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Preliminary: comments welcome

Abstract

This paper investigates how switching costs affect product compatibility and market dynamics in network industries. A reduction in the switching cost makes the firms' products more attractive relative to the outside good, which diminishes the market expansion benefit of making products compatible. As a result, the larger firm is more likely to veto compatibility in order to maintain its installed base advantage over its rival. Therefore, public policies that reduce switching costs in network industries can change the market outcome from compatible products to incompatible products. In the former, price competition is mild and the market is often fragmented, whereas in the latter, there is fierce price competition when firms are of comparable size and in the long run the market is likely dominated by one firm.

JEL: L11, L13

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1 Introduction

Switching cost is an important feature of network industries: consumers can switch between networks but it is costly for them to do so (in terms of money and/or effort). Examples

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include PC operating systems, mobile networks, banking services, etc. In recent years, there is a growing trend of regulations that aim at reducing switching costs in network industries in order to increase competition. For instance, during the past few years, mobile number portability (MNP) was implemented in more than forty countries, which reduces mobile phone users' switching costs by enabling them to retain their phone numbers when changing from one network to another. In the EU retail banking and payments systems markets, the European Competition Authorities Financial Services Subgroup recommends the implementation of switching facilities (objective and up-to-date comparison sites, switching services, etc.) and account number portability to lower switching costs (ECAFSS (2006)). While there are many studies on the effects of switching costs on market concentration and prices, little is known about how a change in switching costs affects firms' product compatibility choices (shared free in-net calling, shared ATM networks, etc.) Since product compatibility has significant impact on competition, consumer welfare, and total surplus, research on this aspect is much needed and will generate rich policy implications. This paper aims at filling this gap.

In this paper, I build an oligopolistic model of firms' compatibility choices and price competition, which incorporates both network effects and switching costs. Firms dynamically optimize. They first choose product compatibility and then prices. A Markov perfect equilibrium is numerically solved for, and I investigate how switching costs affect product compatibility and market dynamics in such industries.

When the network effect is strong and the switching cost is modest, firms do not make their products compatible. There is fierce price competition when firms are of comparable size and in the long run the market is likely dominated by one firm (*Tipping* equilibrium). In contrast, when the switching cost is strong, firms often make their products compatible. Price competition is mild and the market is often fragmented (*Compatibility* equilibrium). Public policies that reduce switching costs in network industries can change the market outcome from Compatibility equilibrium to Tipping equilibrium, which significantly increases market concentration and eliminates compatibility between firms' products. Thus in order to make sound decisions, regulators need to carefully predict and evaluate the evolution of the market outcome that would result from the proposed policy change.

Related Literature. There are a number of papers that investigate whether compatibility will emerge in a standard two-stage model: in the first stage, firms make compatibility decisions, and then given such decisions, they engage in price or quantity competition. Examples include Katz and Shapiro (1986), Economides and Flyer (1997), Cremer, Rey, and Tirole (2000), Malueg and Schwartz (2006), and Tran (2006). Also see the review of Farrell and Klemperer (2007).

To go beyond the initial emergence of compatibility and understand whether compatibility will be maintained as the industry evolves over time, we need to investigate the long-run industry dynamics. Studies that explore the long-run market structure in network industries include Mitchell and Skrzypacz (2006), Llobet and Manove (2006), Driskill (2007), Markovich (2008), and Cabral (2009), among others. Nonetheless, these studies do not allow firms the option to make their product compatible, and hence cannot address the issue of whether compatibility can be maintained in the long run. An exception is Chen, Doraszelski, and Harrington (2009), which endogenizes product compatibility in a dynamic stochastic setting. The paper, however, abstracts from consumer switching costs. In fact, previous dynamic models of network industries generally assume that in each period, the consumers who make buying decisions do not face any switching costs (examples include Beggs and Klemperer (1992), Cabral (2009), and Chen, Doraszelski, and Harrington (2009), etc.). In reality, some consumers in the marketplace are loyal to certain products and face switching costs. A consumer's loyalty can arise from prior use of the product (now her product dies and she returns to the market) or from her relationship with current users (if a consumer's relatives, friends, or colleagues are users of a product, then she may become familiar with and hence loyal to this product even if she has never purchased from this market before). See Farrell and Klemperer (2007) for a review of the many papers that investigate switching costs. Those papers are not in the context of network industries and do not study firms' long-run compatibility choices. Given the consumer loyalty and switching costs that exist in real-world network industries, it will be interesting to explore how the analysis of firms' compatibility decisions and industry dynamics is changed when we incorporate switching costs into the model.

The next section describes the model. Section 3 presents the different types of equilibria

that emerge in this model. Section 4 shows how the market outcome, especially market concentration and compatibility of products, depends on the combination of the network effect and the switching cost. Section 5 considers a counterfactual in which a reduction in the switching cost changes the outcome from compatible products and a fragmented market to incompatible products and market dominance. Section 6 concludes.

2 Model

This section describes a dynamic oligopoly model of network industries in which firms have the option to make their products compatible and consumers face switching costs. The model builds on Chen, Doraszelski, and Harrington (2009) and adds switching costs.

2.1 State Space and Firm Decisions

The model is cast in discrete time with an infinite horizon. $N \geq 2$ firms sell to a sequence of buyers with unit demands. Each firm sells a single product and sets price. Firms' products are referred to as the inside goods, and are durable subject to stochastic death. There is also an outside good ("no purchase"), indexed 0. At the beginning of a period, a firm is endowed with an installed base which represents users of its product. $b_i \in \{0, 1, \dots, M\}$ denotes the installed base of firm i where M is the bound on the sum of the firms' installed bases. $b_0 = M - b_1 - \dots - b_N$ is the outside good's "installed base", though it does not offer network benefits. The industry state is $b = (b_1, \dots, b_N)$, with state space $\Omega = \{(b_1, \dots, b_N) | 0 \leq b_i \leq M, i = 1, \dots, N; b_1 + \dots + b_N \leq M\}$.

Given (b_1, \dots, b_N) , firms engage in a two-stage game, choosing compatibility in the first stage and prices in the second stage. In the first stage, each firm decides whether or not to "propose compatibility" with each of the other firms. Let $d_{ij} \in \{0, 1\}$ be the compatibility choice of firm i with respect to firm j , where $d_{ij} = 1$ means "propose compatibility." Products of firms i and j are "compatible" if and only if $d_{ij} \cdot d_{ji} = 1$. After compatibilities are determined, firms simultaneously choose prices in the second stage.

2.2 Demand

Demand in each period comes from a random consumer who chooses one among the $N + 1$ goods. $r \in \{0, 1, \dots, N\}$ denotes the good that has her loyalty. A consumer may be loyal to a firm's product because she previously used that product and now her product dies and she returns to the market. A consumer may also be loyal to a firm's product because of her relationship with current users. For example, if a consumer is familiar with a particular product because her relatives, friends, or colleagues are users of this product, then she may be loyal to this product even if she has never purchased from this market before.

Assume r is distributed according to $\Pr(r = j|b) = b_j/M$, $j = 0, 1, \dots, N$, so that a larger installed base implies a larger expected demand from loyal consumers. The utility that a consumer who is loyal to good r gets from buying good i is

$$v_i + \mathbf{1}(i \neq 0)\theta g \left(b_i + \sum_{j \neq i} d_{ij}d_{ji}b_j \right) - p_i - \mathbf{1}(r \neq 0, i \neq 0, i \neq r)k + \epsilon_i.$$

Here v_i is the intrinsic product quality, which is fixed over time and is common across firms: $v_i = v$, $i = 1, \dots, N$. Since the intrinsic quality parameters affect demand only through the expression $v - v_0$, without loss of generality I set $v = 0$, but consider different values for v_0 .

$b_i + \sum_{j \neq i} d_{ij}d_{ji}b_j$ is the effective installed base of firm i given the set of compatible products. The increasing function $\theta g(\cdot)$ captures network effects, where $\theta \geq 0$ is the parameter controlling the strength of network effect. There are no network effects associated with the outside good. The results reported below are based on linear network effects, that is, $g(b_i) = b_i/M$. I have also allowed g to be convex, concave, and S-shaped, and the main results are robust.

p_i denotes the price for good i . The price of the outside good, p_0 , is always zero.

The nonnegative constant k denotes switching cost, and is incurred if the consumer switches from one inside good to another. A consumer who switches from the outside good to an inside good incurs a start-up cost, which is normalized to 0. Increasing the start-up cost above 0 has the effect of lowering the inside goods' intrinsic quality relative to that of the outside good.

ϵ_i is the consumer's idiosyncratic preference shock. $(\epsilon_0, \epsilon_1, \dots, \epsilon_N)$ and r are unknown to the firms when they set prices.

The consumer buys the good that offers the highest current utility. I am then assuming that consumers make myopic decisions. Such a parsimonious specification of consumers' decision-making allows rich modeling of firms' prices and industry dynamics. Allowing consumers to be forward-looking with rational expectations in the presence of both network effects and switching costs is an important but challenging extension of the current work.

Assume ϵ_i , $i = 0, 1, \dots, N$ is distributed type I extreme value, independent across products, consumers, and time. The probability that a consumer who is loyal to good r buys good i is then

$$\phi_{ri}(b, d, p) \equiv \frac{\exp\left(v_i + \mathbf{1}(i \neq 0)\theta g\left(b_i + \sum_{h \neq i} d_{ih}d_{hi}b_h\right) - p_i - \mathbf{1}(r \neq 0, i \neq 0, i \neq r)k\right)}{\sum_{j=0}^N \exp\left(v_j + \mathbf{1}(j \neq 0)\theta g\left(b_j + \sum_{h \neq j} d_{jh}d_{hj}b_h\right) - p_j - \mathbf{1}(r \neq 0, j \neq 0, j \neq r)k\right)}, \quad (1)$$

where b is the vector of installed bases, d is the vector of compatibility choices, and p is the vector of prices.

Note that in this model, switching costs are unchanged when firms make their product compatible. Such a specification fits the examples mentioned in the Introduction, which are implemented or being considered by regulators and which are the motivation of this paper. For example, if two banks make their ATM networks compatible by allowing consumers from each network to access ATMs in the other network for free, a consumer who switches from one bank to the other still incurs the switching cost as she still needs to inform relevant parties (direct deposits, automatic payments, one-click purchases, etc.) of her new account number. Similarly, if two mobile service providers extend their free in-net calling to include both networks, a consumer who switches from one network to the other still incurs the switching cost as she still needs to inform her contacts of her new phone number.

There is another type of switching costs, which are eliminated when firms make their products compatible. For example, if two producers of office applications software (spreadsheets, charts, presentations, word processing documents, etc.) make their products compatible by adopting the same standard, a consumer who switches no longer needs to convert her old files to a new format and hence the switching cost of file conversion is eliminated. I

do not investigate such switching costs in this paper.

2.3 Transition Probabilities

In each period, each unit of a firm's installed base independently depreciates with probability $\delta \in [0, 1]$, for example due to product death. Thus the expected size of the depreciation to a firm's installed base is proportional to the size of its installed base. Let $\Delta(x|b_i)$ denote the probability that firm i 's installed base depreciates by x units. We have

$$\Delta(x|b_i) = \binom{b_i}{x} \delta^x (1 - \delta)^{b_i - x}, \quad x = 0, \dots, b_i,$$

since x is distributed binomial with parameters (b_i, δ) .

Let $q_i \in \{0, 1\}$ indicate whether or not firm i makes the sale. Firm i 's installed base changes according to the transition function

$$\Pr(b'_i|b_i, q_i) = \Delta(b_i + q_i - b'_i|b_i), \quad b'_i = q_i, \dots, b_i + q_i.$$

If the joint outcome of the sale and the depreciation results in an industry state outside of the state space, the probability that would be assigned to that state is given to the nearest state(s) on the boundary of the state space.

2.4 Bellman Equation and Strategies

The consumer's idiosyncratic preference shocks and the good that has her loyalty are stochastic and unknown to the firms when they set prices. Let $V_i(b)$ denote the expected net present value of future cash flows to firm i in state b *before* compatibility decisions are made, and let $U_i(b, d)$ denote the expected net present value of future cash flows to firm i in state b *after* compatibility decisions are made and revealed to all firms. For the second-stage game, we have¹

$$U_i(b, d) = \max_{p_i} E_r \left[\phi_{r_i}(b, d, p_i, p_{-i}(b, d)) p_i + \beta \sum_{j=0}^N \phi_{r_j}(b, d, p_i, p_{-i}(b, d)) \bar{V}_{ij}(b) \right], \quad (2)$$

¹Recall that firms' products are durable (subject to stochastic death), and that demand in each period comes from a random consumer.

where $p_{-i}(b, d)$ are the prices charged by firm i 's rivals in equilibrium (given the installed bases and the compatibility choices), the (constant) marginal cost of production is normalized to zero, $\beta \in [0, 1)$ is the discount factor, and $\bar{V}_{ij}(b)$ is the expected continuation value to firm i given that firm j wins the current consumer:

$$\bar{V}_{ij}(b) = \sum_{b'} \Pr(b'|b, q_j = 1) V_i'(b').$$

Differentiating the right-hand side of equation (2) with respect to p_i and using the properties of logit demand yields the first-order condition

$$E_r \left[-\phi_{ri}(1 - \phi_{ri})(p_i + \beta \bar{V}_{ii}) + \phi_{ri} + \beta \phi_{ri} \sum_{j \neq i} \phi_{rj} \bar{V}_{ij} \right] = 0. \quad (3)$$

The pricing strategies $p(b, d)$ are the solution to the system of first-order conditions.

Folding back to the first-stage game, we have

$$V_i(b) = \max_{d_i \in \{0,1\}^{N-1}} U_i(b, d_i, d_{-i}(b)), \quad (4)$$

where $d_i = (d_{i1}, \dots, d_{ii-1}, d_{ii+1}, \dots, d_{iN})$ and $d_{-i}(b)$ are the compatibility choices of firm i 's rivals in equilibrium (given the installed bases).

2.5 Equilibrium

I focus attention on symmetric Markov perfect equilibria (MPE), where symmetry means agents with identical states are required to behave identically. For example, if there are two firms, then symmetry means firm 2's price in state $(b_1, b_2) = (\hat{b}, \hat{b})$ is identical to firm 1's price in state $(b_1, b_2) = (\hat{\hat{b}}, \hat{\hat{b}})$, and similarly for the value function. I therefore define $p(b_1, b_2) \equiv p_1(b_1, b_2)$ and $V(b_1, b_2) \equiv V_1(b_1, b_2)$, and note that $p_2(b_1 = \hat{b}, b_2 = \hat{\hat{b}}) = p(\hat{\hat{b}}, \hat{\hat{b}})$ and $V_2(b_1 = \hat{b}, b_2 = \hat{\hat{b}}) = V(\hat{\hat{b}}, \hat{\hat{b}})$.

I restrict attention to pure strategies, which follows the majority of the literature on numerically solving dynamic stochastic games (Pakes and McGuire (1994), Pakes and McGuire (2001)). A symmetric MPE in pure strategies always exists (Doraszelski and Satterthwaite (2010)), but as is true with many other dynamic models, there may exist multiple MPE. I therefore take a widely used selection rule in the dynamic games literature by computing

the limit of a finite-horizon game as the horizon grows to infinity (for details see Chen, Doraszelski, and Harrington (2009)).

A second source of multiplicity of MPE comes from firms' compatibility choices. Recall that products are compatible between firms i and j if and only if both firms propose compatibility. Therefore, for any state there is always an equilibrium outcome in which firms' products are incompatible. When it is also an equilibrium for products to be compatible, I select that equilibrium because my interest is in exploring the implications of product compatibility, and because the equilibrium with compatible products Pareto dominates the one with incompatible products. Additionally, if a firm is indifferent about whether or not to make its product compatible, I assume it proposes incompatibility.² With the above equilibrium selection rules in place, the iterative algorithm always converged and resulted in a unique MPE.

2.6 Parameterization

The key parameters of the model are the strength of network effect θ , the switching cost k , the rate of depreciation δ , and the quality of the outside good v_0 . I examine several values for v_0 between $-\infty$ and 0 and set the baseline at -4 , representing a case in which there exists an outside good but it is inferior compared to the inside goods. The lower bound for δ is zero and corresponds to the unrealistic case in which installed bases never depreciate. On the other hand, if δ is sufficiently high then the industry never takes off. I consider many values for δ between 0 and 0.15. I investigate the following values for the strength of network effect and the switching cost: $\theta \in \{0, 0.5, \dots, 4\}$, and $k \in \{0, 0.5, \dots, 3\}$. While I extensively vary the key parameters, I hold the remaining parameters constant at $N = 2$, $M = 20$, and $\beta = \frac{1}{1.05}$, which corresponds to a yearly interest rate of 5%.

While the model is not intended to fit any specific product, the own-price elasticities for the parameterizations that I consider are reasonable compared with findings in several empirical studies. As representative examples of the equilibria in the model, the own-price elasticities for the parameterizations in Figures 1-3 range from -0.71 to -0.62 . These numbers are in line with the own-price elasticities reported in Gandal, Kende, and Rob (2000)

²Experimentation with the tie-breaking rule revealed that it does not make a difference for the results.

(-0.54 for CD players, computed according to results reported in the paper), Clements and Ohashi (2005) (ranging from -2.15 to -0.18 for video game consoles), and Dick (2008) (ranging from -0.87 to -0.12 for banking services).³ Additionally, the aggregate market shares of the inside goods for the parameterizations in Figures 1-3 range from 93.5% to 98.9%. These numbers are consistent with, for instance, the cellular mobile penetration rates in OECD countries, which averaged at 96.1% in 2007 (OECD (2009)).

3 Types of Equilibria

In this model three types of equilibria emerge, Rising, Tipping, and Compatibility.

Rising Equilibrium. A *Rising* equilibrium (depicted in Figure 1) occurs when both network effect and switching cost are weak. A firm's price monotonically rises in its own installed base and falls in its rival's installed base (see Panel 1, which plots firm 1's equilibrium price against the firms' installed bases). Products are generally incompatible, except possibly when the firms have identical installed bases (see Panel 2, which reports the compatibility region, that is, the states for which both firms prefer compatibility and thus products are compatible.).

Panels 3 and 4 show the evolution of the industry structure over time. They plot the 15-period transient distribution of installed bases (which gives the frequency with which the industry state takes a particular value after 15 periods, starting from state $(0, 0)$ in period 0) and the limiting distribution (which gives the frequency with which the state takes a particular value as the number of periods approaches infinity), respectively. The unimodal transient distribution and limiting distribution show that the market is generally fragmented, as the industry spends most of the time in fairly symmetric states.

Panel 5 plots the probability that a firm makes a sale, and Panel 6 plots the resultant forces, which report the expected movement of the state from one period to the next (for visibility of the arrows, the lengths of all arrows are normalized to 1, therefore only the direction, not the magnitude, of the expected movement is reported). The larger firm wins

³Some other studies, such as Dranove and Gandal (2003), Ohashi (2003), and Doganoglu and Grzybowski (2007), find evidence of more elastic demand in several network industries.

the consumer with a higher probability (Panel 5). However, the larger firm's expected size of depreciation is also larger. In a Rising equilibrium, the difference in expected depreciation more than offsets the difference in expected sales, and as a result the difference in installed bases shrinks in expectation (Panel 6).

Tipping Equilibrium. A *Tipping* equilibrium (depicted in Figure 2) occurs when the network effect is strong and the switching cost is modest. There is a deep trench along and around the diagonal of the price function (Panel 1), indicating intense price competition when firms' installed bases are of comparable size. Once a firm pulls ahead, the smaller firm gives up the fight by raising its price, thereby propelling the larger firm into a dominant position. Products are almost always incompatible (Panel 2).

The transient distribution (Panel 3) and the limiting distribution (Panel 4) are bimodal. Over time, the industry moves towards asymmetric states, and the market tends to be dominated by a single firm. The larger firm enjoys a significant advantage in expected sales (Panel 5), which results from the smaller firm's willingness to surrender (by charging high prices), and gives rise to the forces that pull the industry away from the diagonal once an asymmetry arises (Panel 6).

Compatibility Equilibrium. A *Compatibility* equilibrium (depicted in Figure 3) occurs when the switching cost is strong. Products are compatible when firms have comparable installed bases (Panel 2). In the compatibility region, prices are high, peaking at the point where each firm has half of the consumers (Panel 1). Off of the peak, the smaller firm drops its price in order to bring the industry back to the peak. In particular, around the border of the compatibility region, the smaller firm lowers its price significantly, in an effort to keep the industry in the compatibility region. Away from the peak, the larger firm also drops its price, but that is a response to the smaller firm's aggressive pricing rather than an effort to achieve market dominance.

The switching cost segments the market into submarkets, with each submarket consisting of consumers that are locked-in by a firm. Firms focus on charging high prices to "harvest" their locked-in consumers, rather than fighting for market dominance. As a result, the market tends to be fragmented, as shown by the unimodal transient distribution and limiting

distribution in Panels 3 and 4.

The resultant forces (Panel 6) show global convergence towards the symmetric modal state. Outside the compatibility region, the larger firm enjoys a larger expected sale, but inside the compatibility region, the smaller firm has an advantage (Panel 5). Such an advantage for the smaller firm results from its aggressive pricing away from the peak, aimed at keeping the industry in the compatibility region.

4 Market Concentration and Compatibility

For the primary dynamic forces of the model to be at work, the relevant part of the parameter space is when the rate of depreciation δ is neither too low (so that there is customer turnover) nor too high (otherwise the industry never takes off). In that part of the parameter space, the switching cost and its interaction with the network effect have significant impact on market concentration and the firms' compatibility choices.

Panel 1 in Figure 4 shows the expected long-run Herfindahl-Hirschman Index (HHI; based on installed bases and weighted by probabilities in the limiting distribution) for different combinations of the network effect θ and the switching cost k . The higher is the HHI, the more likely market dominance is to occur. When the network effect is low to modest ($\theta \in [0, 2]$), the HHI is low throughout, increasing slightly in the switching cost. Examination of the policy function and the limiting distribution in this part of the parameter space indicates that the equilibrium gradually morphs from a Rising equilibrium at low switching cost to a Compatibility equilibrium at modest to high switching cost.

When the network effect is modest to high ($\theta \in [2.5, 4]$), the HHI starts with a relatively high level (above 0.6) at $k = 0$. As the switching cost increases, the HHI initially increases but later drops significantly. When the switching cost is modest, the market is dominated by a single firm (Tipping equilibrium), but when the switching cost is high, the market becomes fragmented (Compatibility equilibrium).

Next, Panel 2 shows the long-run probability that products are compatible using the limiting distribution. The panel shows that when the switching cost is low, the probability of compatible products is small for weak network effect and essentially zero for strong network

effect. However, in both cases, the probability of compatible products increases significantly as the switching cost increases, indicating that the switching cost plays an important role in determining firms' compatibility choices.

5 Counterfactual: Reduction in Switching Cost

Here we study a counterfactual in which a public policy reduces the switching cost in a network industry. Examples of such policies include phone number portability in the mobile phone industry, account number portability in the banking industry, etc. In particular, we are interested in how product compatibility (shared free in-net calling, shared ATM networks, etc.) and market dynamics are affected by such a policy change.

Consider the Compatibility equilibrium depicted in Figure 3, with $(\theta, k) = (3, 2.5)$. In this market, both the network effect and the switching cost are high, and the industry is characterized by relatively symmetric firms and a substantial probability of compatible products.

Now suppose the regulator implements a policy that reduces the switching cost k from 2.5 to 0.5, so that we reach the parameterization in the Tipping equilibrium depicted in Figure 2. Assume that the policy change is unanticipated (so that firms do not alter their behavior beforehand) and that the reduction in the switching cost is permanent. Figure 5 shows the evolution of the market following such a change. From top to bottom, the four panels plot the time paths of the firms' installed bases, probability of compatible products, prices, and probabilities of sale, respectively, from period 0 to period 50. In period 0, k is 2.5 and we assume the industry is in the expected long-run state (given by the limiting distribution) in the Compatibility equilibrium. In period 1 k is permanently reduced to 0.5, and the industry gradually evolves towards the expected long-run state under the new parameterization. The solid lines show the expectations (based on the transient distributions) of the variables for the larger firm, and the dashed lines show those for the smaller firm.

Panel 1 indicates that before the reduction in k , the two firms' expected installed bases are similar in size, 9.5 for the larger firm and 6.3 for the smaller firm. When k is reduced to 0.5, the difference between the installed bases gradually widens, reaching 8.3 in the long run

(12.2 for the larger firm and 3.9 for the smaller firm). This panel shows that following the reduction in k , market fragmentation in the Compatibility equilibrium morphs into market dominance in the Tipping equilibrium.

Panel 2 shows that in period 0, the two firms' products are compatible with probability 0.55, but the probability drops to 0 following the reduction in k and stays at 0. Examination of the firms' payoffs associated with compatible products and incompatible products shows that it is the larger firm who vetoes compatibility. Making products compatible expands the market for the firms by making their products more attractive relative to the outside good (the *market expansion effect*), and eliminates the larger firm's installed base advantage over its rival (the *business gift effect*). While both effects are helpful for the smaller firm, they affect the larger firm in opposite directions: the market expansion effect helps the larger firm whereas the business gift effect hurts the larger firm. See Chen, Doraszelski, and Harrington (2009) for a discussion of these two effects. In the current model, a reduction in the switching cost makes the firms' products more attractive and reduces the relevance of the outside good. Consequently, the market expansion benefit is diminished, making the larger firm more likely to veto compatibility. In fact, when k is reduced to 0.5, the market outcome changes to a Tipping equilibrium, in which the probability of compatibility is 0.

Panel 3 shows the changes in the firms' prices following the reduction in k . In period 0, the larger firm's price is 3.0 and the smaller firm's price is 2.0. In period 1, these prices drop significantly to 0.1 and 0.6, respectively. Note that in its drive to achieve market dominance, the larger firm drops its price much more aggressively than the smaller firm. In fact, starting from period 1, the larger firm consistently charges a lower price than the smaller firm until period 14, by which time the installed base differential has reached 6.5 and the larger firm's dominant position is all but secured.

Panel 4 shows the evolution of the probabilities of sale by the two firms. In period 0, the two firms have nearly identical probabilities of sale: 0.47 for the larger firm and 0.50 for the smaller firm. Once k is reduced to 0.5 and the larger firm starts pricing aggressively, its probability of sale is much larger than its rival's. From period 1 to period 50, the larger firm's probability of sale increases slightly from 0.72 to 0.74, while the smaller firm's probability decreases slightly from 0.28 to 0.24. This large difference between the two firms'

probabilities of sale is the force that allows the larger firm to achieve and maintain market dominance.

Together, the four panels in Figure 5 illustrate the substantial changes in the market outcome when the switching cost is reduced. In particular, it shows that market concentration can significantly increase and compatibility between firms' products can disappear following such a policy change. Thus in order to make sound decisions, regulators need to carefully predict and evaluate the evolution of the market outcome that would result from the proposed policy change.

6 Conclusion

In this paper, I investigate how switching costs affect product compatibility and market dynamics in network industries. A reduction in the switching cost makes the firms' products more attractive relative to the outside good, which diminishes the market expansion benefit of making products compatible. As a result, the larger firm is more likely to veto compatibility in order to maintain its installed base advantage over its rival. Therefore, public policies that reduce switching costs in network industries can change the market outcome from compatible products to incompatible products. In the former, price competition is mild and the market is often fragmented, whereas in the latter, there is fierce price competition when firms are of comparable size and in the long run the market is likely dominated by one firm. Thus, when deciding whether to implement a public policy that reduces the switching cost, the regulator needs to carefully predict and evaluate the evolution of the market outcome, including market concentration and compatibility of products, that would result from the proposed policy change.

In ongoing work, I am also analyzing various policies regarding compatibility, such as mandatory compatibility (e.g. government-imposed standardization), endogenous compatibility (*laissez-faire*), and no compatibility. How do these policies perform for a market with network effects and switching costs? From a welfare perspective, how do consumers and firms rank such policies, and how do their rankings change as switching costs are varied? A good understanding of these issues will allow regulators to make informed decisions

regarding product compatibility and switching costs in network industries.

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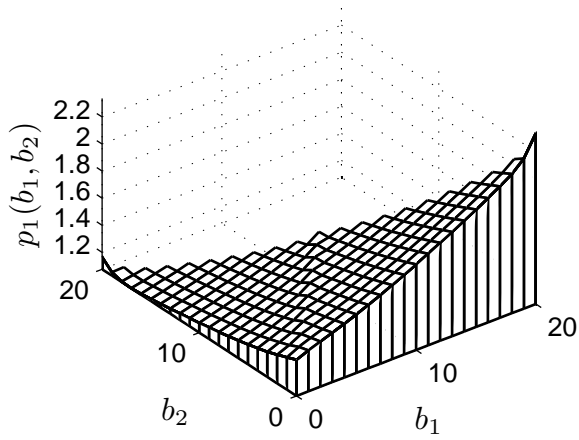
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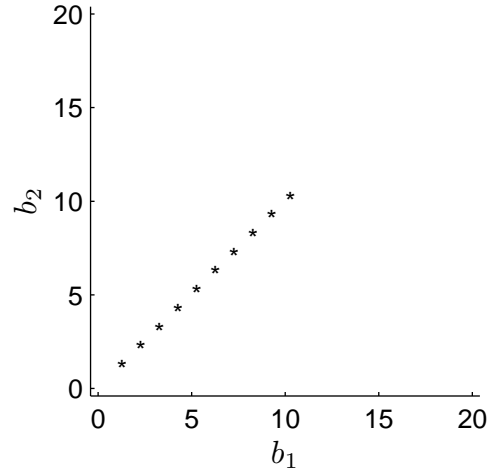
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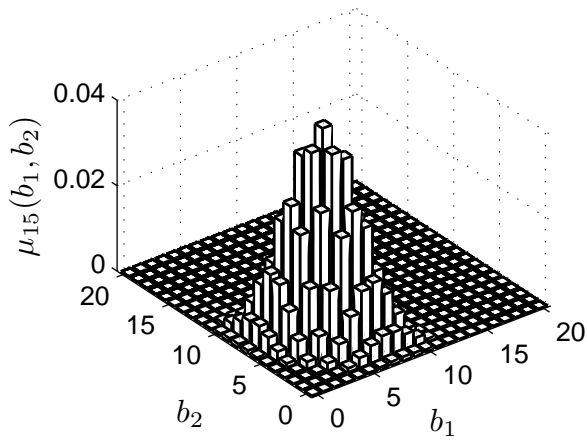
(1) Firm 1's policy function



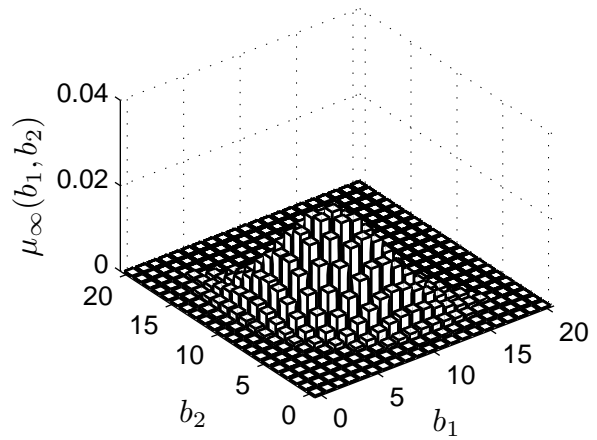
(2) Compatibility



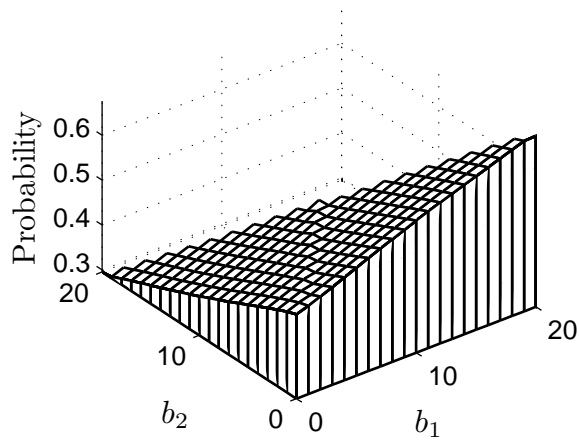
(3) Transient distribution after 15 periods



(4) Limiting distribution



(5) Probability that firm 1 makes a sale



(6) Resultant forces

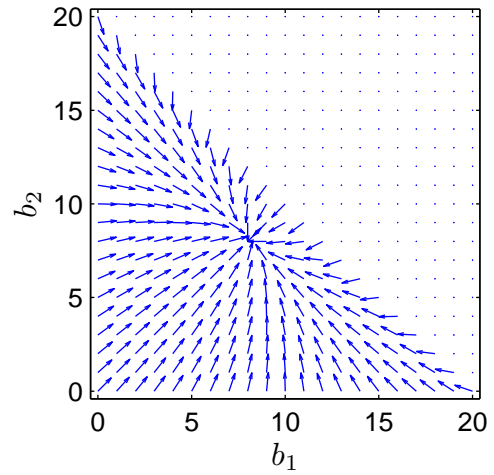
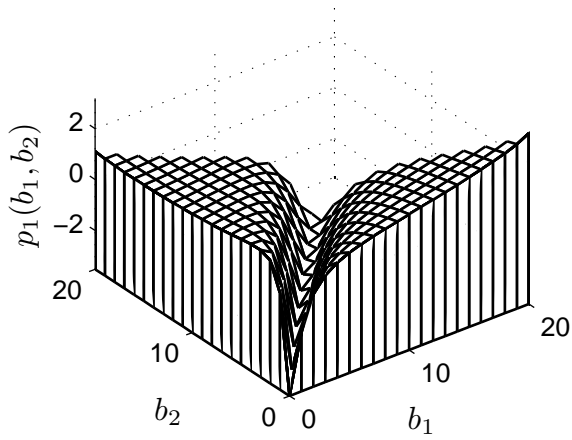
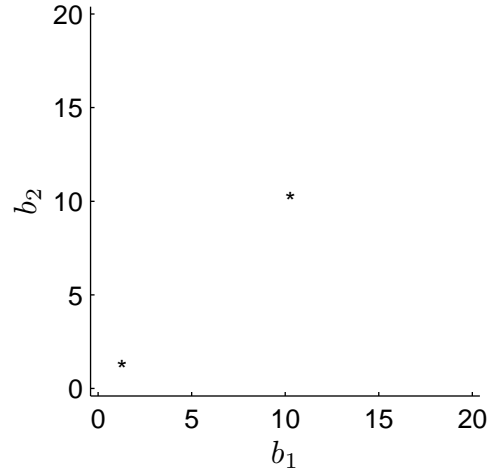


Figure 1. Rising equilibrium: $v_0 = -4$, $\delta = 0.06$, $\theta = 1.5$, $k = 0.5$

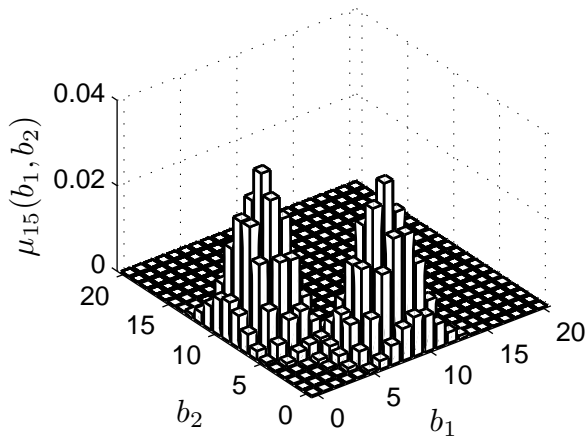
(1) Firm 1's policy function



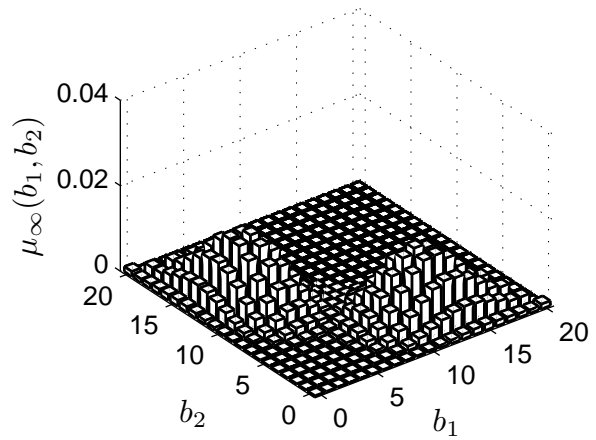
(2) Compatibility



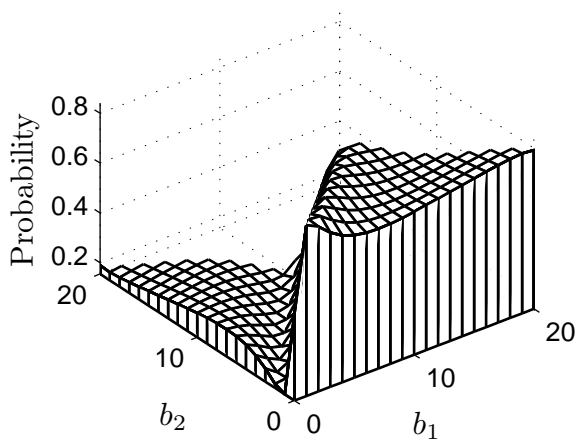
(3) Transient distribution after 15 periods



(4) Limiting distribution



(5) Probability that firm 1 makes a sale



(6) Resultant forces

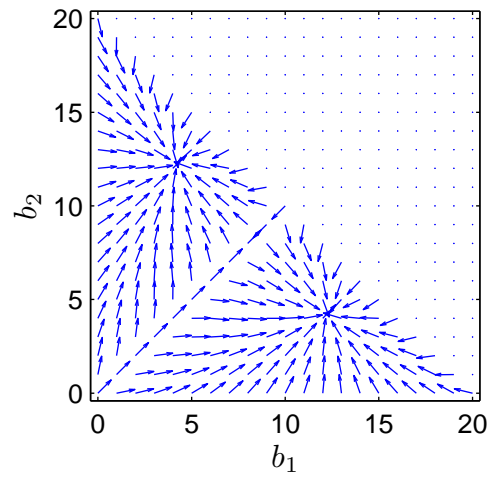
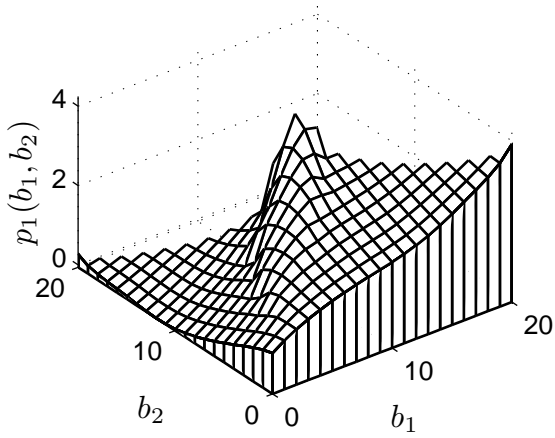
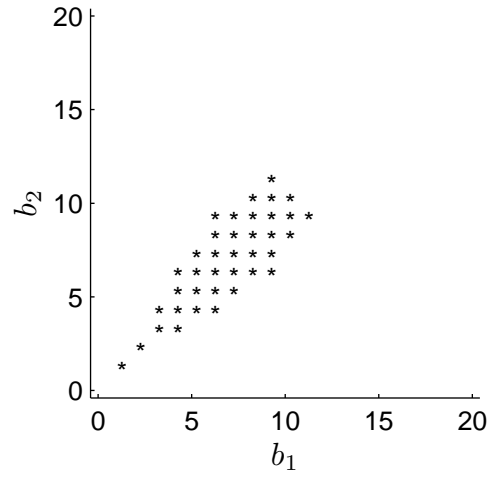


Figure 2. Tipping equilibrium: $v_0 = -4$, $\delta = 0.06$, $\theta = 3$, $k = 0.5$

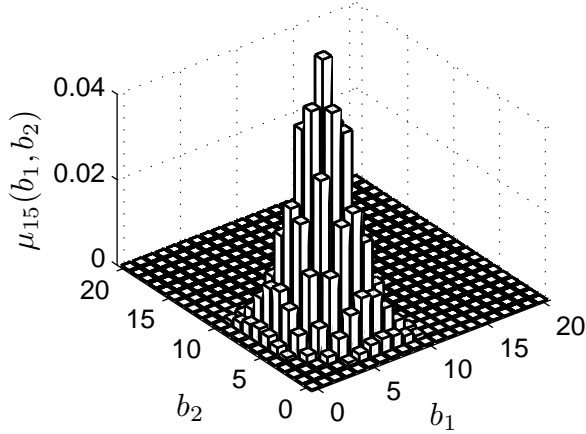
(1) Firm 1's policy function



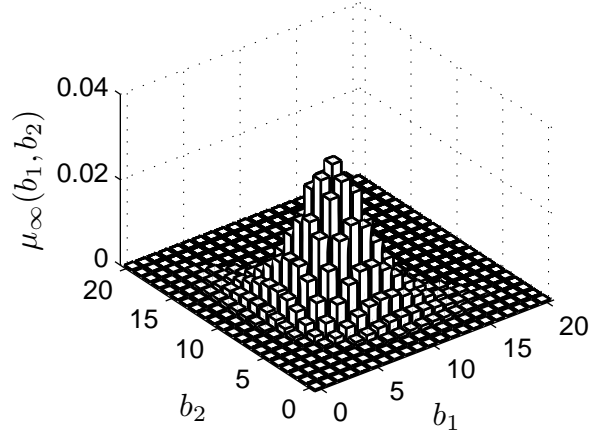
(2) Compatibility



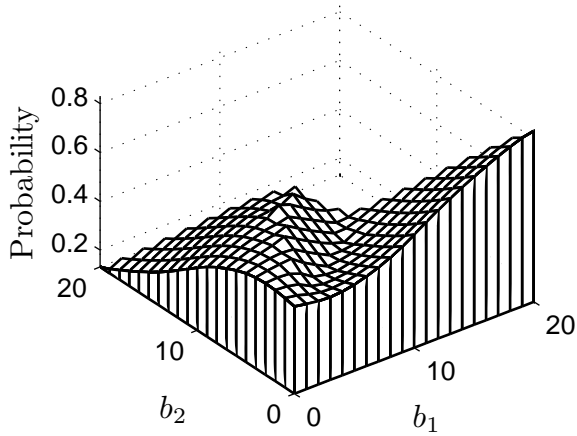
(3) Transient distribution after 15 periods



(4) Limiting distribution



(5) Probability that firm 1 makes a sale



(6) Resultant forces

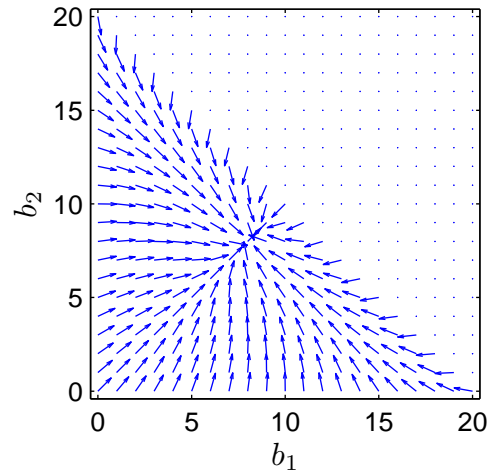


Figure 3. Compatibility equilibrium: $v_0 = -4$, $\delta = 0.06$, $\theta = 3$, $k = 2.5$

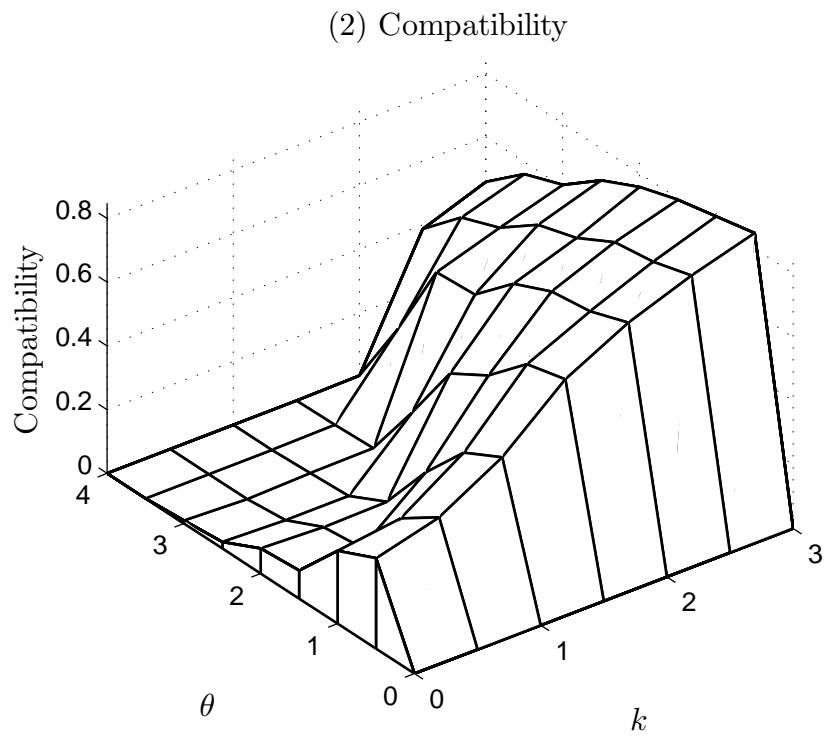
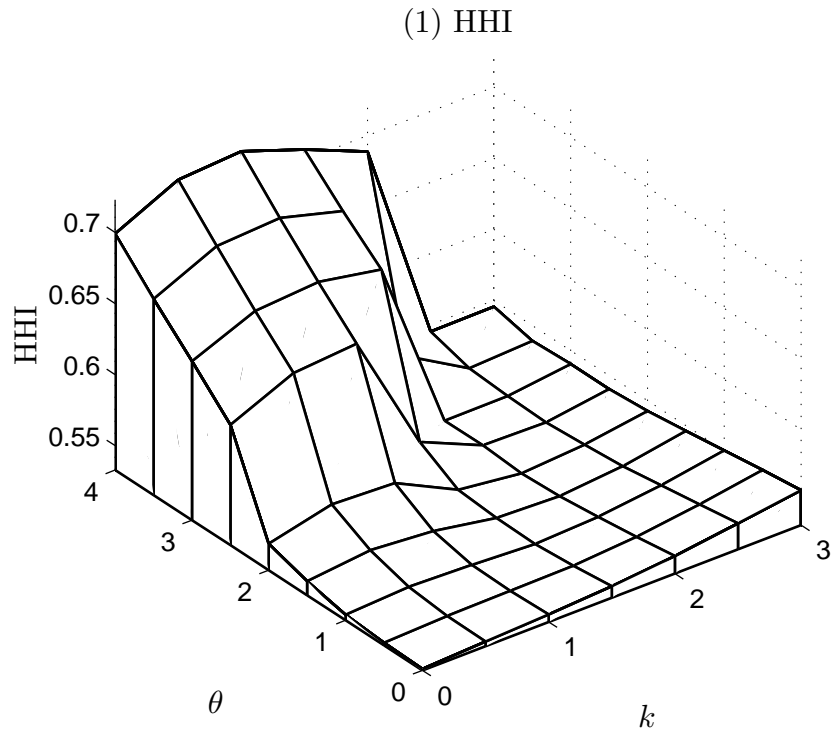


Figure 4. Expected long-run HHI and compatibility

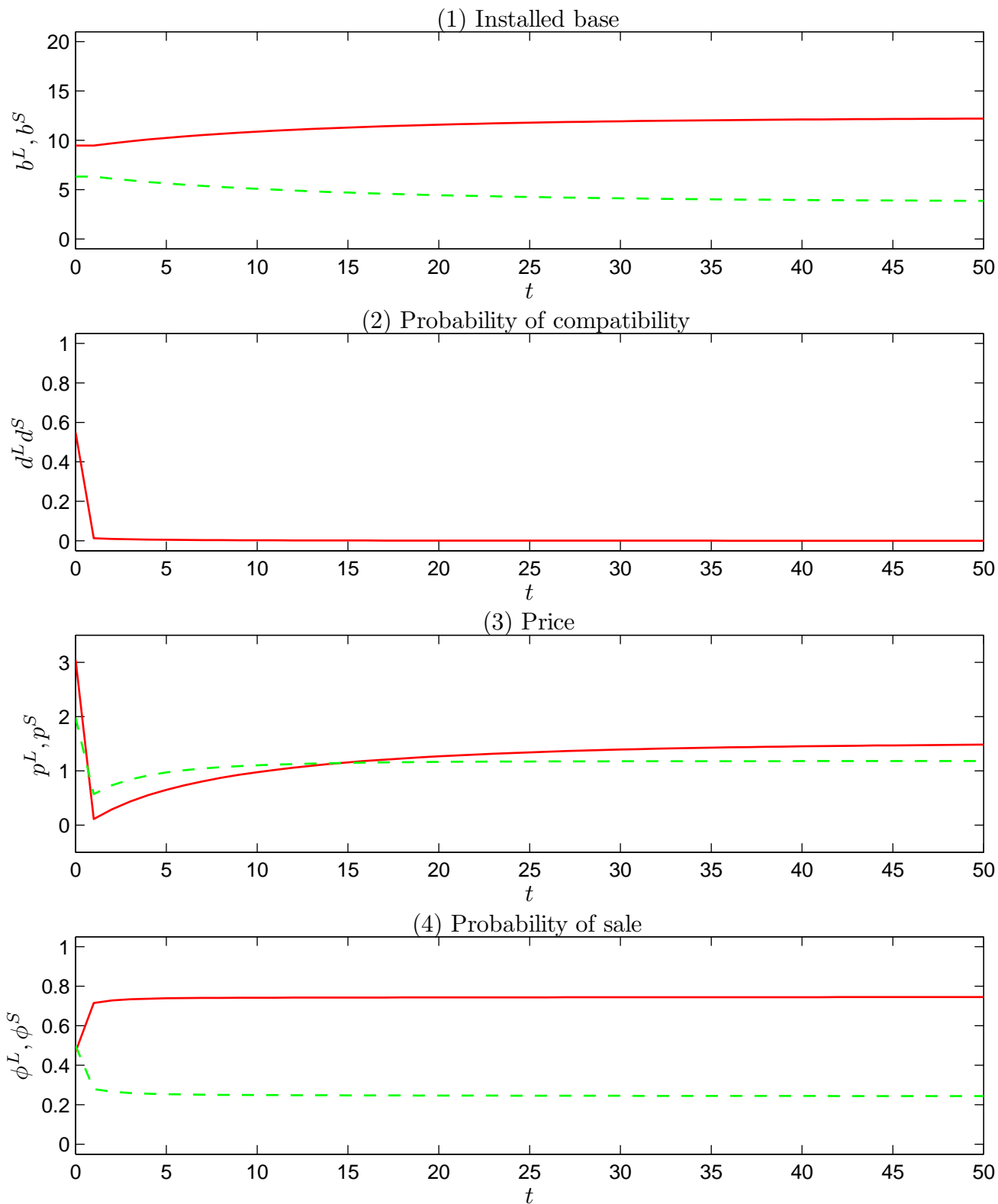


Figure 5. Time paths following a reduction in the switching cost. $v_0 = -4$, $\delta = 0.06$, $\theta = 3$, k is reduced from 2.5 in period 0 to 0.5 in all subsequent periods. Solid line: the larger firm. Dashed line: the smaller firm.