b_j) + \epsilon_j.$$

[12] We interpret the outside good as a previous generation of the inside goods (not to be confused with a previous period's version of the product). For example, in the context of mobile phones, the inside goods refer to smart phones such as Apple's iPhone and Samsung's Galaxy, while the outside good refers to feature phones (i.e., "dumb phones"). In the context of motor vehicles, the inside goods correspond to electric vehicles while the outside good is a gasoline vehicle.

[13] Each firm moves up or down the "installed base ladder" via product sales and depreciation, detailed in Section 2.2. The installed base ladder in our model is analogous to the quality ladder in the dynamic quality ladder models starting with Pakes and McGuire (1994).

[14] The assumption of stochastic product deaths is also used in prior studies on durable goods such as Swan (1972) and Chen et al. (2013).

The intrinsic product quality is v_j, which is fixed over time and common across the inside goods: $v_1 = v_2 = v$. As demand depends only on $v - v_0$, we set $v = 0$ without loss of generality and vary v_0. A consumer incurs an exogenous switching cost $k \geq 0$ if she switches from one inside good to the other, and a portion of her switching cost is reimbursed by the firm if $d_j \in (0, 1]$.

The firms do not observe r when making their price and reimbursement decisions, though they do know its distribution. Each firm announces a single price and a switching cost reimbursement policy. Hence, price discrimination occurs only through the reimbursement channel.

The network effect is captured by $\theta g(b_j)$, where $\theta \geq 0$ denotes its strength and $g(\cdot)$ its shape. We assume the outside good exhibits no network effects. Note that we model the network effect based on the installed base at the beginning of the period, before the random product death and the attentive consumer's purchasing decision.[15]

For sharpness and tractability, we assume that, when purchasing, a consumer chooses the good that offers the highest current utility, i.e., consumers make myopic decisions. In some real-world markets such as the printer and ink cartridge market (Miao, 2010), there is evidence that consumers behave myopically, while in some other markets such as the car market (Busse et al., 2013), there is evidence that consumers are forward-looking. We therefore consider in an extension (Subsection 6.1) the case with forward-looking consumers, and vary the degree to which consumers are forward-looking to explore how results are affected.

In our context, when a myopic consumer buys an inside good, she incurs a one-time investment expenditure in the amount of the price plus any switching cost, and the return on this investment is assessed only in the current period while the utilities that this investment provides in future periods are ignored. One possible reason suggested in the literature for such myopic behavior is that consumers may rely on the immediate payoff as a practical heuristic in scenarios involving complex decision-making, and may over-generalize this heuristic to other scenarios where it is not optimal (Miao, 2010).

The consumer's preference shock, ϵ_j, is distributed type I extreme value and iid across products, consumers, and time. Hence, the probability that a consumer who is loyal to good r buys good j is

$$\phi_{rj}(b, d, p) \equiv \frac{\exp(\bar{u}_{rj})}{\sum_{h=0}^{2} \exp(\bar{u}_{rh})},$$

where $\bar{u}_{rj} \equiv u_{rj} - \epsilon_j$ is the deterministic component of u_{rj}. The expected demand for firm j's product, without observing r, is then $\mathbb{E}_r(\phi_{rj}(b, d, p))$, where the expectation is taken over the distribution of r.

[15] The motivation for this specification is that network effects often come from a complementary stock that enhances the value of the network, such as apps for a smartphone ecosystem or video game titles for a video game console, which takes time to build up.

2.3 Bellman Equation

Denote by $V_j(b)$ the expected present value of current-period and future cash flows to firm j in state b. Firm j's Bellman equation is given by

$$V_j(b) = \max_{p_j, d_j} \mathbb{E}_r \Bigg[\phi_{rj}\left(b, d_j, d_{-j}(b), p_j, p_{-j}(b)\right)\left(p_j - \mathbf{1}\left(r \neq 0, r \neq j\right) d_j k\right) \\ + \beta \sum_{h=0}^{2} \phi_{rh}\left(b, d_j, d_{-j}(b), p_j, p_{-j}(b)\right) V_j(b') \Bigg], \quad (2)$$

where $p_{-j}(b)$ and $d_{-j}(b)$ are the equilibrium price and equilibrium reimbursement set by firm j's rival, $\beta \in [0, 1)$ is the firms' common discount factor, and b' denotes the next-period industry state.

2.4 Solution Concept

We find a symmetric Markov perfect equilibrium (MPE). Existence follows from Doraszelski and Satterthwaite (2010). In general, there may exist multiple MPE, so we use a selection rule in the dynamic games literature where we compute the limit of the MPE of a finite-horizon game as the horizon grows to infinity (Chen et al., 2009).[16]

3 Dynamic Equilibrium

For our analysis, it is useful to define the Markov perfect equilibria according to the limiting (long-run) market structure, as we find two distinct market structures emerge. A *tipping equilibrium* is a symmetric MPE in which the limiting distribution of the inside firms' installed bases is bimodal. A *splintered equilibrium* is a symmetric MPE in which the limiting distribution of the inside firms' installed bases is unimodal. In a tipping equilibrium, the firm that obtains an initial advantage is able to build on that advantage and dominate the market, resulting in a highly concentrated market. In a splintered equilibrium, the market converges to a symmetric outcome from any initial industry state, resulting in minimal market concentration.

We consider two regimes in our main analysis: the endogenous reimbursement regime (ER) in which firms are free to choose their switching cost reimbursements, and the no reimbursement regime (NR) in which firms are prohibited from reimbursing switching costs. We also consider the handicap regime (HR) in an extension (Subsection 6.2), which prohibits only the larger firm from reimbursing consumers' switching costs with the intention of curbing its dominance and promoting competition.

[16]Computation of the MPE via value function iteration is carried out using MATLAB and the solver KNITRO in the TOMLAB optimization environment.

Parameter	Values†
Number of consumers M	$\{12, 14, \ldots, 20^*, \ldots, 24\}$
Outside good value v_0	$\{-7, -6, -5^*, -4, -3\}$
Network effect θ	$\{0, 0.5, \ldots, 2^*, \ldots, 5\}$
Shape of network effect	{Linear*, Convex, Concave, S-shaped}
Switching cost k	$\{0, 0.25, \ldots, 1^*, \ldots, 2^*, \ldots, 3\}$
Consumers' discount factor β_c	$\{0^*, 0.1, \ldots, 0.9\}$
Firms' discount factor β	$1/1.05^*$
Long-run (MPE) own-price elasticity range	-1.02 to -0.37
Long-run (MPE) market coverage range	89.4% to 99.8%

† Values with a $*$ correspond to those reported in the text. The remaining parameter combinations are reported in the figures and as extensions and robustness checks.

Table 1: Summary of parameter values across all specifications.

3.1 Parametrization

Table 1 summarizes the parameter values used in the analysis. For the baseline specification, we set the quality of the outside good $v_0 = -5$, so the inside goods' intrinsic quality ($v = 0$) is higher than the outside good's, though not high enough to guarantee full market coverage. For the baseline specification, we investigate $11 \times 13 = 143$ (θ, k) combinations. With $M = 20$, the depreciation rate $(1/M)$ is 5%. Following Chen et al. (2009), we consider the following network effects:

$$\text{Linear:} \quad g(b_j) = b_j/M \qquad \text{Convex:} \quad g(b_j) = \sin\left(\frac{b_j}{M} \times \frac{\pi}{2} + \frac{3\pi}{2}\right) + 1$$

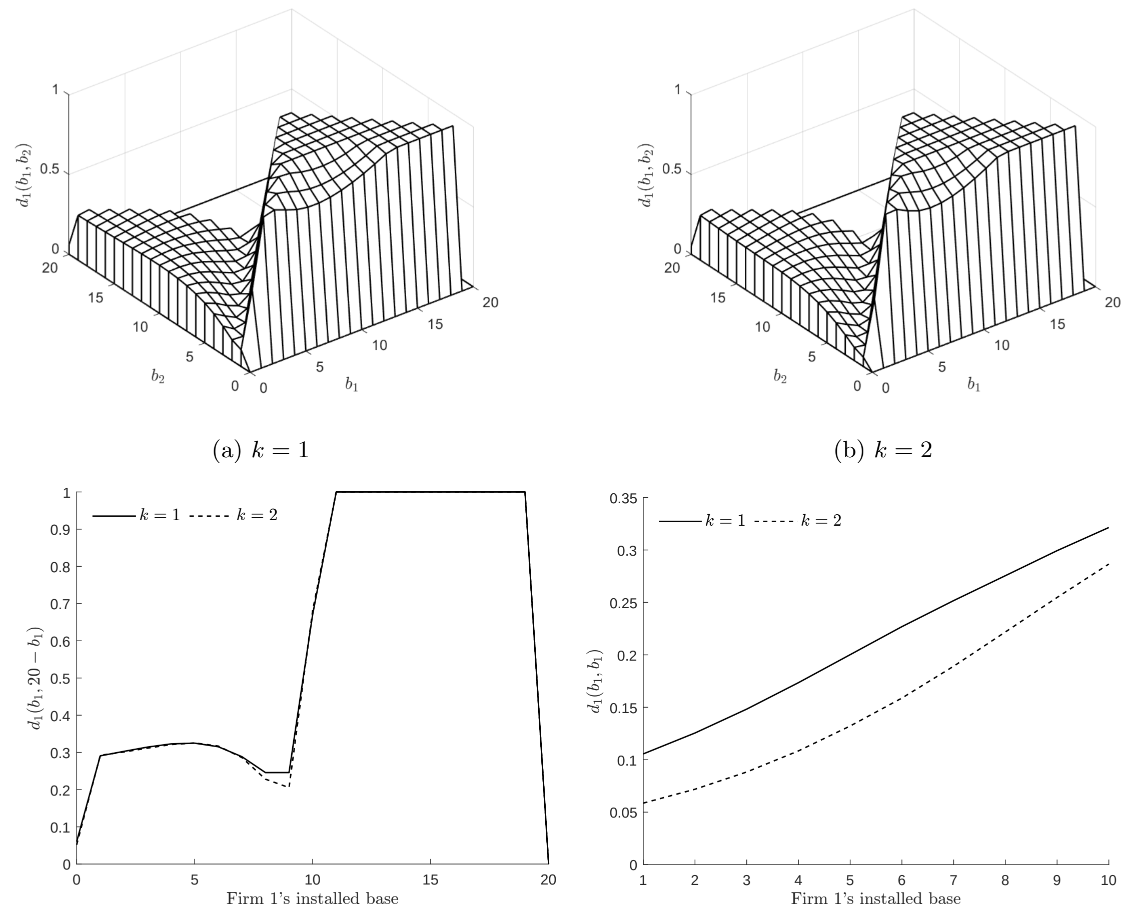
$$\text{Concave:} \quad g(b_j) = \sin\left(\frac{b_j}{M} \times \frac{\pi}{2}\right) \qquad \text{S-shaped:} \quad g(b_j) = \left(\sin\left(\frac{b_j}{M} \times \pi + \frac{3\pi}{2}\right) + 1\right)/2.$$

The remaining parameter specifications are presented as robustness checks in Section 5 and Appendix A2. While our model is not intended to fit any particular industry, some market characteristics emerging from the baseline parameterizations that we consider are consistent with empirical findings. The own-price elasticities of demand for the firms' products range from -1.02 to -0.37, which are consistent with those reported in Clements and Ohashi (2005) for video game consoles (-2.15 to -0.18), Dick (2008) for banking services (-0.87 to -0.12), and Gandal et al. (2000) for CD players (-0.54).[17] Additionally, the combined market share of the inside goods ranges from 89.4% to 99.8%. These percentages are consistent with the percentage of U.S. households with a bank account at 93% in 2013 (Furman, 2016).

3.2 Equilibrium Reimbursement

This section focuses on the equilibrium reimbursement strategy, highlighting three properties of the firms' switching cost reimbursement strategy in the MPE. First, the share of the switching cost reimbursed is a non-monotonic function of a firm's installed base. Second, the firm with the

[17] This elasticity is computed from the results reported in Gandal et al. (2000).



(a) $k = 1$ (b) $k = 2$

(c) $b = (b_1, 20 - b_1)$ (d) $b = (b_1, b_1)$

Figure 1: Reimbursement policies given $k = 1, 2$ and $\theta = 2$.

larger installed base reimburses a greater share of the switching cost than their smaller competitor. Third, the entire switching is often reimbursed by the larger firm in the limiting state.[18] That the constraint is binding implies that there is a distinction between traditional behavior-based price discrimination and a reimbursement policy explicitly tied to a measurable switching cost. Figures 1(a) and 1(b) plot the equilibrium reimbursement policy for all states $b = (b_1, b_2)$. To more clearly visualize the reimbursement policy, Figure 1(c) plots the equilibrium reimbursement policy when $b_2 = 20 - b_1$ (full market coverage).

Suppose that firms initially start with approximately equal installed bases, so competition is intense to gain the early advantage. Then, each firm reimburses between 10% and 33% when $k = 1$ and between 5% and 29% when $k = 2$. The share of the switching cost reimbursed during this intense stage of competition is strictly increasing in the market size, i.e., the value of the inside

[18]This property holds in many, but not all parameterizations, as illustrated in Figure 10(a) in Section 5.

goods relative to the outside good, as illustrated in Figure 1(d). The firm that obtains the early advantage leverages its position by significantly and rapidly increasing the reimbursed share, though this increase may slightly taper off if the winning firm attracts enough consumers. The losing firm initially increases its share reimbursed as well, but this reimbursement tapers off as it loses consumers. Hence, the reimbursement policy is nonmonotonic and highly dependent on both market shares and the degree of market coverage.

When the degree of market coverage increases, there are more consumers who face switching costs and fewer consumers who do not. Therefore, our analysis of the dependence of firms' policies on market coverage is related to Biglaiser et al. (2013), who point out that the *distribution* of switching costs can have considerable influence on firms' strategic choices.

It is *a priori* not obvious that the larger firm reimburses a larger share than their smaller competitor. Nonconvex network effects imply that, all else equal, the smaller firm has a greater marginal benefit of attracting a new customer, as that will (weakly) increase the value of their good by (weakly) more than it would for the larger firm. Hence, by attracting the new customer, the smaller firm can increase its price (and thus profits) by more than the larger firm. On the other hand, the firm with the larger installed base can charge a higher price to locked-in customers due to the network effect and thus by adding an additional customer can further increase its price. Our analysis suggests that the second effect dominates the first.[19]

Inspecting Figures 1(a)-(c), the larger firm reimburses a greater share of the switching cost than the smaller firm.[20] This pattern is particularly obvious by taking $v_0 \to -\infty$, so the market is covered ($b_1 + b_2 = 20$). In this case, when $b_1 = b_2 = 10$, each firm reimburses 67% when $k = 1$ and 68% when $k = 2$. If firm 1 obtains the advantage and the subsequent state is $b_1 = 11$ and $b_2 = 9$ (a five percentage point transfer of market share), then firm 1 reimburses the entire switching cost for both $k = 1$ and $k = 2$ while firm 2 reimburses only 25% when $k = 1$ and 21% when $k = 2$.[21] Figure 1(c) shows the persistence of this pattern for all asymmetric states.

We discuss the third result – that the larger firm often reimburses the entirety of the switching cost in the limiting state – in greater detail below when we discuss the market structure. Computing the difference in the switching costs across all states when $k = 1$ and $k = 2$, we find that the difference in reimbursements between $k = 1$ and $k = 2$ is bounded above (in absolute terms) by 0.0681 percentage points.

[19] We show in Section 5 that the second effect continues to dominate even with concave network benefits.

[20] This pattern holds in every parametrization considered (see Figure 10(a)).

[21] Sensitivity of firms' actions to slight changes in market shares, as found here, is often seen in markets that feature increasing dominance, in which small differences among firms tend to amplify into large differences and therefore firms tend to engage in a preemption race. See, for example, Besanko and Doraszelski (2004).

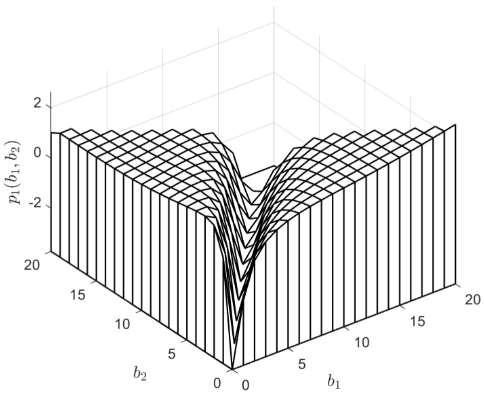
3.3 Equilibrium Pricing

When switching costs can be reimbursed, the firms pricing strategies balance the well-known harvesting and investing tradeoff (Farrell and Klemperer, 2007) by employing what resembles a bargain-then-ripoff strategy (Chen, 1997), which we plot in Figures 2(a) and 2(b). When installed bases are approximately equal, the firms price below marginal cost—the bargain—to invest in new customers. Combining the low price with the approximately 67% switching cost reimbursement, one of the firms obtains the early advantage. Then, the smaller firm increases its price while lowering the share of the switching cost reimbursed—the ripoff—to harvest its existing demand. The larger firm also raises its price, harvesting its locked in consumers while *raising* its reimbursed share to simultaneously invest in new customers by inducing switching. Hence, the market ends in a tipping equilibrium with the firm obtaining the early advantage maintaining and growing that advantage. We plot the market dynamics in Figures 2(c) and 2(d). Increasing the switching cost amplifies the bargain and subsequent ripoff, but does not change the type of equilibrium in the market.

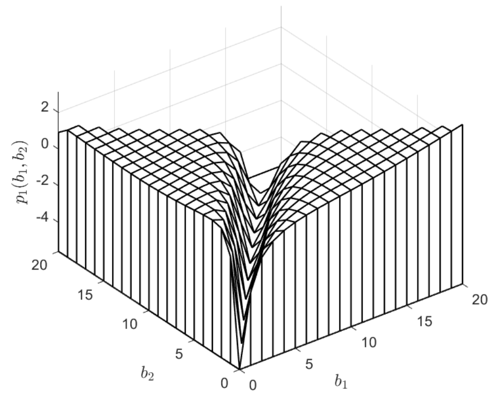
3.4 Effects of Network Effect and Switching Cost

We now analyze how changes in the network effect and switching cost affect the average price, consumer surplus, and producer surplus when the firms reimburse the switching costs. The *average price* is the average effective price charged to the attentive consumer by the firms, weighted by the probabilities of the attentive consumer's attachment, the two firms' expected sales, and the probabilities of the industry state in the limiting distribution. For switching consumers, the effective price is equal to the nominal price minus the switching cost reimbursement which the consumer receives from the firm. The *consumer surplus* (CS) is the net per-period individual utility aggregated over all consumers, both attentive and inattentive, averaged across all industry states using the probabilities in the limiting distribution as weights. The *producer surplus* (PS) is expected firm profits in one period aggregated over both firms, averaged across all industry states using the probabilities in the limiting distribution as weights.

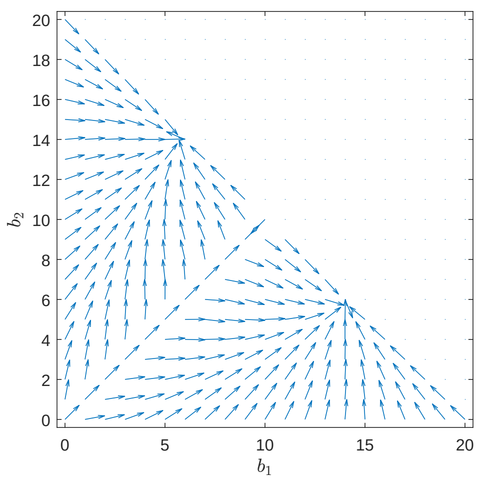
Network Effect For any given switching cost, we find that the average price takes on a U-shape as the network effect increases (Figure 3(a)). An increase in the network effect has two opposing effects on the average price in the long run. On the one hand, a stronger network effect means a larger installed base is more valuable for the firm's profits and a smaller installed base is more detrimental; this tends to intensify the firms' price competition and result in lower equilibrium prices, particularly in relatively symmetric states. On the other hand, with a stronger network effect, the long-run market structure is more asymmetric and the larger firm has a bigger installed base advantage over its smaller rival, hence the larger firm—which accounts for a majority of the sales—charges a higher price, resulting in a higher average price. The results indicate that when the



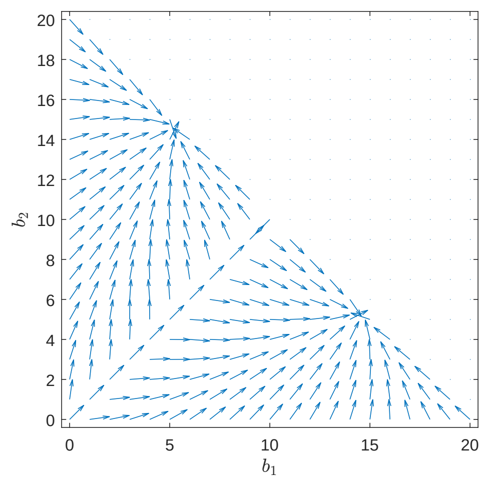
(a) pricing policy, $k = 1$



(b) pricing policy, $k = 2$



(c) resultant forces, $k = 1$

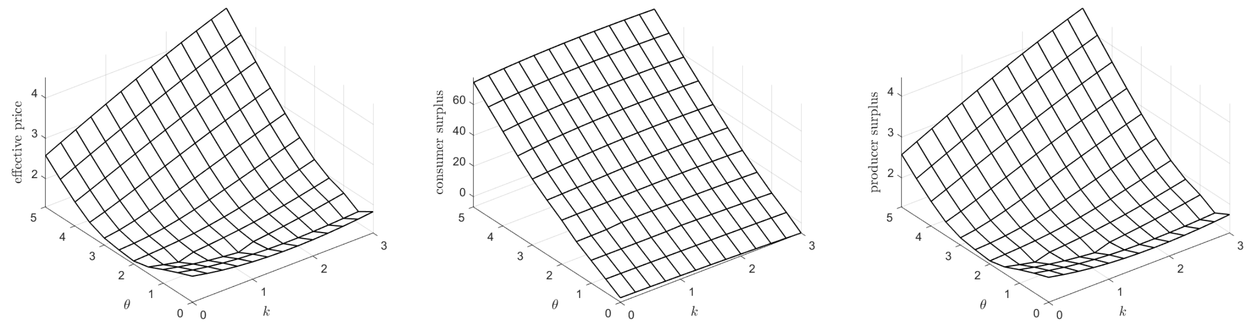


(d) resultant forces, $k = 2$

Figure 2: Equilibrium pricing policies and resultant forces given $\theta = 2$, endogenous reimbursement.

network effect is modest, the first effect tends to dominate and the average price tends to decrease in the network effect, while the opposite is true when the network effect is strong.

Switching Cost For a fixed but small network effect, the average price is also U-shaped in the switching cost, as in Cabral (2016). However, when the network effect becomes strong enough to cause a tipping equilibrium, we find that this pattern is eliminated and the average price is monotonically increasing in the switching cost. In a tipping equilibrium, the long-run market structure is highly asymmetric and the larger firm has a sizable installed base advantage. The main effect of an increase in the switching cost is that it firms up the larger firm's installed base advantage, thereby allowing the larger firm to charge a higher price in equilibrium. Consequently, a policy that reduces the switching cost would decrease the average price. Producer surplus (Figure



(a) average price (b) consumer surplus (c) producer surplus (profits)

Figure 3: The average price, consumer surplus, and producer surplus for $(\theta, k) \in \{0, 0.5, \ldots, 5\} \times \{0, 0.25, \ldots, 3\}$, endogenous reimbursement.

3(c)) follows the average price closely and exhibits the same pattern.[22]

In contrast, a reduction in the switching cost has little effect on consumer surplus (Figure 3(b)). This is not surprising given the reimbursement option, as in the limiting distribution, essentially all of the switching costs are reimbursed by the seller. Hence, the (small) changes in consumer surplus are not driven by the switching cost itself, but by how the reduced switching cost slightly changes prices and network benefits for consumers.

The above results shed light on the comparison between a market with no switching costs and a market with high switching costs and reimbursement, which is particularly relevant given policymakers' focus on reducing or eliminating switching costs (with policies such as phone number portability and bank account number portability). With $\theta = 2$ and endogenous reimbursement, we find that when k is reduced from 2 to 0, average price decreases from 1.78 to 1.38, consumer surplus barely changes going from 22.87 to 22.14, and producer surplus decreases from 1.75 to 1.38. A public policy that reduces consumers' switching costs would increase consumer welfare if firms do not have the option to reimburse switching costs (Figure A6(a) in Appendix A2), but would have little effect on consumer welfare if firms have that option, highlighting the important role that switching cost reimbursement plays in determining the effects of switching costs on consumer welfare.

3.5 Transition Dynamics

Our model based on the Ericson and Pakes (1995) framework allows us to examine the industry's transition dynamics in addition to its long-run structure. Panels (e) and (f) of Figures A1-A4 in

[22]The firms' combined profits, which approximately equal the sum of the firms' expected sales times the average price, are close to the average price because the sum of the firms' expected sales is close to 1 due to the inferiority of the outside good relative to the inside goods.

Appendix A2 provide, for our baseline parameterizations, the transient probability distribution of the industry state after 15 periods, starting from state $(0, 0)$ in period 0, as well as the limiting (asymptotic) probability distribution as the number of periods approaches infinity. When there is a tipping equilibrium, both the transient and the limiting distributions are clearly bimodal, indicating an asymmetric market structure both in the short run and in the long run. In comparison, when there is a splintered equilibrium, both distributions are unimodal, indicating that the market structure remains roughly symmetric throughout.

To further illustrate the industry's transition dynamics, Panels (g)-(l) of Figures A1-A4 plot the evolution (time paths based on the transient distribution) of several key variables, including the larger firm's and the smaller firm's prices, reimbursement, installed bases, probabilities of sales, and producer surplus, as well as the attentive consumer's surplus and the average consumer surplus for the inattentive consumers.

In a tipping equilibrium, the larger firm's price remains below the smaller firm's until around period 20, and is only slightly above the smaller firm's afterwards. This combined with the larger firm's bigger network and more generous reimbursement policy (under the ER regime) allows it to enjoy a significant advantage in the probability of making a sale, which in turn enables it to expand and maintain an installed base much higher than the smaller firm's. In contrast, in a splintered equilibrium, throughout the evolution, the larger firm charges a noticeably higher price than the smaller firm, and the two firm's probabilities of sales are roughly equal, with the smaller firm having a slight advantage in the long run. Consequently, the larger firm's installed base is never much higher than the smaller firm's.

In terms of PS, a key difference between a tipping equilibrium and a splintered equilibrium is that in the latter, the two firms enjoy higher, and much more similar, PS, due to the much milder competition between the two. Turning to CS, in a tipping equilibrium, the attentive consumer enjoys a high CS during the initial periods, thanks to the low prices charged by two firms locked in fierce competition, though such CS dissipates after a few periods as the preemption race is over and both firms heighten their prices. The average CS for the inattentive consumers, on the other hand, increases steadily—due to the enlarging networks of the inside goods—until around period 40 and stabilizes afterwards; it crosses the attentive consumer's CS from below around period 30. Compared to a tipping equilibrium, the evolution of CS in a splintered equilibrium follows a similar pattern, although both the attentive consumer and the inattentive consumers are worse off, the former due to the higher prices charged by the firms and the latter due to the splintered nature of the networks, which reduces network benefits.

We are also interested in understanding how fast the industry approaches the long-run limiting distribution. Note that the transient distribution is never exactly equal to the limiting distribution, but can get arbitrarily close to it as t—the number of periods since the initial period—increases. We therefore calculate $\bar{t}$ for each parameterization, the first period in which the relative change from the previous period to the current period is below 1% for each of the following variables: the larger firm's and the smaller firm's prices, reimbursement (under the ER regime), and installed bases. We find that across different parameterizations (and different types of equilibria), $\bar{t}$ remains somewhat similar. For example, for the parameterizations plotted in Figures A1-A4, $\bar{t}$ is 41, 39, 40, and 38, respectively. That $\bar{t}$ is not very different across different parameterizations is closely related to the somewhat similar amount of time it takes for the inside goods to gradually capture most of the market, at which point the two firm's installed bases largely stabilize (near the $(0, M)$ – $(M, 0)$ border of the state space).

4 Effects of Switching Cost Reimbursement

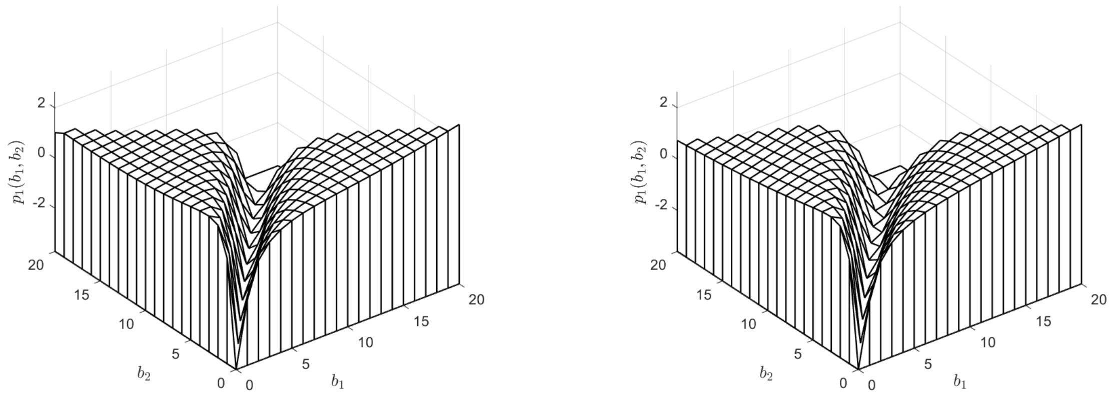
We now analyze how switching cost reimbursements affect prices, market structure, and surpluses. We do so by comparing, for each (θ, k) combination, the prices, market structure, and surpluses under the ER and NR regimes. When switching costs are small, the effects are minimal as the switching cost, and thus the reimbursement, do not significantly alter the consumer's optimization problem. However, with larger switching costs, the reimbursement channel significantly impacts pricing strategies, the market structure, and the corresponding CS and PS.

4.1 Low Switching Costs ($k = 1$)

When the switching cost is small, there is little effect of the reimbursement on the MPE structure and pricing policies. With or without the reimbursement channel, the MPE is a tipping equilibrium where the firms practice the well-established bargain-then-ripoff strategy (Chen, 1997; Farrell and Klemperer, 2007), illustrated in Figures 4(a) and 4(b).

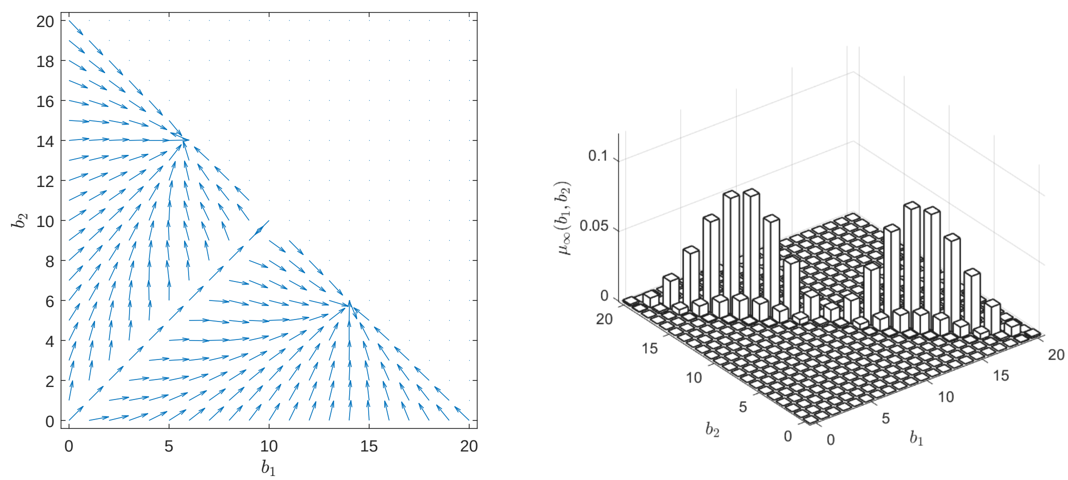
The firm that obtains the early advantage maintains it, leading to the tipping equilibrium. The resultant forces are depicted in Figure 5(a). The dominant firm builds on their advantage with the increasing network benefits stemming from an increasing installed base allowing them to charge higher prices than their smaller competitor. However, this process does not rely on the reimbursement channel and occurs regardless. The limiting distribution, plotted in Figure 5(b), illustrates the bimodal tipping equilibrium, which again persists with or without the switching cost.[23] Overlaying the limiting distribution with the reimbursement policy illustrates our fourth property of the reimbursement channel: for all $b = (b_1, b_2)$ with significant mass in the limiting distribution, the larger firm reimburses the entirety of the switching cost. While this complete reimbursement pattern does not hold for all 4,200 parameter specifications (including the robustness checks) the larger

[23] Figure A1 in Appendix A2 plots these figures when there is no reimbursement.



(a) endogenous reimbursement (b) no reimbursement

Figure 4: Equilibrium pricing policy given $k = 1$ and $\theta = 2$.



(a) resultant forces (b) Limiting distribution

Figure 5: Resultant forces and limiting distribution of installed bases with reimbursements and a switching cost of $k = 1$.

firm always reimburses over 50% of the switching cost while the smaller firm always reimburses under 50%.

Given that the switching cost is low (at $k = 1$), it is unsurprising that the reimbursement channel has little effect on the market structure. In this case, the dynamics are driven by the network effect. Recall that, in the baseline specification, the network effect is $\theta = 2$ and $g(b_j) = b_j/20$. Hence, when competition is intense and firms are battling to obtain a majority, $\theta g(b_j) \approx 2 \times (1/2) = k$. Once a firm obtains an advantage, the network effect dominates the switching cost, so reimbursements have relatively little effect on the consumers' decisions.

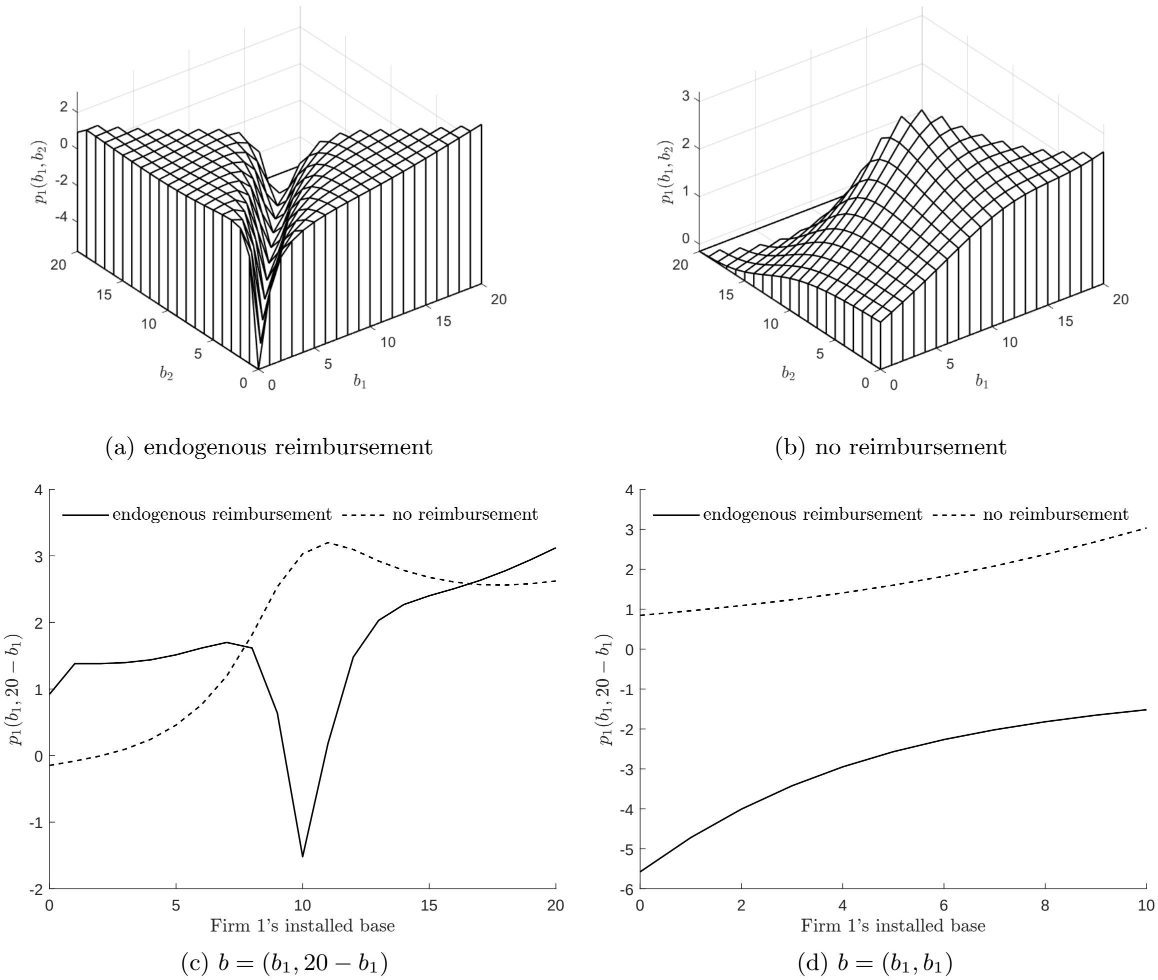
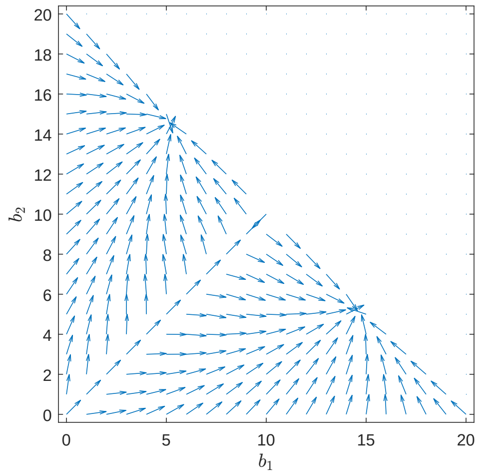


Figure 6: Equilibrium pricing policy given $k = 2$ and $\theta = 2$.

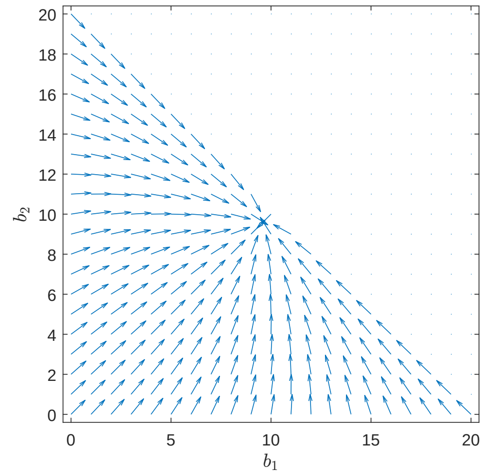
4.2 High Switching Costs ($k = 2$)

With a large switching cost, the reimbursement channel has significant effects on both pricing and the market structure, and therefore the resulting welfare effects. Under the NR regime, the firms do not engage in a bargain-then-ripoff strategy. While the larger firm still sets a higher price than their smaller competitor, prices are at their peak when installed bases are approximately symmetric for any degree of market coverage. This symmetry price is correspondingly increasing in the degree of market coverage, as illustrated in Figure 6(d). Prices then trend downward as the degree of asymmetry in installed bases increases, though for a large enough installed base, the network effect allows the price to rise slightly. This pricing policy without reimbursement is illustrated in Figure 6(b) and the case of full market coverage in Figure 6(c).

With a large switching cost and no reimbursement, the degree to which consumers are locked in



(a) endogenous reimbursement



(b) no reimbursement

Figure 7: Resultant forces given $k = 2$ and $\theta = 2$.

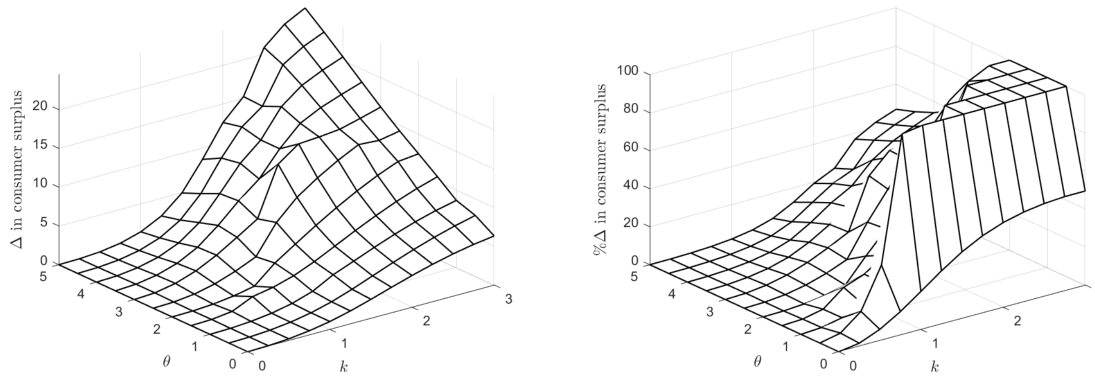
is significant. As a result, only those with strong unobserved preferences for an inside good that is different than their current good switch. In this instance, a splintered equilibrium with high prices persists in the long run. Hence, we see a pattern of reversion to the mean as in Cabral (2011). The ER regime eliminates this lock-in problem and allows firms to continue to implement the bargain-then-ripoff strategy.

The effect of the bargain-then-ripoff pricing strategy, when coupled with the reimbursement channel, is identical to the low switching cost case. Rather than a splintered equilibrium, a tipping equilibrium emerges. The firm that obtains the early advantage maintains that advantage and achieves market dominance in the long run.

Chen (2016) studies in an extension the case of an exogenously determined switching cost subsidy, in which half of a consumer's switching cost is subsidized by the firm that she switches to. That paper finds that in such a case, switching costs continue to have the ability to transform the market equilibrium from tipping to splintered, but under the subsidy it takes a larger switching cost to bring about such a transformation. In contrast to that scenario, here we study endogenously determined switching cost reimbursement, where, as we discuss earlier, the larger firm always reimburses more of the switching cost than its smaller competitor. This endogenous asymmetry in switching cost reimbursement strengthens the larger firm's installed base advantage and prevents the transformation from tipping equilibrium to splintered equilibrium as switching cost is increased.

4.3 Switching Cost Reimbursement and Welfare

We now examine how the reimbursement channel affects CS and PS.



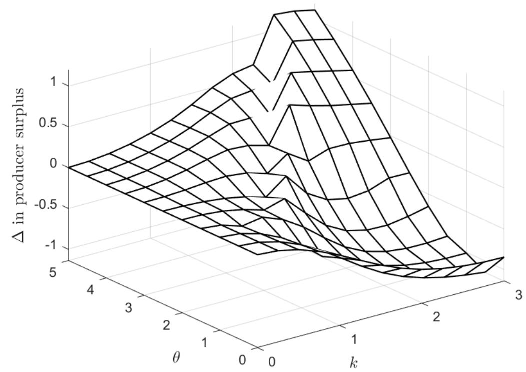
(a) change in consumer surplus

(b) percent change in consumer surplus

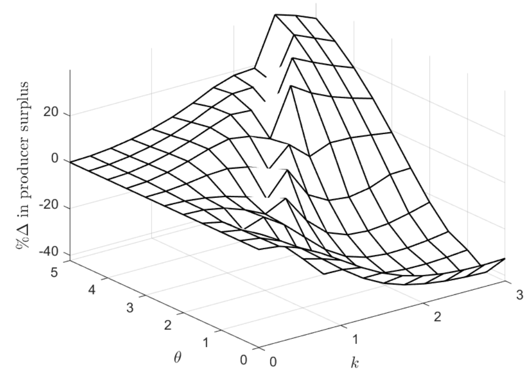
Figure 8: Changes in consumer surplus for $\theta \in \{0, 0.5, \ldots, 5\}$ and $k \in \{0, 0.25, \ldots, 3\}$. For expositional clarity, the percentage change figure has been capped at 100%, though for small θ and large k, the percentage changes significantly exceed 100%.

Consumers never find themselves worse off when the firms are given the option to reimburse the switching costs, regardless of their magnitude or the magnitude of the network effect. Not only are the consumers always better off, but the increases in consumer surplus generated through the reimbursement channel can be substantial. With strong network effects and high switching costs, e.g., $\theta = 5$ and $k = 3$, the reimbursement channel increases CS by approximately 47%, from 52.5 to 76.9. In the baseline case with low switching costs, $\theta = 2$ and $k = 1$, the reimbursement channel increases CS by approximately 5.1%, from 21.5 to 22.6. When the switching costs are increased to 2, the reimbursement channel increases CS by approximately 57.5%, from 14.5 to 22.9. The sharp difference follows from the change in equilibrium structure for $k = 2$. When $k = 1$, there is a tipping equilibrium with and without reimbursement. However, for $k = 2$, the market structure changes from a splintered equilibrium to a tipping equilibrium when turning on the reimbursement channel.

Three general patterns emerge with respect to the effect of the reimbursement on CS. First, for any given network effect θ, the increase in CS generated by the reimbursement channel is monotonically increasing in the magnitude of the switching cost k, as illustrated in Figure 8(a). Second, and also illustrated in Figure 8(a), for low-to-intermediate switching costs k, the increase in CS generated by the reimbursement channel is non-monotonic in the size of the network effect, while it is monotonically increasing in the network effect for large k. The increases are largest when the switching cost is large, as this is the case when the reimbursement transforms the equilibrium from a splintered equilibrium to a tipping equilibrium. As a result, the market is significantly more concentrated, which generates a larger network benefit from consumers of the good with the larger installed base. Third, the percentage change in CS generated from the reimbursement channel is



(a) change in producer surplus



(b) percent change in producer surplus

Figure 9: Changes in producer surplus for $\theta \in \{0, 0.5, \ldots, 5\}$ and $k \in \{0, 0.25, \ldots, 3\}$.

greatest when the network effects are small. This pattern is illustrated in Figure 8(b).

We now turn our attention to PS and assess whether the reimbursement channel is strategically advantageous or induces a prisoner's dilemma. We find that the answer depends explicitly on the network effect. When the network effect is small, the reimbursement channel lowers PS, indicating that the reimbursement channel induces an asymmetric prisoner's dilemma. This decrease can be substantial, bottoming out at a decrease of approximately -42%, from 2.7 to 1.6. To the contrary, the reimbursement channel increases PS when the network effect is large. Like the decrease in the small network effect case, this increase can be substantial, topping out at approximately 39.6%, from 3 to 4.2. Figure 9(b) plots the percentage change in PS for all baseline parameter combinations. There is significant interaction between the switching cost, network effect, and reimbursement channel. The magnitude of the network effect plays an explicit role in whether firms expect to benefit from the option to reimburse or only use it as a shield to prevent their competitor from using reimbursements against them. While it is clear that consumers would be in support of any policy that makes reimbursements easier, it is less clear whether industry participants would support such a measure.

Furthermore, results indicate that firms' reimbursement of consumers' switching cost is welfare-enhancing (where there is a reduction in PS, the increase in CS is larger in magnitude), and such welfare gains are particularly large in industries with strong network effects and switching costs (Figure A6(i) in Appendix A2), providing support for public policies that allow or even promote this form of behavior-based price discrimination. Our results have useful policy implications, as they show that with endogenous reimbursement of switching costs, even though the market is more concentrated, the network benefit is greater and the average price (which follows a pattern similar to PS) is often lower than a less concentrated market without switching cost reimbursement, thus benefiting consumers. Therefore, an antitrust authority relying on the market concentration for its antitrust analysis must exercise caution in industries with switching costs. If the firms are practicing price discrimination via the reimbursement channel, then consumer surplus is actually greater in these markets than it would be if such price discrimination were to be restricted by the authority.

5 Robustness of Findings

In this section, we examine the robustness of our findings by considering a wide range of parameterizations. By varying $v_0 \in \{-7, -6, -5, -4, -3\}$, we allow the quality differential between the inside goods and the outside good to vary considerably, which results in a wide range of market size (the degree of market coverage), ranging from 76.63% to 99.99%. In our model, one out of M consumers in each period experiences product death and becomes attentive, while the other $M - 1$ consumers are inattentive and keep their existing products, exhibiting consumer inertia.[24] In the robustness checks, we vary the rate of product death (products die at the rate of $1/M$ in each period) and the degree of consumer inertia (a fraction $1/M$ of the consumers are attentive in each period) by varying the value of $M \in \{12, 14, ..., 24\}$. In the main analysis, we assumed $g(b_j) = b_j/M$. In the robustness checks we consider three additional network effect functions, concave, convex, and s-shaped, as described in Subsection 3.1.[25] For network effect and switching cost, we consider $\theta \in \{0, 1, ..., 5\}$ and $k \in \{1, 2, 3\}$. We also consider both the ER and NR regimes.

Hence, we run a total of $5 \times 7 \times 4 \times 6 \times 3 \times 2 = 5,040$ parameterizations. We compute the equilibrium for each parametrization in this set and examine whether the results discussed above hold. Figures 10 and 11 provide succinct summaries of the robustness checks. While the large set of parameterizations we consider here result in a wide range of market outcomes in terms of firms' reimbursement choices, market size, market concentration, and welfare measures, those market outcomes continue to be consistent with the results described in Section 4, summarized below.

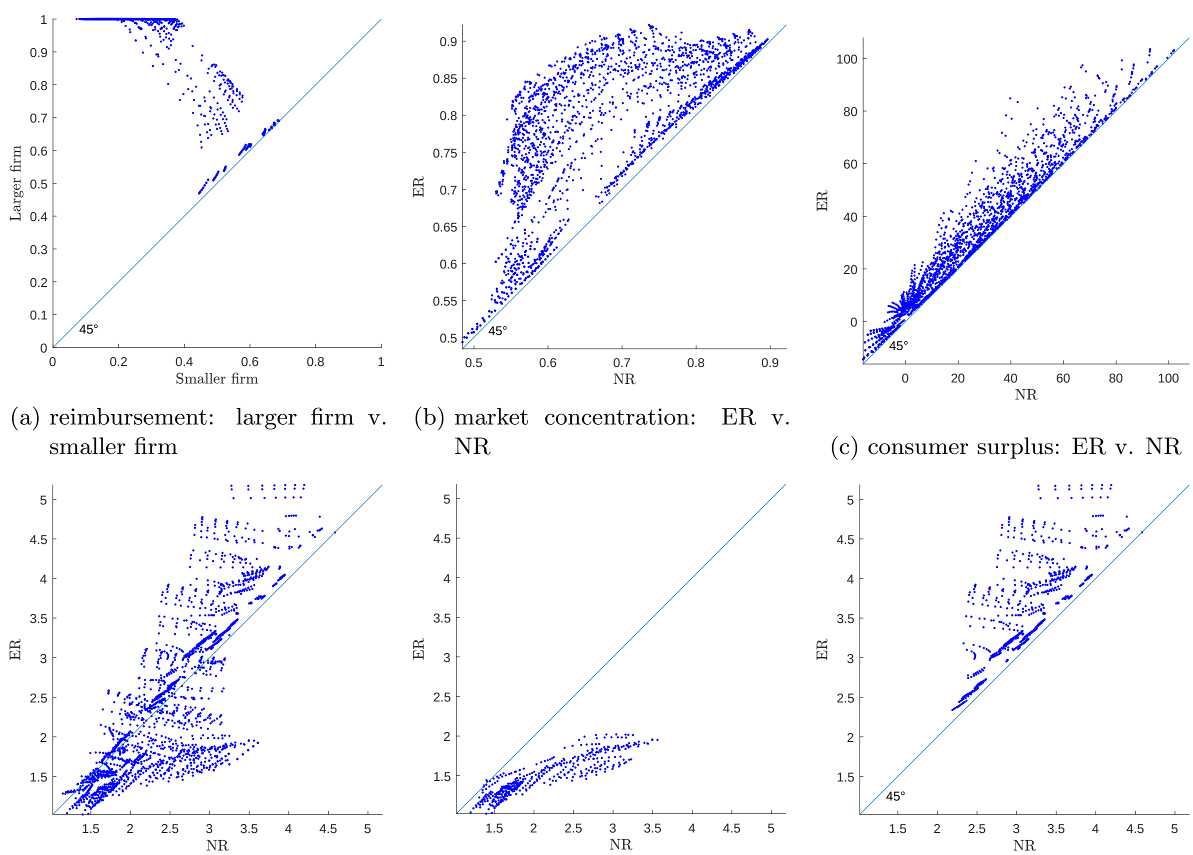
1. The larger firm reimburses a greater share of the switching cost than the smaller firm.

2. The option to reimburse switching costs increases the market concentration. Increasing the switching cost further increases the market concentration.

3. The option to reimburse switching costs decreases producer surplus when network effects are small or absent but increases it when large. Higher switching costs increase producer surplus.

[24] See Dubé et al. (2010), Handel (2013), and Hortaçsu et al. (2017) for examples of consumer inertia in consumer packaged goods markets, health insurance markets, and residential electricity markets, respectively

[25] For example, Swann (2002) explores functional forms of network effects in a model of a telephone network and suggests that in theoretical models with network effects, the character of the results depends on the functional form of network effects.



(a) reimbursement: larger firm v. smaller firm

(b) market concentration: ER v. NR

(c) consumer surplus: ER v. NR

(d) producer surplus: ER v. NR

(e) producer surplus: $\theta = 1$

(f) producer surplus: $\theta \in \{4, 5\}$

Figure 10: Scatter plots of robustness check results. Each point corresponds to a parametrization. $\theta \in \{0, 1, ..., 5\}$, $k \in \{1, 2, 3\}$, $v_0 \in \{-7, -6, -5, -4, -3\}$, $M \in \{12, 14, \ldots, 24\}$, shape of network effect function$\in$ {linear, convex, concave, s-shaped}.

4. The option to reimburse switching costs increases consumer surplus. Higher switching costs leave consumer surplus largely unaffected.

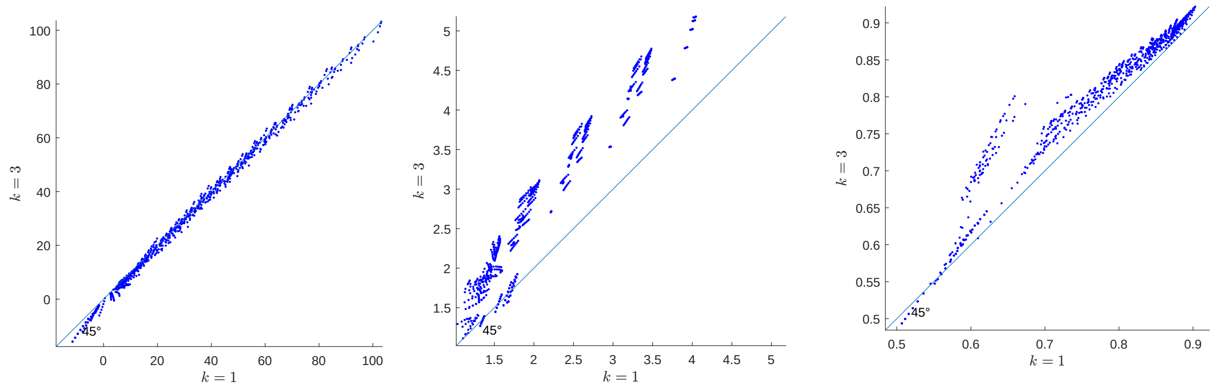
6 Extensions

In this section, we study two extensions of our model.

6.1 Forward-Looking Consumers

Consider an extension in which consumers are forward-looking with discount factor $\beta_c \in (0, 1)$. The other assumptions of the model remain unchanged, including the assumption that consumers are attentive only when their existing products die. The details of this modified version of the model are presented in Appendix A1.

The results from this extension show that our earlier findings are robust and furthermore shed



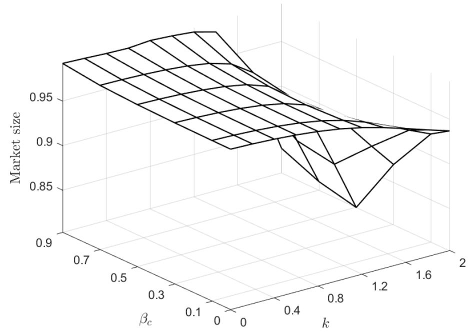
(a) consumer surplus (ER) (b) producer surplus (ER) (c) concentration (ER): $k = 3$ v. $k = 1$

Figure 11: Scatter plots of robustness check results for $k = 3$ v. $k = 1$. Each point corresponds to a parametrization. $\theta \in \{0, 1, ..., 5\}$, $v_0 \in \{-7, -6, -5, -4, -3\}$, $M \in \{12, 14, \dots, 24\}$, shape of network effect function$\in$ {linear, convex, concave, s-shaped}.

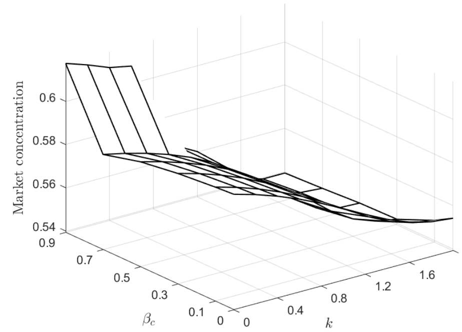
light on the effects of consumers' forward-looking behavior, as illustrated by Figure 12. The figure plots for $v_0 = -5$, $M = 20$, $\theta = 0.4$, $k \in \{0, 0.2, ..., 2\}$, and $\beta_c \in \{0, 0.1, 0.3, 0.5, 0.7, 0.9\}$. In the figure, the left column of panels plot the market size (the two firms' combined installed base as a proportion of M), and the right column of panels plot the market concentration (the larger firm's installed base as a proportion of the two firms' combined installed base). We discuss three findings.

First, when consumers are myopic, increases in the switching cost k don't cause market size to shrink much (see $\beta_c = 0$ in Panels (a) and (c)), as consumers do not internalize the switching cost that they would incur in the future if they choose an inside good now and decide to switch to the other inside good later. This pattern changes when consumers are forward-looking when the reimbursement channel is disabled. In this case consumers take into consideration future switching costs, and as a result increases in k lower the attractiveness of the inside goods relative to the outside good, thereby increasing the outside good's market share and shrinking the market size. When the reimbursement channel is enabled, firms are able to reimburse consumers' switching costs, and as a result increases in k continue to have little impact on market size even when consumers are forward-looking ($\beta_c > 0$ in Panel (c)). Thus, the reimbursement channel results in a higher market size whenever $k > 0$. The difference in market size is particularly large when both β_c and k are large (Panel (e)).

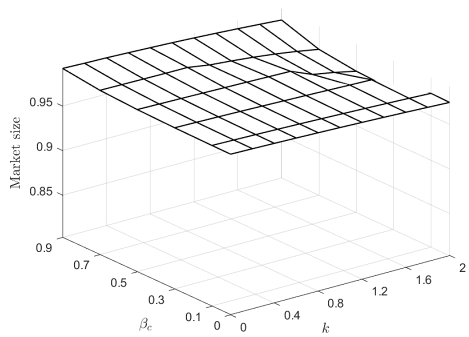
Second, the right-column of panels shows that our previous findings regarding market concentration when consumers are myopic continue to hold when consumers are forward-looking: switching costs reduce market concentration when the reimbursement channel is disabled (Panel (b)) and increase market concentration with reimbursements (Panel (d)). The reimbursement channel results in a higher market concentration (Panel (f)). The difference in market concentration is particularly



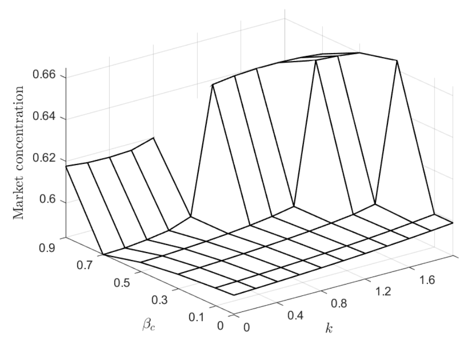
(a) market size, NR



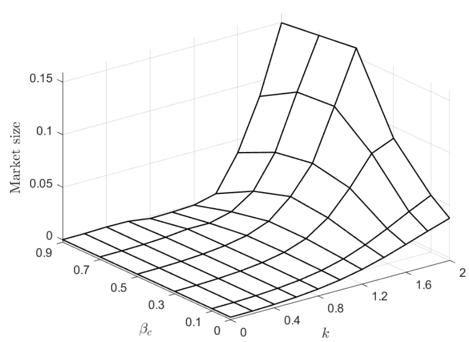
(b) market concentration, NR



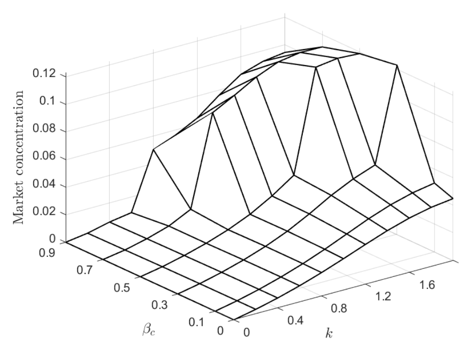
(c) market size, ER



(d) market concentration, ER



(e) market size, ER-NR



(f) market concentration, ER-NR

Figure 12: Market size and market concentration: forward-looking consumers. $v_0 = -5$, $M = 20$, $\theta = 0.4$. NR: No reimbursement. ER: Endogenous reimbursement.

large when both β_c and k are large.

Third, forward-looking consumers internalize future network benefits that they would enjoy if they choose one of the inside goods (recall that the products are durable and consumers make purchasing decisions only when their existing products die). Therefore, consumers' forward-looking behavior amplifies network effects and tends to lead to a tipping equilibrium, especially when firms can reimburse. Without reimbursements (Panel (b)), a tipping equilibrium occurs when β_c is 0.9 and k is less than or equal to 0.6; further increases in k transition the equilibrium from tipping to splintered, a pattern that we saw previously in the case with myopic consumers and larger network effects. With reimbursements, when k is increased, there is a splintered equilibrium throughout for small values of β_c ($\beta_c = 0$ or 0.1) and there is a tipping equilibrium throughout when $\beta_c = 0.9$. For intermediate values of β_c, there is a splintered equilibrium at low switching costs, which is then changed to a tipping equilibrium at high switching costs as in the main analysis.

Note that if consumers are attentive in every period, then when $k = 0$, whether consumers are forward-looking or myopic won't make a difference, because when there are no switching costs, each consumer can costlessly re-optimize in every period, thus for forward-looking consumers, their dynamic decision problem boils down to a period-by-period optimization problem that has no inter-temporal linkages and is no different from the decision problem facing myopic consumers. However, in our model, consumers make decisions infrequently (they are attentive only when their existing products die), so consumers' forward-looking behavior (indexed by β_c) makes a difference even when $k = 0$, as can be seen most clearly in Panels (b) and (d) of Figure 12.

Additional results (not shown) show that our previous findings continue to hold in the new runs with forward-looking consumers: the larger firm reimburses a larger proportion of the switching cost than the smaller firm does, increases in the network effect tend to decrease average price and producer surplus when the network effect is modest but increase them when the network effect is strong, and firms' option to reimburse consumers' switching costs increases consumer surplus and total surplus while its effect on producer surplus is ambiguous. The patterns of transition dynamics with respect to key variables such as prices, reimbursement, installed bases, PS, and CS are also similar to those in the myopic consumers case described in Subsection 3.5. $\bar{t}$, as defined in that subsection, ranges from 34 to 43 for the parameterizations shown in Figure 12, in line with those reported for the myopic consumers case.

6.2 Handicap Regime

Our model is a flexible tool for simulating different policy interventions. Here, we consider one such case: a policy that prohibits only the larger firm from reimbursing consumers' switching costs. This restriction places the larger firm at a disadvantage—or "handicap"—with the goal of curbing its dominance and promoting competition. We refer to this policy as the handicap regime (HR). The results for this regime are provided in Appendix A2.

Relative to ER, HR reduces market concentration, network benefit, consumer surplus, and total surplus, particularly when k is large and θ is small to medium (Figures A5(m), A5(n), A6(m), and A6(o) in Appendix A2). In these cases, ER results in a tipping equilibrium while HR results in a splintered equilibrium. When switching costs are high, the advantage conferred to the smaller firm under HR is substantial, enabling it to catch up with the larger firm and preventing market tipping. However, if network effects are especially strong, the larger firm's network size advantage remains insurmountable, and tipping still occurs.

Relative to NR, however, HR increases market concentration, network benefit, consumer surplus, and total surplus when both k and θ are large (Figures A5(p), A5(q), A6(p), and A6(r)). In these cases, NR results in a splintered equilibrium while HR results in a tipping equilibrium. With strong network effects and under NR, high switching costs convert the market from tipping to splintered by inducing the larger firm to charge high prices to harvest its locked-in consumers, which allows the smaller firm to gain market share. In contrast, under HR, the smaller firm's reimbursement of switching costs reduces consumer lock-in. As a result, the larger firm does not focus on harvesting with high prices, thus preventing the market from reverting to a splintered equilibrium.

Therefore, if the existing policy is NR and the policymaker introduces HR with the intention of reducing market concentration, the opposite will occur if the industry has strong network effects and high switching costs. This finding further underscores the need to carefully assess these industry characteristics when designing regulatory policies.

7 Discussion and Concluding Remarks

This paper develops a dynamic duopoly model of price competition with switching costs and network effects, where firms have the ability to reimburse consumers' switching costs. We use the model to investigate firms' pricing and reimbursement strategies and how competition and welfare are affected by these strategies. This setup yields several interesting and novel results.

Introducing the ability to reimburse switching costs benefits the larger firm and facilitates market tipping and winner-takes-most. A consequence is that the economy remains in a tipping equilibrium even at high switching costs. Even though the market is more concentrated, consumer welfare is higher. This finding has useful antitrust and consumer welfare policy implications, illustrating that in such industries, policy analysis relying heavily on the market concentration may be problematic.

In addition, we find that compared to the NR regime, firms' option to reimburse switching costs increases consumer surplus and total surplus, and increases producer surplus when network effects are strong. Switching costs decrease consumer surplus if firms do not have the option to reimburse switching costs, but leave consumer surplus largely unchanged if firms have that option. These results demonstrate that the welfare outcome in the market critically depends on whether firms have the option to reimburse consumers' switching costs.

Though we did not incorporate discounts or exit into our analysis, we can intuit their effects. In addition to reimbursing switching costs, a firm may also offer discounts to existing users of its product who are making a purchasing decision. By offering a benefit that an existing user would forgo if she switches, such discounts are a form of endogenous switching costs. Shi's (2013) theoretical analysis finds that firms create higher endogenous switching costs when exogenous switching costs are lower. Consequently, the option to offer discounts for existing customers may strengthen our findings. The introduction of the discounts enlarges the overall switching cost, particularly when the exogenous switching cost is low. Therefore, without reimbursements, the market would be more likely to have a splintered equilibrium, even when the exogenous switching cost is low. With reimbursements, the increase in the overall switching cost would increase the level of market concentration but would not change the type of equilibrium.

Given a sufficiently large discount factor β for firms, our modeling specification does not induce exit: in the long run, each firm's per-unit profit $p_j - d_j k$ is strictly positive. If fixed costs are introduced into the model, exit can occur. As the reimbursement option leads to an asymmetric outcome, fixed costs can induce the smaller firm to exit in the long run. Hence, a seemingly pro-competitive strategy can lead to an anti-competitive outcome.

Lastly, we reiterate that we have abstracted from issues such as endogenous switching costs and endogenous product quality. Nonetheless, an unambiguous finding that emerges is the role that switching cost reimbursement plays in determining the market outcome including market concentration and consumer welfare, as well as the importance of taking such reimbursement into account when designing public policies.

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Appendix

A1 A Model with Forward-Looking Consumers

In this appendix, we modify the main model in Section 2 to incorporate forward-looking consumers. In what follows, we will use $i \in \{1, 2, ..., M\}$ to index consumers, and use $j \in \{0, 1, 2\}$ to index goods and firms.

A1.1 Consumers' Problem

Let $r_i \in \{0, 1, 2\}$ denote the good that consumer i has at the beginning of the period. Below we will use superscript 0 to indicate expressions for an inattentive consumer, and use superscript 1 to indicate expressions for an attentive consumer.

Consumer i's single-period utility when she is inattentive is

$$u^0(b, r_i, \epsilon_i) = v_{r_i} + \mathbf{1}(r_i \neq 0)\theta g(b_{r_i}) + \epsilon_{i,r_i}, \tag{A1}$$

and her single-period utility when she is attentive and chooses to purchase good j is

$$u^1(b, p, d, r_i, \epsilon_i, j) = v_j + \mathbf{1}(j \neq 0)\theta g(b_j) - p_j - \mathbf{1}(r_i \neq 0, j \neq 0, r_i \neq j)(1 - d_j)k + \epsilon_{ij}. \tag{A2}$$

Let $\tilde{W}(b, p, d, r_i) = \mathbb{E}_{\epsilon_i} W(b, p, d, r_i, \epsilon_i)$ denote consumer i's expected value function, where $W(\cdot)$ denotes the consumer's value function at the beginning of a period *before* knowing whether her product unit dies in that period. The consumer's Bellman equation in expected value function is:

$$\tilde{W}(b, p, d, r_i) = \left(1 - \frac{1}{M}\right)\tilde{W}^0(b, p, d, r_i) + \frac{1}{M}\tilde{W}^1(b, p, d, r_i), \tag{A3}$$

where

$$\tilde{W}^0(b, p, d, r_i) = \tilde{u}^0(b, r_i) + \beta_c \mathbb{E}_{b'}\left[\tilde{W}(b', P(b'), D(b'), r_i)\right] \tag{A4}$$

and

$$\tilde{W}^1(b,p,d,r_i) = \log\left[\sum_{j=0}^{2} \exp\left\{\tilde{u}^1(b,p,d,r_i,j) + \beta_c \tilde{W}(b', P(b'), D(b'), j)\right\}\right]. \tag{A5}$$

In the above, $\tilde{u}^0(\cdot)$ and $\tilde{u}^1(\cdot)$ denote the deterministic parts of $u^0(\cdot)$ and $u^1(\cdot)$, respectively, $\beta_c \in [0,1)$ is the consumers' discount factor, $P(\cdot) = (P_1(\cdot), P_2(\cdot))$ and $D(\cdot) = (D_1(\cdot), D_2(\cdot))$ denote the two firms' price and reimbursement policy functions, respectively, and $b' = (b_1', b_2')$ is the next-period industry state. The consumer's Bellman equation in expected value function does not involve the stochastic ϵ_i and is used in the value function iteration in our algorithm to solve for the dynamic equilibrium.

Consider the attentive consumer in the current period, consumer a, whose original product r_a dies and who returns to the market to make a purchasing decision. Let

$$\psi(b,p,d,r_a,j) = \tilde{u}^1(b,p,d,r_a,j) + \beta_c \tilde{W}(b', P(b'), D(b'), j) \tag{A6}$$

denote this consumer's expected value associated with choosing good j. In the above expression, the next-period industry state b' is pinned down given b, r_a, and j; see the state transition function Eq. (A8) below. Using the logit choice probability formula, we can write the probability that this consumer chooses good j as

$$\phi(b,p,d,r_a,j) = \frac{\exp\left[\psi(b,p,d,r_a,j)\right]}{\sum_{h=0}^{2} \exp\left[\psi(b,p,d,r_a,h)\right]}. \tag{A7}$$

Given our assumption that in every period, one random consumer out of the M consumers experiences product death and becomes attentive, the probability distribution of r_a—the attentive consumer's original product—is given by $\Pr(r_a = j|b) = b_j/M$, for $j = 0,1,2$.

Let $s_a \in \{0,1,2\}$ denote the attentive consumer's product choice. The industry state then transitions based on the joint outcome of the installed base depreciation (product death) and the attentive consumer's purchasing decision:

$$b' = B(b, r_a, s_a) = (\underbrace{b_1 - \mathbf{1}(r_a = 1) + \mathbf{1}(s_a = 1)}_{b_1'}, \underbrace{b_2 - \mathbf{1}(r_a = 2) + \mathbf{1}(s_a = 2)}_{b_2'}). \tag{A8}$$

A1.2 Firms' Problem

Firm j chooses its price p_j and reimbursement d_j in each period. Let $V_j(b)$ denote the expected net present value of current-period and future cash flows to firm j in state b. Firm j's Bellman equation is given by

$$\begin{aligned} V_j(b) = \max_{p_j, d_j} \mathbb{E}_{r_a} \Bigg[&\phi\left(b, (p_j, P_{-j}(b)), (d_j, D_{-j}(b)), r_a, j\right)\left(p_j - \mathbf{1}\left(r_a \neq 0, r_a \neq j\right) d_j k\right) \\ &+ \beta \sum_{h=0}^{2} \phi\left(b, (p_j, P_{-j}(b)), (d_j, D_{-j}(b)), r_a, h\right) V_j(b') \Bigg], \end{aligned} \tag{A9}$$

where $\beta \in [0,1)$ is the firms' discount factor, the (constant) marginal cost of production is normalized to zero, $P_{-j}(b)$ is the equilibrium price charged by firm j's rival, $D_{-j}(b)$ is the equilibrium proportion of the switching cost reimbursed by firm j's rival, and the next-period industry state b' at the end of the equation is $b' = B(b, r_a, h)$ according to the state transition function Eq. (A8).

A1.3 Equilibrium

In equilibrium, from consumers' point of view, both p and d are functions of the industry state b based on the firms' equilibrium price and reimbursement policy functions: $p = P(b) = (P_1(b), P_2(b))$ and $d = D(b) = (D_1(b), D_2(b))$. Therefore, we can rewrite consumers' expected value function $\tilde{W}(b, p, d, r_i)$ as a function of b and r_i only, by substituting p and d with $P(b)$ and $D(b)$, respectively. Consequently, consumers' Bellman equation Eq. (A3) can be rewritten as an equation that involves only two variables, b and r_i:

$$\tilde{W}(b, r_i) = \left(1 - \frac{1}{M}\right) \left\{ \tilde{u}^0(b, r_i) + \beta_c \mathbb{E}_{b'} \left[\tilde{W}(b', r_i) \right] \right\} + \frac{1}{M} \log \left[\sum_{j=0}^{2} \exp \left\{ \tilde{u}^1(b, P(b), D(b), r_i, j) + \beta_c \tilde{W}(B(b, r_i, j), j) \right\} \right]. \quad \text{(A10)}$$

The Markov perfect equilibrium of the infinite-horizon dynamic game described above consists of the following equilibrium functions: the firms' price and reimbursement policy functions $P_j(b)$ and $D_j(b)$, the firms' value function $V_j(b)$, and the consumers' expected value function $\tilde{W}(b, r_i)$, $r_i = 0, 1, 2$. In equilibrium, those functions jointly satisfy the following conditions for every industry state b: (i) $(P_j(b), D_j(b))$ is the solution to firm j's maximization problem in its Bellman equation Eq. (A9), (ii) $V_j(b)$ satisfies firm j's Bellman equation, and (iii) $\tilde{W}(b, r_i)$, $r_i = 0, 1, 2$ satisfies consumer i's Bellman equation Eq. (A10). We use value function iteration based on these conditions to solve for the Markov perfect equilibrium.

A2 Figures from Main Analysis

This section offers six figures that plot additional details from the main analysis. Figures A1-A4 each consists of twelve panels. Panels (a)-(c) of each figure plot firm 1's price policy function, reimbursement policy function, and value function, respectively.[A1] Panel (d) plots the resultant forces. Panel (e) plots the transient distribution of the industry state after 15 periods and Panel (f) plots the limiting distribution.

Panels (g)-(l) plot the industry's evolution (time paths based on the transient distribution) from $t = 0$ (the initial period, with $b = (0, 0)$) to $t = 100$. The variables being shown are the larger firm's and the smaller firm's prices, reimbursement, installed bases, probabilities of sales, and PS, as well as the attentive consumer's CS and the average CS for the inattentive consumers.

Figures A1 and A2 plot the case in which the reimbursement channel is disabled for $k = 1$ and $k = 2$, respectively. Figures A3 and A4 plot the case in which the firms reimburse customers' switching costs for $k = 1$ and $k = 2$, respectively.

Figures A5-A6 plot the market concentration, network benefits, average prices, consumer surplus, producer surplus, and total surplus for the NR, ER, and HR regimes as well as the differences between them. Each panel is plotted as a function of the network effect θ and the switching cost k for $\theta \in \{0, 0.5, \ldots, 5\}$ and $k \in \{0, 0.25, \ldots, 3\}$.

[A1] Recall that the MPE is symmetric, so by permutating the state with respect to b_1 and b_2, firm 2's policy and value functions are found.

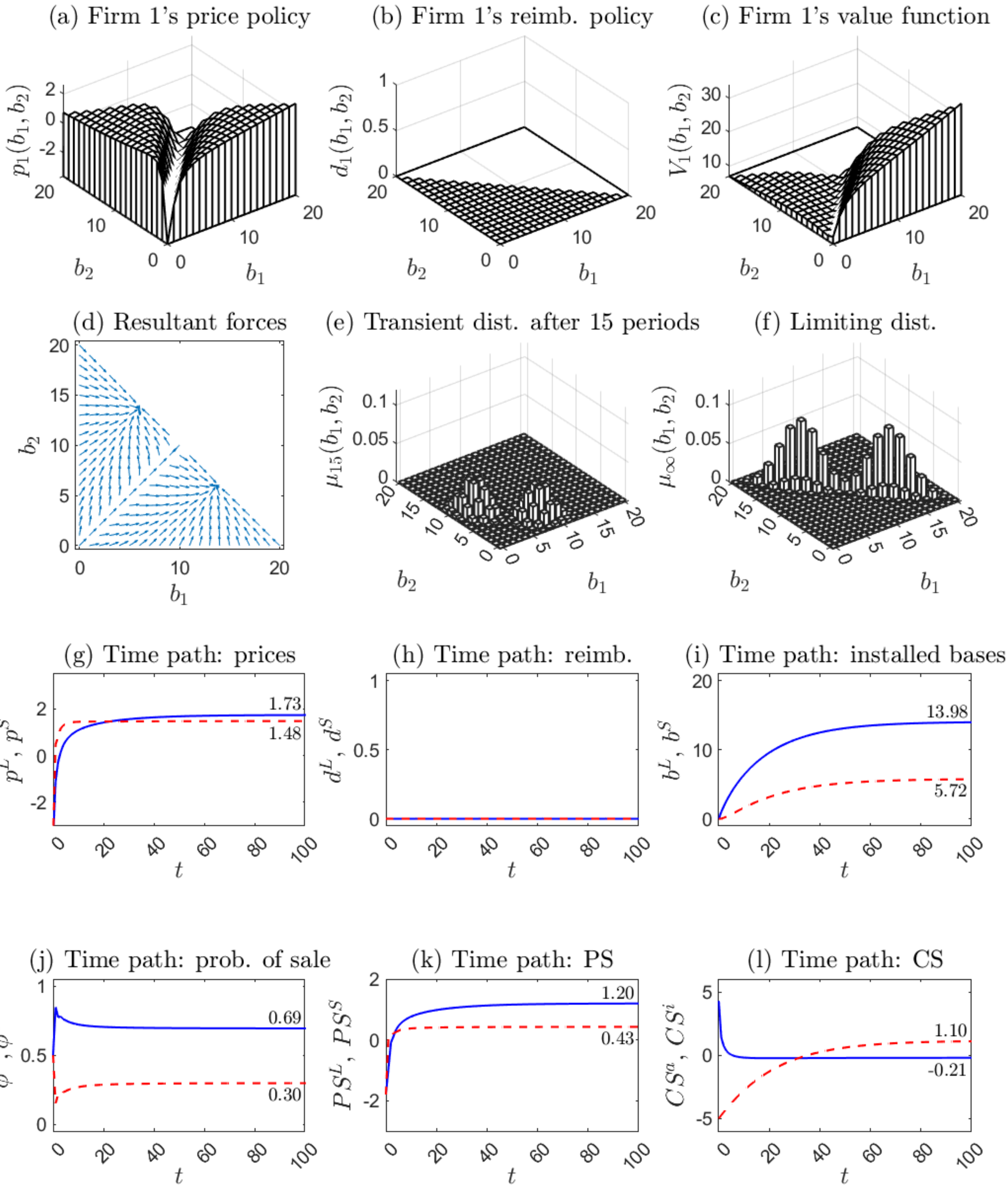

Figure A1. No reimbursement (NR): Tipping equilibrium at low switching cost.
$v_1 = v_2$ normalized to 0, $v_0 = -5$, $M = 20$, $\theta = 2$, $k = 1$.
Solid line indicates the larger firm (Panels (g)-(k)) or the attentive consumer (Panel (l));
dashed line indicates the smaller firm or the average for inattentive consumers.

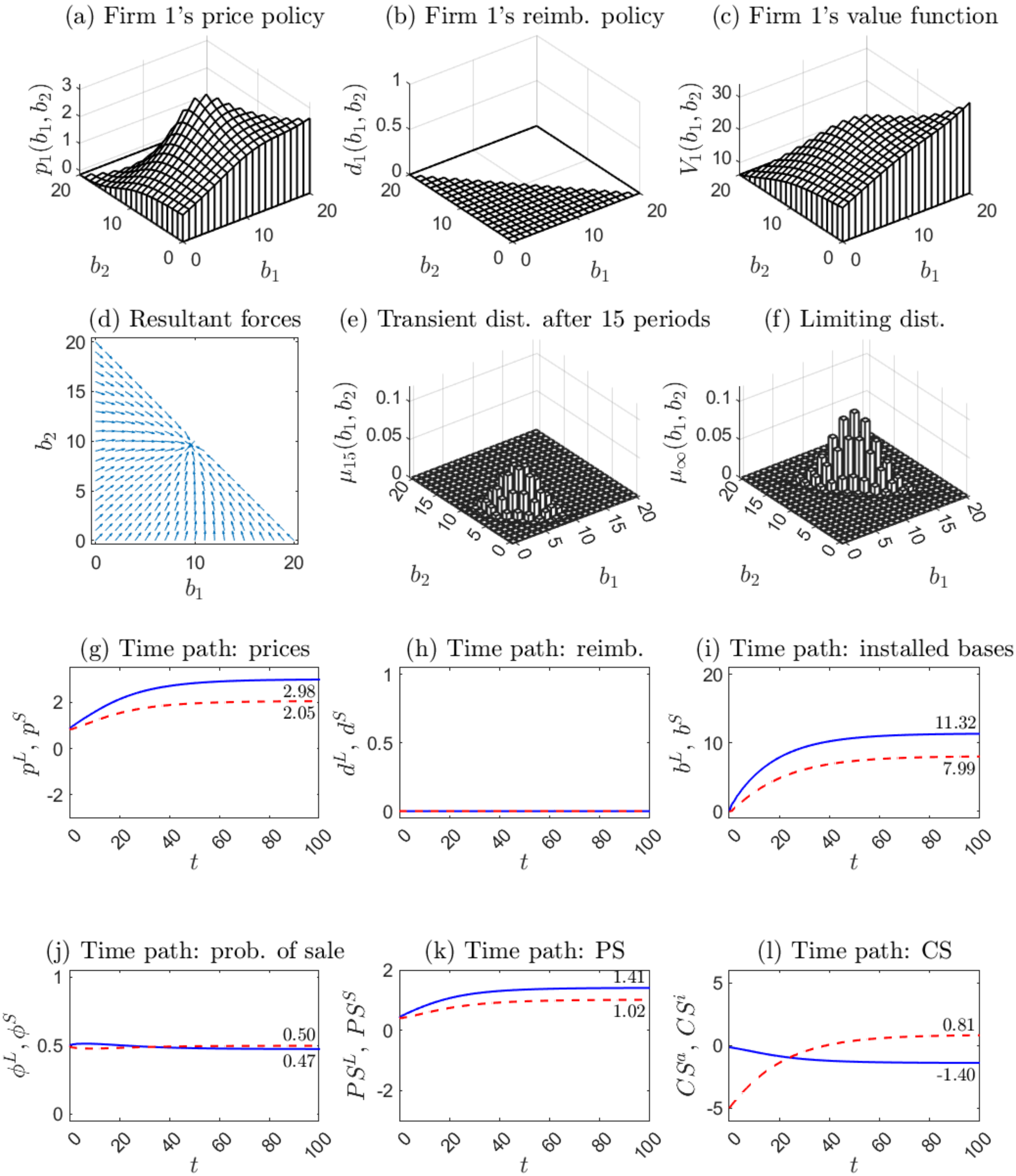

Figure A2. No reimbursement (NR): Splintered equilibrium at high switching cost.
$v_1 = v_2$ normalized to 0, $v_0 = -5$, $M = 20$, $\theta = 2$, $k = 2$.
Solid line indicates the larger firm (Panels (g)-(k)) or the attentive consumer (Panel (l));
dashed line indicates the smaller firm or the average for inattentive consumers.

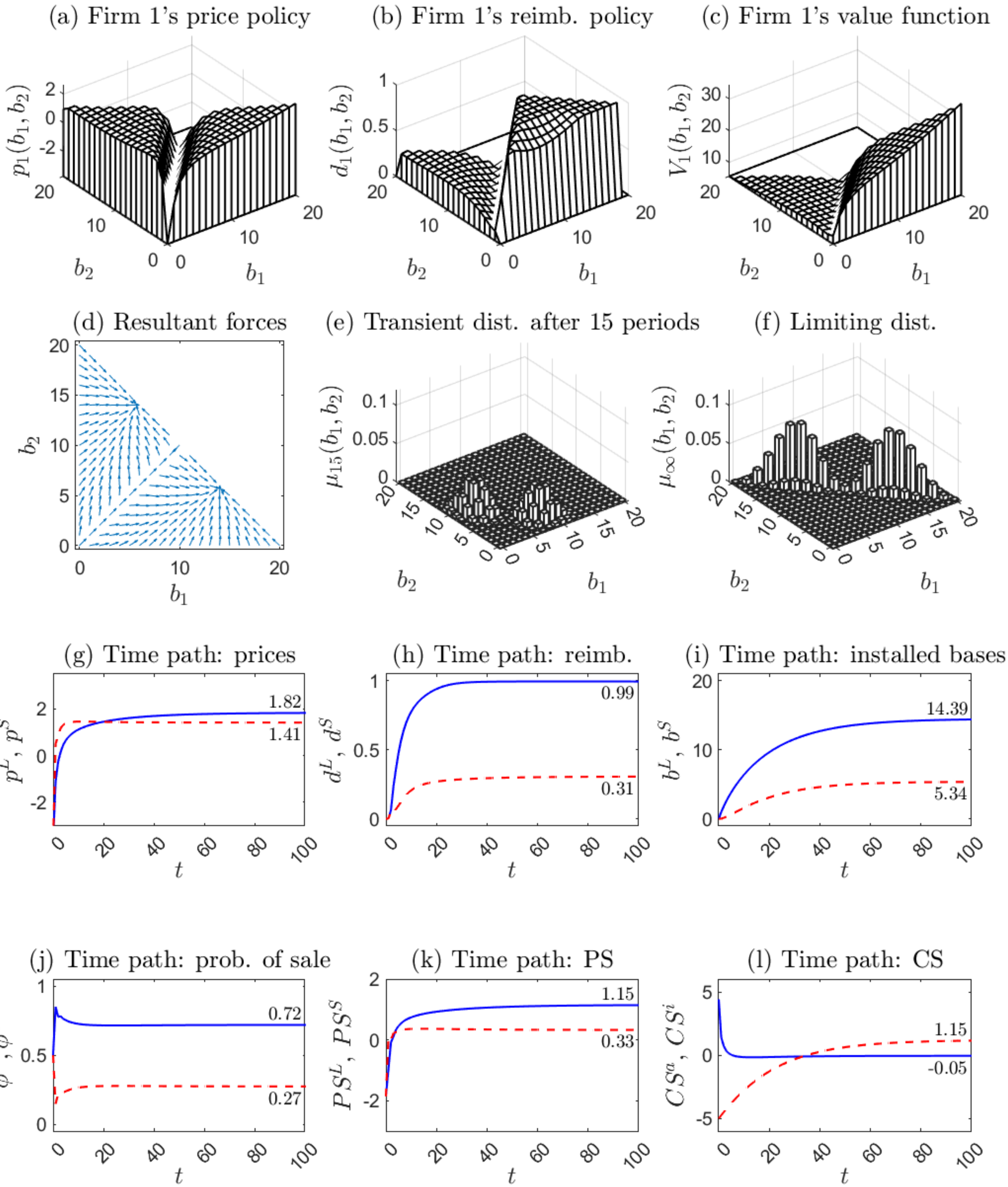

Figure A3. Endogenous reimbursement (ER): Tipping equilibrium at low switching cost.
$v_1 = v_2$ normalized to 0, $v_0 = -5$, $M = 20$, $\theta = 2$, $k = 1$.
Solid line indicates the larger firm (Panels (g)-(k)) or the attentive consumer (Panel (l));
dashed line indicates the smaller firm or the average for inattentive consumers.

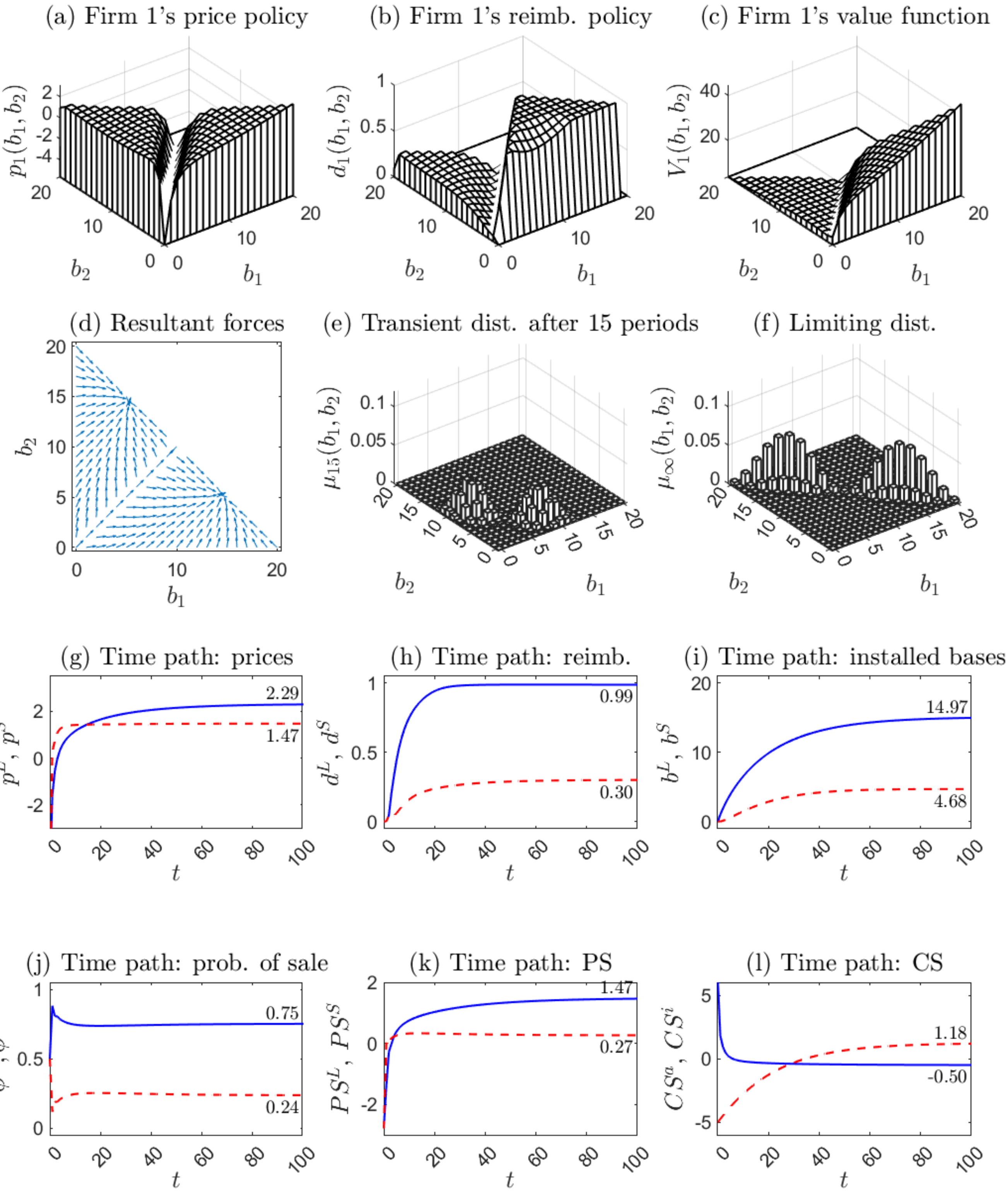

Figure A4. Endogenous reimbursement (ER): Tipping equilibrium at high switching cost.
$v_1 = v_2$ normalized to 0, $v_0 = -5$, $M = 20$, $\theta = 2$, $k = 2$.
Solid line indicates the larger firm (Panels (g)-(k)) or the attentive consumer (Panel (l)); dashed line indicates the smaller firm or the average for inattentive consumers.

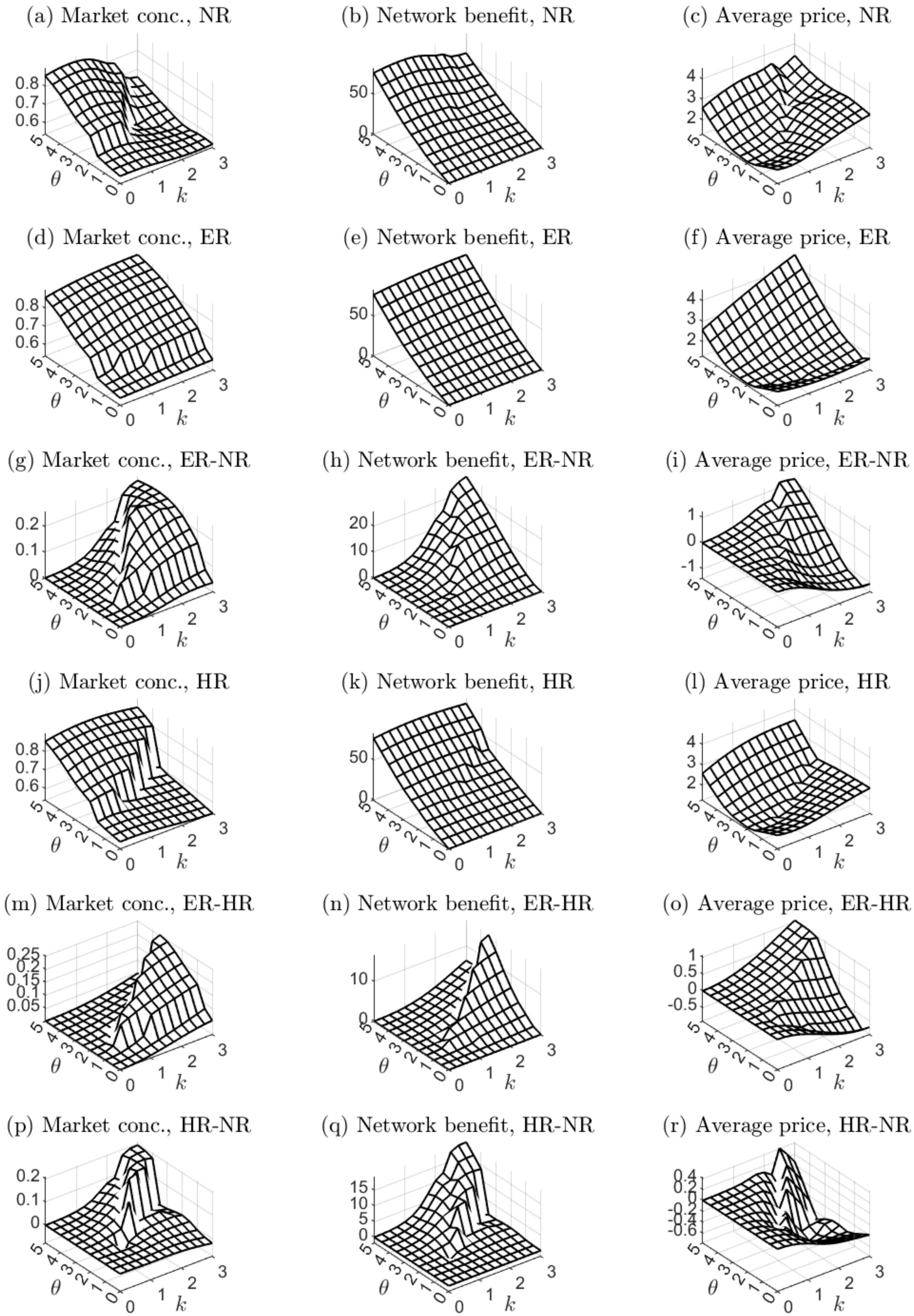

Figure A5. Market concentration, network benefit, and average price. $v_0 = -5$, $M = 20$.

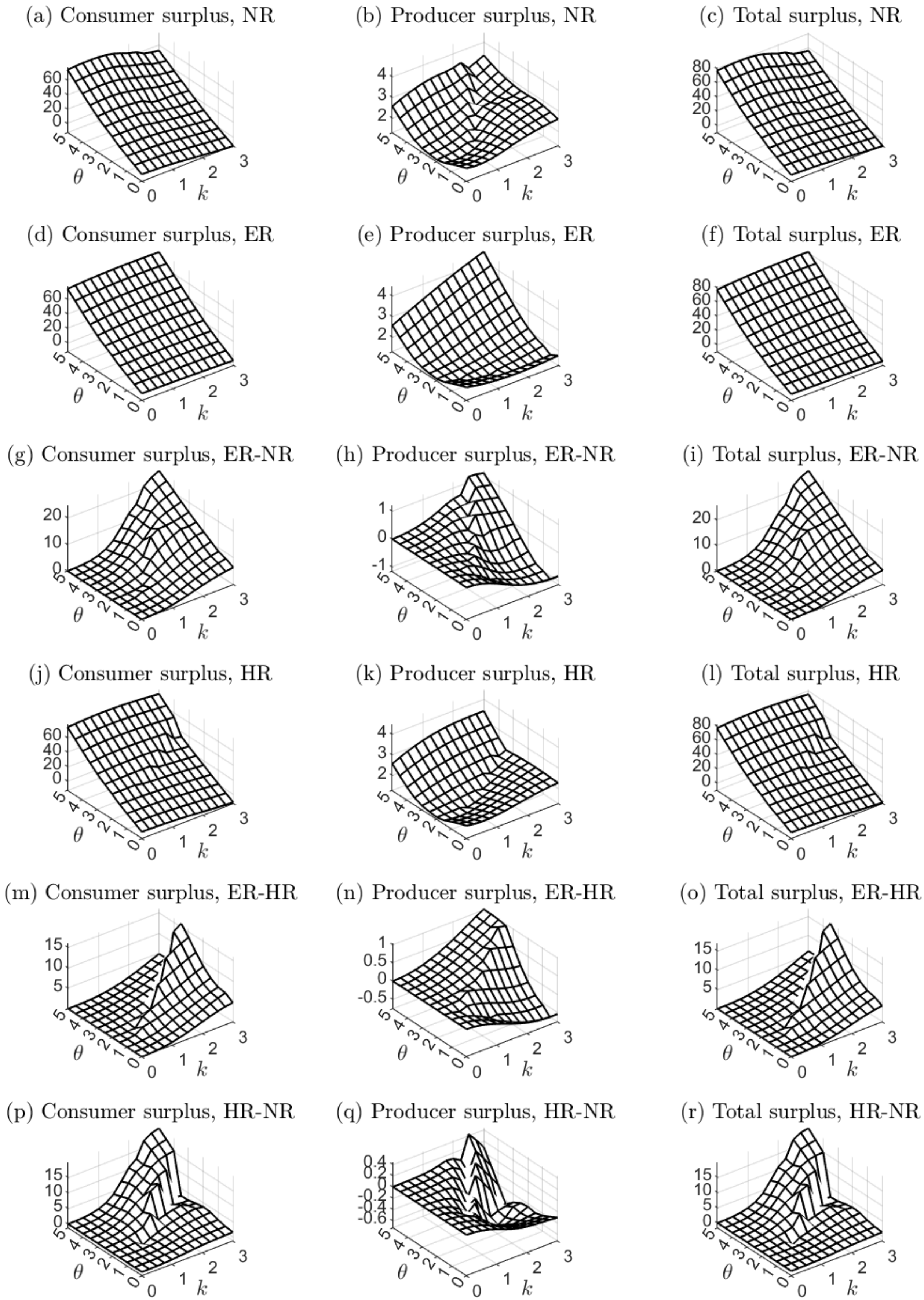

Figure A6. Consumer surplus, producer surplus, and total surplus. $v_0 = -5$, $M = 20$.