Compatibility in Tied-Goods Markets: Evidence from Razors and Blades

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Abstract

In markets for tied goods, consumers buy a durable base good and then repeatedly purchase compatible consumables. I study how compatibility between base goods and consumables affects demand, using the U.S. razor and blade market as an empirical setting. Allowing more of a firm's consumables to fit a given base good changes demand through two channels. First, it expands the market: a base good that fits more consumables is more valuable to own, attracting new buyers and making existing owners less likely to switch away. Second, it intensifies cannibalization: owners can choose among more of the firm's consumables, so a newly compatible line takes sales from the firm's existing lines. The balance between these channels matters for interoperability policy and for firms' product decisions. Reduced-form evidence shows that compatibility shapes adoption and substitution: households that own a compatible handle more readily adopt new lines, and households substitute strongly between compatible cartridges. To separate the two channels, I estimate a dynamic demand model in which forward-looking households choose each month whether to buy a razor pack, a compatible cartridge pack, or nothing. Counterfactuals at fixed prices show that market expansion dominates cannibalization when a firm makes its product lines compatible, both across families that differ in price and quality and among similarly priced lines within a family.

Keywords: Tied goods; Compatibility; Dynamic demand; Stockpiling.

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1 Introduction

Many consumer products are sold as proprietary systems that consist of a reusable base good and complementary consumables. Examples include coffee machines and pods, printers and ink cartridges, and razor handles and replacement cartridges. Such markets are commonly referred to as tied-goods markets. In these markets, firms typically offer several product families. Each family has its own compatibility standard, and a family may contain several differentiated product lines that share that standard.[1] Compatibility arrangements between base goods and consumables have fundamental implications for consumer demand. First, they affect the value of owning a base good: allowing more consumables to fit it expands its owners' choices and makes it more attractive, which can draw new buyers to the firm's system and make existing owners less likely to switch away. Second, they shape substitution among consumables: owners of a base good can choose among all the consumables that fit it; a new compatible line may therefore cannibalize sales from the firm's existing ones.

Understanding this trade-off matters for both policymakers and firms. Policies that encourage interoperability expand the set of consumables compatible with consumers' existing base goods.[2] Whether such policies expand the market or mainly redistribute sales across product lines depends on how consumers respond to this larger choice set. When cannibalization is strong, interoperability can also reduce product variety, since some lines may no longer be worth offering once they share a base good with close substitutes. For firms, how consumers substitute between compatible and incompatible product lines is a key input into evaluating product introductions, pricing, and compatibility decisions.

Evaluating how product compatibility affects demand is challenging, since demand in tied-goods markets is inherently dynamic. Consumers choose which base good to buy today, and that choice determines which consumables they can use in the future. The dynamics are further complicated in some tied-goods markets, such as air fresheners and refills, razors and cartridges, and water filter pitchers and filters, where the base good is relatively inexpensive and consumers may replace it over time. A model of demand in these markets must therefore allow consumers to switch base goods as well as consumables. Otherwise, it cannot capture consumers switching to a base good that becomes more attractive when a change in compatibility gives them access to more consumables. Moreover, the effect of a change in

[1] For example, Oral-B's standard electric toothbrushes and its iO series are distinct product families: iO brush heads do not fit standard Oral-B handles, and standard brush heads do not fit iO handles. Within the standard family, CrossAction and Sensitive Clean brush heads are distinct product lines that differ in design but fit the same handles. Similarly, Ultimate Clean and Gentle Care are distinct lines within the iO family.

[2] For example, the 2024 criteria of the EPEAT ecolabel for imaging equipment require that printers be designed to allow the use of third-party cartridges.

compatibility on demand depends on which products it makes available to consumers and how much they value those products. These valuations depend in part on product quality, including attributes the researcher does not observe. Ignoring such unobserved characteristics biases estimated price responses and substitution patterns (Berry, 1994; Berry et al., 1995; Gandhi and Nevo, 2021). In this paper, I develop a novel dynamic model of demand in tied-goods markets that captures these features. While several structural models of such markets exist (e.g., Chintagunta et al., 2018; Hartmann and Nair, 2010), mine is, to my knowledge, the first to allow consumers to switch between base goods and to account for unobserved quality differences in both base goods and consumables.

I apply the model to the U.S. razor and blade market, where razor systems consist of reusable handles and replacement cartridges. In this market, each firm sells several product families that are incompatible with one another, and within a family it offers multiple product lines whose handles and cartridges are interchangeable. Lines within a family often have similar observed cartridge characteristics. In most families, for example, most lines have an identical number of blades, yet some lines sell far better than others, which suggests that they may differ in attributes that are difficult to measure, such as comfort or closeness of the shave. Across firms, systems are also incompatible because each firm holds patents on the connectors between its handles and cartridges, which prevent rivals from offering compatible cartridges until the patents expire.

These compatibility restrictions shape the choices households face. To study their effects on demand, I combine NielsenIQ Homescan Consumer Panel data on household purchases with NielsenIQ Retail Scanner data on prices and sales across markets. I first examine how compatibility shapes adoption, using the launch of a line whose cartridges fit the handles of an earlier line in the same family.[3] Households that already owned a compatible handle were 39 percentage points more likely to adopt the new line than households without one, and 29 percentage points more likely to adopt it starting with a cartridge pack. A compatible line can therefore reach the firm's existing owners without requiring them to buy a new handle. I also find that households substitute among cartridges that fit their handles. When the price of a household's current cartridges rises by 1%, the probability of purchasing them falls by 0.29 percentage points, and about 63% of the lost purchases shift to other compatible cartridges. Together, these patterns show that compatibility makes it easier for existing owners to adopt a new line, but also exposes the line to competition from other lines that fit the same handle.

However, these patterns do not establish how demand would respond to alternative com-

[3]My data use agreement does not allow me to reveal brand or product names. Throughout the paper, I refer to product families and lines by arbitrary letter labels.

patibility arrangements, or how much of that response would reflect market expansion rather than cannibalization. To answer this question, I estimate a dynamic demand model for razors and cartridges. Each month, a household chooses whether to buy a razor pack, buy a compatible cartridge pack, or make no purchase. When a household does not buy, it uses its existing cartridge stock, which gradually depletes. The household's state consists of the family of the handle it owns, the stock of cartridges it holds, and the quality of those cartridges. The utility a household derives from its cartridges depends on their observed characteristics and unobserved quality, and the household receives it in every month in which it uses the cartridges, not only when it buys them. Compatibility enters the model through the choice set: a household can buy any razor pack, since each comes with a handle, but it can buy a cartridge pack only if the cartridges fit the handle it owns. A change in compatibility therefore affects both the cartridge packs available to existing owners and the value of owning each handle. The first effect determines how much a new line draws demand away from other compatible lines, while the second determines whether the new line attracts additional households.

Estimating the model requires recovering the unobserved quality of each product in each market. These qualities are recovered from market shares, by finding the values at which the model's predicted shares match the observed ones. Most products, however, are bought by few panel households in any given market, so the panel cannot measure market shares precisely. An approach that relies on the household panel alone, as in Hartmann and Nair (2010), is therefore infeasible in my setting. Store-level scanner data fill this gap by recording transactions across the whole market and providing precise market shares. Following Gowrisankaran and Rysman (2012) and Hodgson (2023), I nest the solution to the households' dynamic problem within the share inversion of Berry et al. (1995). For each candidate value of the nonlinear parameters, I solve the dynamic problem and invert observed market shares to recover the mean utility of each product in each market. Unlike these papers, which estimate the nonlinear parameters by GMM, I estimate them by maximum likelihood on households' purchase histories. These histories show how each household's choices depend on what it already owns and on the prices it faces, variation that aggregate market shares do not capture. This approach extends the strategy of Chintagunta and Dubé (2005), who combine household panel and store-level data in a static model, to a dynamic model of a tied-goods market.

The estimates show why accounting for dynamics matters. In a dynamic model, households respond differently to a price increase depending on whether they expect it to last, and the two responses work through different channels. When households expect a line's cartridge price increase to be temporary, most of those that still hold cartridges postpone their

purchase, and those that switch mostly buy other cartridges that fit the same handle. When they expect it to be permanent, they also reconsider which handle to own. A permanently higher cartridge price makes a compatible handle less attractive, so fewer households buy or keep one, and cartridge demand falls by more in the long run than in the short run. The gap is largest for the largest line of Family M, whose cartridge price elasticity is -3.1 in the long run, compared with -2.3 in the short run. A static model cannot capture these dynamic responses because it ignores both purchase timing and the link between handle ownership and future cartridge choices.

I use the estimated model to simulate demand under alternative compatibility scenarios, holding prices fixed. The main finding is that compatibility within a firm expands demand for the affected families by more than it cannibalizes sales between them. I first make two families owned by the same firm compatible, so that their handles and cartridges can be used interchangeably. One family (Family D) has cheaper and lower-quality cartridges, while the other (Family M) offers more expensive and higher-quality ones. Making the two families compatible increases demand for the combined system. More households own a handle from these families, many switching from rival systems, whose revenues fall by 71.1%. Existing owners also buy more cartridges because they can now choose from a wider range of compatible products. At the same time, there is some cannibalization: Family M owners buy 19.4% fewer Family M cartridges per month, as some switch to the cheaper Family D cartridges. This loss is more than offset by the larger number of Family M handle owners and by Family D owners who now buy Family M cartridges, so total sales of both Family D and Family M cartridges increase. Households benefit regardless of which handle they initially own. For existing owners of either family, compatibility expands their cartridge options; for owners of rival systems, it makes the combined system a more attractive option when they next replace their handle.

In the counterfactual discussed above, the two families differ substantially in price and quality. Making them compatible therefore gives each handle access to a very different set of cartridges. By contrast, joining lines that are similar in price and quality adds less variety, which could potentially weaken the expansion channel. I therefore examine whether making similar lines compatible still generates enough demand expansion to outweigh the cannibalization of sales between them. I focus on Line M-2, which the firm introduced within Family M and which is similar to the family's other lines. I examine what would have happened had the firm instead launched Line M-2 as a separate family, so that its cartridges do not fit the other Family M handles and its handles do not fit their cartridges. Separating the line would eliminate cannibalization between Line M-2 and the rest of Family M. But it would also reduce the number of cartridges compatible with each handle, making both handles less

attractive to own. Line M-2 handles would lose more, since they lose access to all other Family M cartridges, while the other Family M handles lose access only to Line M-2. The results show that the loss in demand outweighs the reduction in cannibalization. Line M-2's sales fall by 49.7%, mostly because its share of handle ownership roughly halves. Sales of the rest of Family M fall by a smaller 11.2%, as fewer households buy or keep its handles. Rival systems recover only a small part of these lost sales, and total demand falls by 22.8%. Varying the price of Line M-2 between 0.6 and 1.4 times its observed level shows that cannibalization arises only when the products being made compatible differ substantially in price: owners of the more expensive line then shift some purchases to the cheaper one. Holding prices at observed levels, where they are more similar, the demand lost from separating line M-2 exceeds the sales recovered by eliminating cannibalization. Thus, even for similar lines, the increase in demand from making them compatible outweighs the resulting cannibalization of sales between them.

This paper relates to structural models of demand for tied goods. Models estimated on aggregate sales data, such as those of single-serve coffee machines and pods (Chintagunta et al., 2018) and video-game consoles and games (Derdenger, 2014; Lee, 2013), account for the unobserved quality of each product, but assume that consumers choose a base good once and afterwards choose only among its compatible products, which imposes complete lock-in.[4] Models estimated on individual-level data, such as those of razors and blades (Hartmann and Nair, 2010), cameras and memory cards (Liu et al., 2018), and camera bodies and lenses (Huang, 2022), allow consumers to replace their base good, but capture quality only at the brand or technology level. In this paper, I bring these two features together by allowing households to replace their base goods while accounting for the unobserved quality of each product in each market. The counterfactuals illustrate the importance of this flexibility: changes in compatibility induce households to switch between handle families, a response that models imposing complete lock-in would miss.

Methodologically, this paper brings together features of dynamic demand for durable and storable goods. As in the durable-goods frameworks of Gowrisankaran and Rysman (2012) and Hodgson (2023), households are forward looking, form expectations about future products and prices through the inclusive value of their choice set, and current purchases change the value of future options. Here, the handle determines which cartridges a household can buy later, and the quality of the cartridges it buys carries over into later months. As in models of storable goods (Erdem et al., 2003; Hendel and Nevo, 2006; Ching and Osborne,

[4]Lee (2013) allows consumers to buy more than one console, but consoles are kept once bought, so a new console adds access to another platform's games rather than replacing the first. His setting also features indirect network effects, which are absent in mine.

2020), households also hold inventories and consume them over time. Unlike models in which all brands are identical once purchased (e.g., Hendel and Nevo, 2006), my model allows the quality of a household's inventory to depend on which cartridges it holds, so inventory affects not only when a household buys but also what it buys.

This paper also relates to theoretical work on tied goods. Oi (1971), for example, shows that a firm can charge heavy users more through a two-part tariff, which in tied-goods markets takes the form of a low price for the base good and a high price for the consumable. Mariñoso (2001) shows that incompatibility makes the price of the base good a switching cost for consumers who change brands. Locked-in owners in turn give the firm market power in its aftermarket (Borenstein et al., 2000), and control over the interface can be used to exclude rivals (Whinston, 1990; Carlton and Gertner, 2003; Economides and White, 1994). More directly related to this paper, Matutes and Régibeau (1988) and Economides (1989) show that compatibility can increase demand by expanding the variety of product combinations available to consumers. These papers focus on compatibility between competing firms, whereas my counterfactuals examine compatibility among a firm's own product lines. In the context of successive product generations, Choi (1994) studies how compatibility affects a firm's incentives to introduce new products and induce consumers to replace existing ones. My paper contributes to this literature by empirically quantifying how compatibility expands demand for a firm's system while also inducing cannibalization among its existing product lines.

The remainder of the paper is organized as follows. Section 2 describes the market, and Section 3 introduces the data. Section 4 presents descriptive evidence. Sections 5 and 6 develop the model and estimation procedure. Section 7 reports preliminary estimates, Section 8 presents the counterfactual analysis, and Section 9 concludes.

2 The Razor Market

This paper studies tied razor systems, in which a reusable handle is used with replaceable cartridges. The market offers two types of products: razor packs, which contain a handle and a small number of cartridges, and cartridge packs, which contain replacement cartridges only. The handle is the durable component, while cartridges are consumables that must be replaced periodically. Households enter a system by purchasing a razor pack and can subsequently purchase cartridge packs as needed. Disposable razors, which have no reusable handle, are treated as part of the outside option. The razor market consists mainly of two leading firms, Firm A and Firm B, along with a smaller firm and store brands.

A cartridge attaches to a handle through a connector, a mechanical interface whose shape,

dimensions, and locking mechanism determine which handles the cartridge fits. Connector designs are typically patented, and patents generally last 20 years from the filing date. While a patent is in force, it prevents rivals from producing cartridges that use the protected design. Incompatibility, however, is not a technical constraint. Adapters that allow handles and cartridges with different connectors to be used together are technically feasible, although no firm offered one during the sample period. Firms have also introduced cartridges designed to fit competitors' handles, most notably after the relevant connector patents expired.[5] Firms therefore choose which handles their cartridges fit, and this choice extends to their own product families, which a firm could make compatible without any patent barrier.

Products that share a connector form a *product family* and are compatible with one another. Each firm sells several families, and each family usually contains several *product lines* that share the family's connector.[6] Each line consists of many products, which differ in pack type (razor pack or cartridge pack) and pack size (the number of cartridges in the pack). A household can purchase cartridges from any line in its handle's family but must buy a new razor pack to switch to another family. Families differ primarily in cartridge design: across all firms, each newer family has more blades per cartridge than earlier ones. Lines within a family often have similar observed characteristics but very different market shares, which suggests there might be differences in shaving performance or comfort that observed characteristics do not capture. This motivates the inclusion of the unobserved quality term ξ_{jt} in the model. Handles, by contrast, play a smaller role in shaving quality: they are durable and primarily determine which cartridges a household can use. Following Hartmann and Nair (2010), in my model, per-use utility is derived from cartridges rather than handles.

Table 1 reports prices by product family. Cartridge prices differ substantially across families: among packs containing two to four cartridges, the price per cartridge ranges from \$1.97 for Family H to \$4.54 for Family M, and is \$1.66 for store brands. Prices also vary with pack size, with larger packs offering lower per-cartridge prices. The implied price of a handle ranges from \$2 to \$6 across families. Although a handle costs about as much as one or two cartridges, a household buys many cartridges over the life of each handle, so most revenue should come from cartridges. Figure 1 shows the revenue breakdown between razor packs and cartridge packs for each of the two leading firms, and for the smaller firm and store brands combined. Cartridge packs indeed account for most revenue: for Firm A, they account for 75% to 87% of tied-razor revenue in every year of the sample, compared with 55% to 73% for Firm B.

[5]These examples are drawn from publicly available product information. I do not cite them because doing so would identify the firms and products, which my data use agreement does not allow.

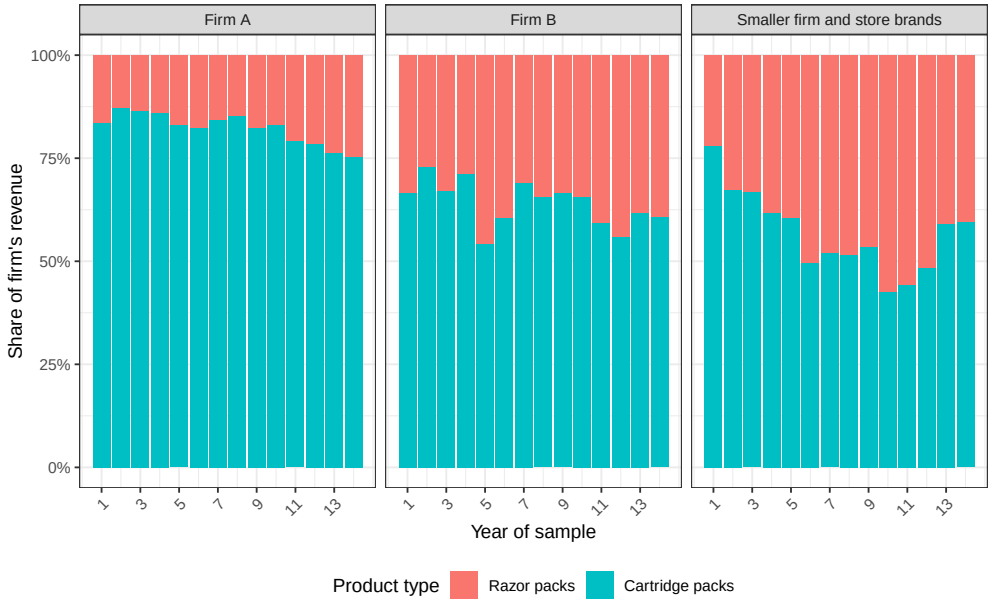
[6]Throughout the paper, families are labeled by arbitrary letters. Where the analysis refers to a specific line, it is labeled by its family letter and a number, such as Line M-2.

Table 1: Prices Across Product Families

	Razor pack ($)		Cartridge pack ($ per cartridge)		
		Implied	Cartridges per pack		
Family	Price	handle	2–4	5–8	10+
Family D	10.22	4.32	2.90	3.10	2.49
Family H	6.60	2.56	1.97	1.79	1.28
Family M	11.15	2.13	4.54	4.12	3.35
Family P	9.50	3.14	3.27	2.62	2.52
Family R	9.54	4.60	2.55	2.13	2.17
Family T	9.92	4.00	2.94	2.49	2.01
Family W	10.16	5.83	2.17	2.02	1.92
Store brand	6.10	2.68	1.66	1.11	0.59

Notes: NielsenIQ Retail Scanner data, 2006–2019. Prices are in 2019 dollars and averaged across markets and months. Razor-pack prices are for packs containing a handle and two cartridges. Cartridge-pack prices are the pack price divided by the number of cartridges in the pack. The implied handle price is the price of a two-cartridge razor pack minus the price of two cartridges from the same product line, computed within each market and month and then averaged; it therefore need not equal the difference between the displayed averages. "Store brand" groups private-label products across all retailers.

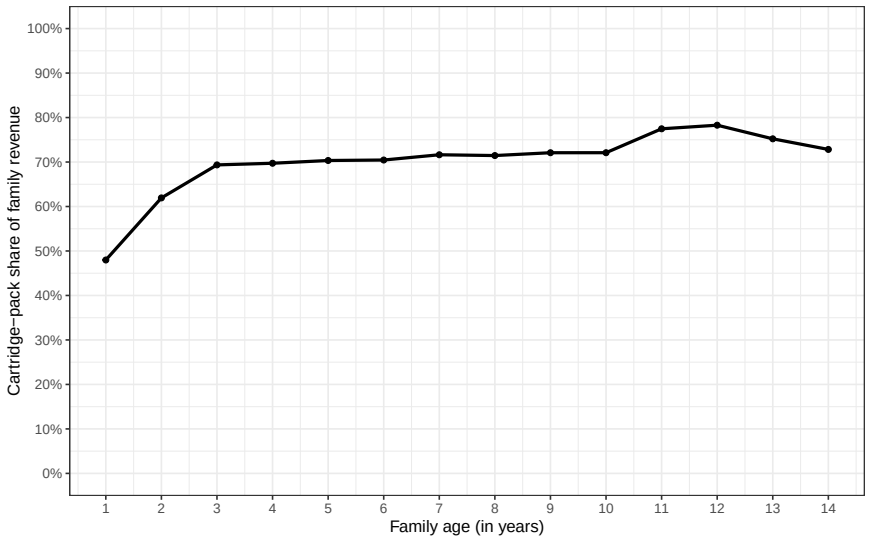
Figure 1: Revenue Shares of Razor Packs and Cartridge Packs



Source: NielsenIQ scanner data. Each panel reports the composition of revenue for the indicated firm. The last panel combines the smaller firm and store brands.

Product launches also change the composition of revenue within a family. Figure 2 shows the cartridge-pack share of family revenue by years since launch for the families launched during the sample period, pooled together.[7] In the launch year, razor packs account for a large share of family revenue, with cartridge packs making up about 48%. The cartridge-pack share then rises over the first two to three years, as the number of consumers who own the family's handle grows and replacement purchases accumulate, and stabilizes thereafter at roughly 70% to 80%. The share of revenue earned on cartridges is therefore lowest at launch and settles at a higher level once an installed base has formed.

Figure 2: Cartridge-pack share of family revenue



Source: NielsenIQ retail scanner data. Families launched during the sample period, pooled.

3 Data

3.1 Household Panel Data

The household-level data come from the NielsenIQ Homescan Consumer Panel for 2004–2019, which records each purchase trip and the products purchased by participating households. I focus on active households with exactly one male of shaving age (16 or older), and observed for at least three years.[8] Restricting the sample to households with one adult male reduces ambiguity about which household member uses the observed shaving products. I further

[7] I restrict the figure to these families because the sample begins after the other families were launched, so their early years on the market are not observed.

[8] A household is active in a month if it records a purchase of any product. See Appendix A for details.

restrict the sample to single-system households. A household is single-system if, at any point in time, all its cartridge purchases come from one product family, so that it can be assigned a single active handle.[9] I also remove households that purchase more than one product in the same month. These restrictions retain about 70% of households with one adult male. The first two years of each household's observation period are used as a burn-in period to construct handle ownership and cartridge stock, and estimation uses the remaining years.

Table 2 summarizes purchase behavior after the burn-in period for households with at least one purchase trip. Households are observed for about three and a half years on average and buy razor or cartridge packs on about one trip per year, with a median of six months between trips. Cartridge packs account for about three quarters of trips. The median household buys no razor pack after the burn-in period, consistent with most households already owning a handle when the estimation period begins. Household demographics are reported in Appendix Table A.1.

Table 2: Household Purchase Behavior

	Mean	SD	Min	Median	Max
Years in sample	3.43	2.80	0.08	2.58	13.00
Purchase trips	3.14	3.78	1	2	66
Razor packs	0.81	1.31	0	0	16
Cartridge packs	2.33	3.65	0	1	66
Trips per year	1.19	1.09	0.08	0.92	12.00
Months between trips	10.31	12.02	1	6	123

Notes: Statistics are computed across the 6,053 households in the final estimation sample (post burn-in period). A purchase trip is a household–month with at least one purchase of a razor pack or cartridge pack; a trip that includes a razor pack is counted as a razor-pack trip. The sample contains 18,987 purchase trips.

Handle ownership and cartridge inventory are not recorded in the data, so I construct both from purchase histories. For households that purchase a razor pack during the burn-in period, handle ownership is observed directly. For households observed buying only cartridges, I treat a cartridge purchase as evidence that the household already owns a compatible handle. If a household buys a cartridge pack that is incompatible with every handle it has purchased, I infer that it acquired a compatible handle during the burn-in period. This rule would misclassify households that buy cartridges in anticipation of a later razor pack purchase, but

[9]The model tracks one handle, one cartridge stock and one cartridge flow utility per household. A household that uses two families at the same time would require tracking two stocks and two flow utilities, as well as a decision about which stock to draw from, which greatly increases the size of the state space and makes the dynamic problem computationally infeasible.

such behavior appears to be rare. Over the full panel history, 85.4% of cartridge purchases made without a previously observed compatible handle are never followed by a razor pack from that family. The rest are followed by one only after a median of 22 months, a delay that is unlikely to reflect buying cartridges in anticipation of a handle purchase (Appendix B).

Cartridge inventory depends on how quickly a household uses cartridges, which is also unobserved. Following Ching and Osborne (2020), I assume each household consumes cartridges at a fixed rate. In particular, I measure a household's monthly consumption rate as the number of cartridges it purchases during the burn-in period divided by the number of months it is observed in that period. I impose a lower bound of 0.5 cartridges per month.[10] The burn-in period also provides each household's handle and cartridge stock at the start of the estimation sample.

3.2 Retailer Scanner Data

Market-level data come from the NielsenIQ Retail Scanner data, which record weekly unit sales and prices by store and product. I define a product as a combination of product type (razor pack or cartridge pack), product line, and pack size. For example, 8-count and 4-count cartridge packs of the same line are separate products. A market is defined as a state–month pair.

Within each market, I aggregate unit sales across stores and weeks and compute each product's price as the unit-weighted mean price per pack, deflated to 2019 dollars. I measure market size as the number of households in the estimation population, defined as households with exactly one adult male of shaving age, using the sum of their panel projection factors within each state and year. A product's market share is its unit sales in packs divided by this market size. The outside share is the share of households that do not purchase a tied-razor product during the month. Because the scanner data cover only a subset of stores and include purchases by households outside the estimation population, I adjust unit sales to account for both sources of coverage. In particular, I scale sales up to account for stores not covered by the scanner and then adjust them to reflect the share of purchases made by households with one adult male of shaving age.[11]

I make two further adjustments to align the scanner data with the household panel. First, I add products that panel households purchase in a market but that do not appear in the scanner data for that market, constructing their shares and prices from projection-weighted

[10] Manufacturer guidance indicates that blades are designed to provide up to one month of shaves, but that blade lifespan varies with factors such as the thickness of the user's hair. A lower bound of 0.5 cartridges per month allows each cartridge to last up to twice this stated lifespan, and is therefore conservative.

[11] See Appendix C for details on this adjustment.

panel purchases. These products account for about 2% of product–market observations. Second, I exclude two types of products from the choice set. The first are products with a market share below 10^{-5} that no panel household purchases in the market. The second are cartridge packs for which no panel household in the market owns a compatible handle. If no household in the sample can choose these products, the model predicts a zero share for them and cannot match their positive observed shares. The final scanner sample contains 231 products and 3,732 markets, for a total of 270,907 product–market observations. Table 3 reports summary statistics. A market contains about 73 products on average, of which about two thirds are cartridge packs. The inside share averages about 10%, so in a typical month most households in the market buy neither a razor pack nor a cartridge pack. Cartridge packs contain about 7.5 cartridges on average, compared with about 2.6 in razor packs.

Table 3: Summary Statistics: Scanner Choice Set

	Mean	SD	Min	Max
Products per market	72.59	12.83	43	102
Razor packs	25.44	6.43	11	44
Cartridge packs	47.15	7.20	28	61
Inside share (%)	9.6	3.3	3.6	41.1
Product share (%)	0.13	0.25	0.001	29.44
Price per pack, razor packs ($)	10.27	6.08	0.01	145.95
Price per pack, cartridge packs ($)	19.90	12.18	0.01	62.85
Cartridges per pack, razor packs	2.58	2.86	1	20
Cartridges per pack, cartridge packs	7.50	3.99	2	25

Notes: A market is a state–month. The sample contains 3,732 markets, 231 products and 270,907 product–market observations. Prices are in 2019 dollars.

4 Reduced-Form Evidence

The dynamic model implies that compatibility shapes how households adopt new products and respond to price changes. This section examines whether household purchases in the panel are consistent with these implications. If so, compatibility should matter in two ways. First, households that already own a compatible handle should be more likely to adopt a new line by purchasing a cartridge pack rather than a razor pack, which requires paying for a handle. Second, a household's cartridge purchases should respond to the prices of compatible cartridges, but not directly to the prices of incompatible cartridges, which cannot be used with the household's existing handle. Sections 4.1 and 4.2 examine these predictions in turn.

4.1 Adoption of a New Cartridge Line

The first exercise asks whether owning a compatible handle changes how a household adopts a new product line. When a new line's cartridges fit a handle the household already owns, the household can adopt the line by buying a cartridge pack alone. When they do not, it must also buy a razor pack. Compatibility therefore lowers the cost of trying a new line for households that own a compatible handle. It should make them more likely to adopt the line through cartridges. The introduction of a new line, which I call Line M-2, provides a setting to test this. Line M-2's cartridges fit the handles of an existing line in the same family. Owners of these compatible handles could therefore adopt Line M-2 by buying cartridges alone, while other households had to buy a razor pack. I compare how owners of a compatible handle and other households adopt Line M-2.

To make this comparison, I use households observed for at least one year before and five years after the launch of Line M-2, and estimate linear probability models of the form

$$Y_i = \tau \,\text{Owner}_i + \psi_1 N_i + \psi_2 R_i + \psi_3 L_i + \eta_m + u_i, \tag{1}$$

where i indexes households and m is the household's state. The outcome Y_i is one of three indicators, one for each column of Table 4. In column 1, it equals one if the household buys any Line M-2 product within five years of the launch. In columns 2 and 3, it equals one if the household adopts Line M-2 starting with a cartridge pack or with a razor pack, respectively. These two outcomes sum to the first, so columns 2 and 3 split the adoption gap by how households first buy the line. The variable Owner_i equals one if the household owned a compatible handle before the launch. Its coefficient τ is the parameter of interest. If compatibility lowers the cost of adopting Line M-2 through cartridges, most of the adoption gap in column 1 should come from column 2.

The controls address three other reasons why owners and other households may differ. The number of purchase trips in the year before the launch, N_i, measures how often the household buys razors or cartridges, since households that shop more often have more occasions to adopt a new line. The share of razor packs among the household's purchases before the launch, R_i, measures its preference for razor packs over cartridge packs, which may affect how it first buys Line M-2. The share of products from the firm that makes Line M-2 among the household's purchases before the launch, L_i, measures its loyalty to the firm. State fixed effects η_m absorb persistent differences across states in prices and product availability.

Table 4 reports the estimates. Owners of a compatible handle are 39.1 percentage points more likely than other households to adopt Line M-2 within five years (column 1), against an average adoption rate of 28%. Most of this gap, 29.4 percentage points, comes from

households that start with a cartridge pack (column 2). The remaining 9.7 percentage points come from households that start with a razor pack (column 3). Every household can buy a razor pack at the same price, so this part of the gap cannot be attributed to compatibility. It reflects a stronger preference for Family M among owners of a compatible handle. The results therefore show that compatibility changes how owners adopt the new line: they adopt it mainly through cartridges, an option only their handle provides.

The controls also behave as expected. Households that bought razor packs more often before the launch are more likely to adopt Line M-2 through a razor pack and less likely to adopt it through cartridges. An additional 10 percentage points of past purchases that were razor packs raises the probability of razor-pack-first adoption by 2.8 percentage points. Households that shop more often are more likely to adopt, but only through razor packs. The coefficient on loyalty to the firm is small and insignificant in all three columns.

These results show that compatibility changes how households adopt a new line. Owners of a compatible handle can adopt a new line by buying cartridges alone, an option other households do not have, and this accounts for most of the adoption gap: owners were 29.4 percentage points more likely to adopt Line M-2 starting with a cartridge pack. However, the comparison across households does not reveal how closely lines that fit the same handle compete with each other relative to incompatible lines. The next exercise examines this by following each household over time and asking how its cartridge purchases shift across compatible lines as their prices change.

4.2 Substitution Among Compatible Cartridges

This next exercise investigates whether compatibility makes cartridge lines that fit the same handle closer substitutes than lines that do not. If compatibility matters, I expect households to respond more strongly to price changes in cartridge lines that fit their current handle than to price changes in lines that require a different handle. For example, when one line's cartridges become more expensive, a household whose handle fits them can switch to cartridges of other lines in the same family without buying a new handle. To test this prediction, I follow each household's purchases over time and examine how its cartridge purchases respond to the prices of the lines its handle can use.

The unit of observation is a purchase occasion, a household–month in which the household buys a razor pack or a cartridge pack. I assign each household to the line of its most recent razor-pack purchase, which I call its current line. For a household whose current line is ℓ in

Table 4: Adoption of Line M-2 by Prior Handle Ownership

	Adopted (1)	Cartridge Pack first (2)	Razor Pack first (3)
Owned prior compatible handle	0.391***	0.294***	0.097***
	(0.022)	(0.025)	(0.019)
Purchase trips before launch	0.028***	0.001	0.028***
	(0.007)	(0.006)	(0.006)
Razor-pack share	0.160***	−0.121***	0.281***
	(0.039)	(0.028)	(0.040)
Same-firm share	−0.008	0.012	−0.020
	(0.026)	(0.013)	(0.021)
Mean of dependent variable	0.28	0.12	0.16
Observations	1,671	1,671	1,671
R^2	0.252	0.215	0.122
Within R^2	0.231	0.186	0.098
State FE	✓	✓	✓

Notes: Linear probability models for the Line M-2 launch. The sample includes all households observed for at least one year before and five years after the launch. The dependent variable indicates adoption of Line M-2 within five years (column 1), and adoption starting with a cartridge pack (column 2) or a razor pack (column 3). The coefficients in columns 2 and 3 sum to column 1. Razor-pack share and same-firm share (the share of purchases from the firm that makes Line M-2) are measured before the launch as fractions from zero to one. Standard errors clustered by state in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

family f, I estimate two linear probability models:

$$Y_{it}^k = \psi_1^k \log p_{\ell,it}^C + \psi_2^k \log p_{f\setminus\ell,it}^C + \psi_3^k \log p_{-f,it}^C + \mathbf{x}_{it}'\boldsymbol{\gamma}^k + \eta_{\ell y}^k + \eta_{\text{moy}}^k + \eta_i^k + u_{it}^k, \qquad (2)$$

where $k = 1, 2$. The dependent variable Y_{it}^1 is a dummy that equals one if household i buys cartridges of its current line in month t, and Y_{it}^2 equals one if it buys cartridges of another line in its family. Both are zero on occasions when the household buys a razor pack. The next three terms are cartridge prices, labeled by their relation to the household's handle. The superscript C denotes cartridge packs. The subscript ℓ denotes the household's current line, $f \setminus \ell$ the other lines in its family f, and $-f$ other families. Each price is the average price per cartridge in the household's state and month, taken over products and weighting each product by its cartridge sales in the state over the year. The vector $\mathbf{x}_{it}$ contains the log prices of razor packs of the household's family and of other families. These prices control for the option of buying a razor pack instead of a cartridge pack. Line-by-year fixed effects $\eta_{\ell y}^k$ account for changes in each line's popularity over time, and month-of-year fixed effects

η^k_{moy} control for seasonality. Household fixed effects η^k_i control for persistent differences in purchase choices, so the estimates compare each household with itself as prices change.

The coefficients of interest are ψ^k_1 and ψ^k_2, on the cartridge prices of lines that fit the household's handle. If these lines are close substitutes, a higher price of the current line should lower purchases of its cartridges and raise purchases of the other lines in the family. Thus ψ^1_1 should be negative and ψ^2_1 positive. A higher price of the other lines should have the opposite effect, so ψ^1_2 should be positive and ψ^2_2 negative. The coefficient ψ^k_3 provides the comparison. Cartridges of other families do not fit the household's handle, so if the handle constrains substitution, their price should have little effect on either outcome, and ψ^k_3 should be close to zero.

Table 5 reports the estimates. The first row shows the effect of the current line's price. When it rises by 1%, the probability that the household buys the current line's cartridges falls by 0.29 percentage points, and the probability that it buys cartridges of another line in its family rises by 0.18 percentage points. That is, about 63% of the purchases the current line loses go to other compatible lines. The second row shows the reverse. When the price of the other lines in the family rises by 1%, the probability of buying their cartridges falls by 0.18 percentage points, and the probability of buying the current line rises by 0.17 percentage points. The third row shows that the cartridge price of other families has no significant effect on either outcome. Together, these results show that households substitute strongly between lines that fit their handle, but not toward cartridges that do not fit it.

Taken together, these two exercises show that compatibility matters for both adoption and substitution. When a new product line is compatible with existing handles, households can adopt it without purchasing a new razor pack. Changes in relative prices also induce substitution between compatible cartridge lines. However, these patterns do not establish how demand would respond to alternative compatibility arrangements, or how much of that response would reflect market expansion rather than cannibalization. Addressing these questions requires a structural model that captures households' dynamic decisions to switch between handles and cartridges. In the next section, I develop such a model and use it to quantify the relative importance of the two channels under alternative compatibility arrangements.

Table 5: Cartridge Purchases and Prices of Compatible Cartridges

	Buys a cartridge pack of	
	Current line	Another line in same family
	(1)	(2)
Log cartridge price of		
Current line	−0.290***	0.182*
	(0.109)	(0.095)
Other lines, same family	0.166**	−0.183***
	(0.083)	(0.065)
Other families	−0.145	0.028
	(0.115)	(0.097)
Mean of dependent variable (%)	45.1	18.8
Purchase occasions	5,628	5,628
Households	1,123	1,123
Razor-pack prices	✓	✓
Household, line × year, month-of-year FE	✓	✓

Notes: Linear probability models on purchase occasions (household–months with a razor-pack or cartridge-pack purchase). The current line is the line of the household's most recent razor pack. Prices are per cartridge, in the household's state and month. Each coefficient is the change in percentage points in the purchase probability after a 1% price increase. Razor-pack prices of the household's family and of other families are included as controls. Standard errors clustered by household in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5 A Dynamic Model of Demand

This section describes my model of household demand for razor packs and cartridge packs. Households are forward looking with an infinite horizon, and they discount the future at rate β. In every period, households choose among purchasing razor packs, cartridge packs, or the outside option. The outside option is defined as consuming the household's stock of cartridges associated with the family of their handle in stock as long as the cartridge stock is positive. If the household has no stock of cartridges, then the outside option corresponds to shaving with a non-tied product or not shaving at all.

Purchasing product j gives the household a pack containing a handle (in the case of razor packs) and a number of cartridges n_j. The number of cartridges in each pack is accounted for through the household's stockpiling behavior. I allow both purchase and consumption of stock to account for the differentiated nature of cartridges, including unobserved quality. This is achieved by extending the framework of Gowrisankaran and Rysman (2012) to the consumable goods setting.

5.1 Household State and Feasible Alternatives

Household i enters month t with state

$$\Omega_{it} = (B_{it}, f_{it}, s_{it}), \tag{3}$$

where B_{it} is the handle family currently owned, f_{it} is the flow utility associated with the cartridge stock in use, and s_{it} is the stock of compatible cartridges. Households may have a razor handle in stock from a particular family and a number of its associated cartridges with a particular quality representing the flow utility it will receive if it chooses to consume stock that period. Given this state, the household will make their discrete choice. Note that I do not model multi-homing across handle families. As described in Section 3, I drop the small minority of households that appear to multi-home, and I assume that each household consumes cartridges at a fixed monthly rate c_i.

Let $\mathcal{R}_t$ and $\mathcal{C}_t$ denote the sets of razor packs and cartridge packs sold in month t. Define $K_{bj,t} = 1$ if the cartridge in product j can be used with a handle of family b, and zero otherwise. The household's choice set is

$$\mathcal{A}_t(B_{it}; K_t) = \mathcal{R}_t \ \cup \ \{j \in \mathcal{C}_t : K_{B_{it}j,t} = 1\} \ \cup \ \{0\}, \tag{4}$$

where 0 denotes no purchase. A household can buy a razor pack from any family because it includes the handle required to use its cartridges. It can buy a cartridge-only pack only if those cartridges are compatible with its current handle. A household without an observed or imputed handle has no compatible cartridge alternative until it acquires one.

As discussed in Section 2, I assume the handle provides no per-shave benefit beyond the cartridges it permits the household to purchase and use. Any one-time value of buying a handle enters through the razor-pack fixed effects described below. To see the role of compatibility, consider a household that owns a handle of family b. Under incompatibility, buying a cartridge from another family b' requires first acquiring the associated handle through a razor pack. If family b' cartridges become compatible with the family b handle, they enter the household's choice set directly. The household can then buy family b' cartridges while retaining the same handle, avoiding the extra cost of buying a family b' razor pack to acquire the handle.

5.2 Purchase Utility and Cartridge Flow Utility

I now specify the utility of each alternative in $\mathcal{A}_t(B_{it}; K_t)$. Household i's utility from purchasing inside product j is

$$u_{ijt} = \underbrace{\mathbf{X}_{jt}^C \boldsymbol{\beta}_C + \xi_{jt}}_{\text{carried cartridge flow utility}} + \underbrace{\mathbf{D}_{jt}\boldsymbol{\beta}_D - \alpha p_{jt}}_{\text{one-time purchase utility}} + \epsilon_{ijt} \equiv v_{ijt} + \epsilon_{ijt}, \tag{5}$$

where the vector $\mathbf{X}_{jt}^C$ includes the number of blades, an indicator for a trimmer, and family fixed effects, with coefficients $\boldsymbol{\beta}_C$, and ξ_{jt} is cartridge quality unobserved by the econometrician. The vector $\mathbf{D}_{jt}$ includes log pack size, family-specific razor-pack fixed effects, and state and year fixed effects, with coefficients $\boldsymbol{\beta}_D$. I discuss the distinction between $\mathbf{X}_{jt}^C$ and $\mathbf{D}_{jt}$ below. The term p_{jt} is the price of product j in month t, and α measures disutility from price. The term ϵ_{ijt} is a choice shock observed by the household but not by the econometrician. The shocks are i.i.d. type I extreme value across households, alternatives, and months, and they affect future states only through the household's choice. Finally, v_{ijt} denotes the remaining, deterministic component of utility. The geographic market subscripts are suppressed for readability.

The component

$$f_{jt} = \mathbf{X}_{jt}^C \boldsymbol{\beta}_C + \xi_{jt} \tag{6}$$

is the flow utility of the purchased cartridge. The household carries it forward as its state variable, so that $f_{i,t+1} = f_{jt}$ if household i buys product j in month t. The split between $\mathbf{X}_{jt}^C$ and $\mathbf{D}_{jt}$ follows from when each characteristic generates utility. Cartridge characteristics such as the number of blades and a trimmer affect every shave, so the household receives them in each month it consumes from stock. I treat the unobserved quality ξ_{jt} in the same way. It captures attributes of the cartridge not measured by $\mathbf{X}_{jt}^C$, such as blade sharpness or comfort, which also affect every shave. This requires that ξ_{jt} reflect persistent cartridge attributes rather than transitory factors at the purchase occasion, such as in-store promotions.

In contrast, $\mathbf{D}_{jt}\boldsymbol{\beta}_D$ and the price term enter only at the time of purchase. These terms describe the purchase occasion rather than the cartridge. Placing them in f_{jt} would count them in every month of consumption and misstate the value of holding inventory. A razor pack already generates value in the model, since its cartridges enter inventory and its handle determines the household's future refill options. The razor-pack-by-family fixed effects in $\mathbf{D}_{jt}$ capture any additional value of buying a handle, relative to a cartridge pack with the same cartridges. For instance, a household may simply like getting a new handle. Similarly, a larger pack already has value in the model because it adds more cartridges to inventory.

Log pack size captures any preference for pack size beyond this inventory value. For instance, households may find it convenient to buy one large pack on a single shopping trip rather than several small packs on separate trips. State and year fixed effects control for any state and year specific demand shocks that cannot be attributed to the quality of cartridges.

When no purchase is made, the household consumes existing stock. I write current no-purchase utility as

$$u_{i0t} = f_{it}\mathbf{1}\{s_{it} > 0\} + \epsilon_{i0t} \equiv v_{i0t} + \epsilon_{i0t}. \tag{7}$$

At zero inventory, the deterministic component v_{i0t} is normalized to zero.

5.3 State Transitions

Let n_j be the number of cartridges in product j, and let $B(j)$ denote the handle family supplied with a razor pack. Table 6 summarizes how each choice changes the household's handle family, cartridge flow utility, and inventory under the baseline compatibility mapping.

Table 6: Household State Transitions

Action	$B_{i,t+1}$	$f_{i,t+1}$	$s_{i,t+1}$
Razor pack, same family	B_{it}	f_{jt}	$\max\{s_{it} + n_j - c_i,\, 0\}$
Razor pack, different family	$B(j)$	f_{jt}	$\max\{n_j - c_i,\, 0\}$
Compatible cartridge refill	B_{it}	f_{jt}	$\max\{s_{it} + n_j - c_i,\, 0\}$
No purchase	B_{it}	f_{it}	$\max\{s_{it} - c_i,\, 0\}$

Notes: For purchased product j, f_{jt} is its flow utility, n_j its number of cartridges, and $B(j)$ the handle family of a razor pack. c_i is the household's monthly consumption rate.

Purchases add n_j cartridges before the household's current-period consumption of c_i is subtracted. A compatible refill and a razor pack from the household's current family, $B(j) = B_{it}$, therefore have the same inventory transition, $s_{i,t+1} = \max\{s_{it} + n_j - c_i, 0\}$. Both also replace the flow utility carried into the next period with that of the purchased cartridges, so that $f_{i,t+1} = f_{jt}$. With no purchase, the household keeps its handle family B_{it} and flow utility f_{it}, while its inventory declines to $\max\{s_{it} - c_i, 0\}$.

A razor pack from a different family, $B(j) \neq B_{it}$, changes the household's handle family to $B(j)$. Under the baseline single-homing assumption, the household discards its existing stock when it switches families, so only the n_j cartridges in the new pack enter next period's inventory. The assumption that households discard remaining cartridges has limited bearing in practice. It matters only if the household holds cartridges when it switches, and in the data households tend to run down their stock before switching. Of razor pack purchases

that switch families, 70.4% are made by households holding no cartridges. For razor pack purchases within the same family, the corresponding share is 47.4%. Households are therefore more likely to have used up their cartridges when they switch, consistent with delaying a switch until their existing stock is exhausted. Overall, households discard cartridges in 14.9% of all razor pack purchases, and the median amount discarded is 2.17 cartridges (Appendix Table D.1).

5.4 The Household's Dynamic Problem

Let M_t denote the market state, including prices, product characteristics, and availability. After observing its shocks, the household chooses the alternative that maximizes its expected discounted utility, so its value function is

$$V_{it}(\Omega_{it}, M_t, \epsilon_{it}) = \max_{j \in \mathcal{A}_t(B_{it}; K_t)} \{W_{ijt} + \epsilon_{ijt}\}, \tag{8}$$

where $W_{ijt} = v_{ijt} + \beta \mathbb{E}[V_{i,t+1}(\Omega'_{it}(j), M_{t+1}, \epsilon_{i,t+1}) \mid \Omega_{it}, M_t, j]$ is the choice-specific value, β is the discount factor, and $\Omega'_{it}(j)$ is the next-month state implied by Table 6.

I define the inclusive value as the expectation of (8) over the current shocks:

$$\delta_{it}(\Omega_{it}, M_t) \equiv \mathbb{E}_\epsilon V_{it}(\Omega_{it}, M_t, \epsilon_{it}) = \log \sum_{j \in \mathcal{A}_t(B_{it}; K_t)} \exp(W_{ijt}). \tag{9}$$

In words, the inclusive value is the expected value of the household's problem before the current shocks are realized, including current utility and the continuation values generated by future choices. Note that the exact expectation also contains Euler's constant; I omit it because it shifts every W_{ijt} by the same amount and does not affect choice probabilities.

Because the shocks are independent over time and of the market state, the law of iterated expectations allows the expectation over $\epsilon_{i,t+1}$ to be taken first, conditional on M_{t+1}. By (9) evaluated one period ahead, this inner expectation equals $\delta_{i,t+1}$. The choice-specific value can therefore be written as

$$W_{ijt} = v_{ijt} + \beta \mathbb{E}\Big[\delta_{i,t+1}\Big(\Omega'_{it}(j), M_{t+1}\Big) \mid \Omega_{it}, M_t, j\Big]. \tag{10}$$

Choice probabilities take the familiar logit form

$$P_{ijt} = \frac{\exp(W_{ijt})}{\sum_{a \in \mathcal{A}_t(B_{it}; K_t)} \exp(W_{iat})}. \tag{11}$$

5.5 Forecasting Future Market Conditions

The continuation value in (10) conditions on the full market state M_t, which includes the price and availability of every razor pack and cartridge pack. Computing it directly would require households to forecast the joint evolution of all these variables, which is computationally infeasible. Following Gowrisankaran and Rysman (2012) and Hodgson (2023), I simplify the problem by assuming that households summarize the market using the inclusive value defined in (9). Intuitively, the inclusive value captures the overall attractiveness of the options available to a household, accounting for both current utility and the continuation values of the states those choices lead to. This value is household-specific because the available options depend on the household's state Ω. For example, a household with a family b handle considers the prices of compatible family b cartridges and razor packs, but not the prices of cartridges it cannot use. Rather than forecasting the evolution of individual prices and products, households forecast next month's inclusive value based on its current level.

Assumption 1 (Inclusive-value Sufficiency (IVS)). *If* $\delta(\Omega, M) = \delta(\Omega, \tilde{M})$, *then* $G_i(\delta'(\Omega', M') \mid \Omega, M, j) = G_i(\delta'(\Omega', \tilde{M}') \mid \Omega, \tilde{M}, j)$

The assumption states that two market states yielding the same current inclusive value at Ω lead to the same beliefs about next month's inclusive value at Ω, even if their prices and available products differ. Since equal conditional distributions imply equal conditional means, the continuation value in (10) becomes $\mathbb{E}[\delta_{i,t+1}(\Omega'_{it}(j)) \mid \delta_{it}(\Omega'_{it}(j))]$. Substituting into (9) gives

$$\delta_{it}(\Omega) = \log \sum_{j \in \mathcal{A}_t(B;K_t)} \exp(v_{ijt}(\Omega) + \beta \mathbb{E}[\delta_{i,t+1}(\Omega'(j)) \mid \delta_{it}(\Omega'(j))]) \tag{12}$$

To compute the expectation in (12), I approximate the inclusive-value transition as

$$\delta_{i,t+1}(B, f, s) = \gamma^B_{0i} + \gamma^B_{1i}\delta_{it}(B, f, s) + \mathbf{h}(f, s)\boldsymbol{\gamma}^B_{2i} + \omega_{i,t+1}(B, f, s), \tag{13}$$

where $\omega_{i,t+1}$ has mean zero conditional on $\delta_{it}(B, f, s)$. The coefficients are handle-family specific. It is important to flexibly capture transitions at the family level since households' choice sets depend on their handle family, whose attractiveness may change differently from family to family. For example, a household that buys a recently launched family might expect the family's attractiveness to improve over time, while a household that buys an older family may expect product availability to decline. The vector $\mathbf{h}(f, s)$ may be any flexible function of held-cartridge flow utility and stock; in practice I use B-splines but have also found polynomial terms to give similar results.

Under (13), the expectation in (12) equals $\gamma_{0i}^B + \gamma_{1i}^B \delta_{it}(\Omega') + \mathbf{h}(f', s')\boldsymbol{\gamma}_{2i}^B$. The solution to household i's problem is therefore a fixed point in $(\boldsymbol{\delta}_i, \boldsymbol{\gamma}_i)$: given $\boldsymbol{\gamma}_i$, (12) determines $\boldsymbol{\delta}_i$, and given $\boldsymbol{\delta}_i$, $\boldsymbol{\gamma}_i$ is recovered by regressing (13).

6 Estimation and Identification

6.1 Nested Estimation Procedure

The parameters to be estimated are $\boldsymbol{\theta} = (\alpha, \boldsymbol{\beta}_C, \boldsymbol{\beta}_D)$, consisting of the price coefficient α, the cartridge flow parameters $\boldsymbol{\beta}_C$, and the purchase utility parameters $\boldsymbol{\beta}_D$. Following Gowrisankaran and Rysman (2012) and Berry et al. (1995), I estimate them in two groups. The coefficients $\boldsymbol{\beta}_C$ and $\boldsymbol{\beta}_D$ are recovered from the non-price mean utilities $\bar{\mu}_{jt} = f_{jt} + \mathbf{D}_{jt}\boldsymbol{\beta}_D$, which absorb all non-price product and market-level variation in utility, so that $v_{ijt} = \bar{\mu}_{jt} - \alpha p_{jt}$ for inside goods. The price coefficient α is kept outside $\bar{\mu}_{jt}$ and estimated from the household panel. The discount factor is calibrated to $\beta = 0.95$.[12]

The estimation has two levels. For each candidate value of α, an inner loop solves for the non-price mean utilities $\bar{\boldsymbol{\mu}}$, inclusive values $\boldsymbol{\delta}$, and belief coefficients $\boldsymbol{\gamma}$ as a joint fixed point. An outer loop then maximizes the household-panel likelihood over α.

I first describe the inner loop. For a given α, it advances the three objects together, rather than solving for each separately to convergence. Each iteration consists of two steps.

1. *Dynamic step.* Taking the current $\bar{\boldsymbol{\mu}}$ as given, update the inclusive values using (12),

$$\delta_{it}^{k+1}(\Omega) = \log \sum_{j \in \mathcal{A}_t(B;K_t)} \exp\Big(v_{ijt}(\Omega) + \beta \mathbb{E}_{\boldsymbol{\gamma}^k}\left[\delta_{i,t+1}^k(\Omega'(j)) \mid \delta_{it}^k(\Omega'(j))\right]\Big), \tag{14}$$

   where k indexes iterations and the expectation is taken under the current belief coefficients $\boldsymbol{\gamma}^k$. Then update $\boldsymbol{\gamma}$ by estimating (13) by OLS on the updated inclusive values.

2. *Share inversion.* Holding $\boldsymbol{\delta}$, $\boldsymbol{\gamma}$, and therefore the continuation values fixed, compute each panel household's choice probabilities from (11) and aggregate them using projection weights w_i,

$$\widehat{s}_{jt} = \frac{\sum_{i \in \mathcal{I}_t} w_i P_{ijt}}{\sum_{i \in \mathcal{I}_t} w_i}, \tag{15}$$

[12] Although monthly dynamic models often set $\beta = 0.99$, I use a lower value based on the evidence that consumers of storable goods may be less forward-looking. Using the detergent market as an example, Ching and Osborne (2020) estimate a mean weekly discount factor of about 0.71, with substantial heterogeneity across households.

where $\mathcal{I}_t$ is the set of panel households in market t. Update mean utilities following Berry et al. (1995):

$$\bar{\mu}_{jt} \leftarrow \bar{\mu}_{jt} + \log s_{jt}^{\text{obs}} - \log \widehat{s}_{jt}, \tag{16}$$

where s_{jt}^{obs} is the observed market share from the scanner data. Finally, regress the updated mean utilities on the characteristics,

$$\bar{\mu}_{jt} = \mathbf{X}_{jt}^{C}\boldsymbol{\beta}_C + \mathbf{D}_{jt}\boldsymbol{\beta}_D + \xi_{jt}, \tag{17}$$

to recover $\boldsymbol{\beta}_C$, $\boldsymbol{\beta}_D$, and the flow utilities $f_{jt} = \bar{\mu}_{jt} - \mathbf{D}_{jt}\boldsymbol{\beta}_D$ that enter the next dynamic step.

The two steps repeat until $\bar{\boldsymbol{\mu}}$, $\boldsymbol{\delta}$, and $\boldsymbol{\gamma}$ no longer change between iterations. Within the share inversion, the dynamic objects are held fixed, so mean utilities affect predicted shares only through current utility, and shares are monotone in $\bar{\boldsymbol{\mu}}$. Across iterations, however, the dynamic objects respond to $\bar{\boldsymbol{\mu}}$. As Gowrisankaran and Rysman (2012) point out, the joint fixed point is therefore not guaranteed to exist. In practice, I find that the iterations converge reliably.

Given the inner-loop solution, the outer loop evaluates the likelihood at each household's own state,

$$\log L(\alpha) = \sum_i \sum_{t \in \mathcal{T}_i} \log P_{ij_{it}t}\Big(\alpha, \bar{\boldsymbol{\mu}}(\alpha), \boldsymbol{\delta}(\alpha), \boldsymbol{\gamma}(\alpha)\Big), \tag{18}$$

where j_{it} denotes the alternative household i chose in month t, including no purchase. The arguments make explicit that $\bar{\boldsymbol{\mu}}$, $\boldsymbol{\delta}$, and $\boldsymbol{\gamma}$ are recomputed at each candidate α. The estimate is

$$\widehat{\alpha} = \arg\max_{\alpha} \log L(\alpha). \tag{19}$$

6.2 Identification

The scanner and household panels provide different information. Scanner shares pin down the mean utility of each product in each state-month market for a given value of α. Household histories show how consumers with different handles choose among those products, given the cartridges they can use. Together, these data distinguish the utility received from a cartridge over time from the utility and cost incurred when it is purchased.

The coefficients in $\boldsymbol{\beta}_C$ are identified from standard variation in cartridge characteristics across products within family, under the assumption that ξ_{jt} is mean independent of the observed characteristics conditional on $\mathbf{D}_{jt}$. These characteristics contribute to the utility of the purchased product and to the flow utility carried into subsequent periods. By contrast,

the terms in $\mathbf{D}_{jt}\boldsymbol{\beta}_D$ contribute only when a purchase occurs. The razor-family and pack-size terms are identified from the relative shares of razor packs, cartridge packs, and pack sizes of the same line within a market. I recover the linear coefficients from the inverted mean utilities within the joint fixed point. In particular, changing a purchase-occasion coefficient changes the flow utility implied by a given mean utility, so the household's dynamic problem must be updated along with the decomposition.

The price coefficient α is estimated in the outer loop and identified from variation in household choices. A change in price shifts purchase probabilities differently across households at different stock levels than a change in mean flow utility does, and this difference separates sensitivity to price from the value of the cartridge. Compatibility adds variation: at a given set of market prices, households owning different handle families have different compatible cartridge alternatives, and their purchases across markets with different relative prices reveal how readily they substitute among refills they can use and when they buy a razor pack to access another family. I estimate α using the household panel likelihood, conditional on the mean utilities and dynamic solution recovered at each candidate value.

7 Estimates

The dynamic model is computationally expensive, so I currently estimate it on data from two states, California and Florida, over 2007–2019. Table 7 reports four specifications on this sample. Columns 1 and 2 report static logit estimates from the scanner data, without and with instruments for price. The instruments are sums of the characteristics of rival firms' products in the same market, following Berry et al. (1995). Column 3 reports static estimates obtained with the estimation procedure of Section 6. That is, I set $\beta = 0$ and normalize the value of holding cartridges to zero, so that no purchase yields zero deterministic utility in every state. Column 4 reports estimates of the dynamic model with $\beta = 0.95$.

I begin with the static logit estimates in columns 1 and 2, which serve as a benchmark. Without instruments (column 1), the price coefficient α is close to zero and the implied median own-price elasticity is -0.21. At this value, products are priced on the inelastic part of their demand curves, which a profit-maximizing firm would not choose. Instrumenting for price resolves this. With BLP instruments (column 2), the price coefficient rises in magnitude by a factor of about 15 and the median elasticity is -3.23. The coefficients on blades, the trimmer, and pack size have the expected positive sign.

I next estimate the household panel model by maximum likelihood. In the static version (column 3), the estimate of α is 0.358, implying a median elasticity of -4.64. This is similar in magnitude to the IV estimate of -3.23 in column 2. The characteristic coefficients also

Table 7: Preliminary Model Estimates for California and Florida

	Logit		MLE	
	No IVs	BLP IVs	$\beta = 0$	$\beta = 0.95$
Price	-0.016^{***}	-0.249^{***}	-0.358	-0.107
	(0.003)	(0.042)	—	—
Has trimmer	1.015^{***}	1.369^{***}	1.533^{***}	0.800^{***}
	(0.055)	(0.093)	(0.066)	(0.039)
Number of blades	0.058^{**}	0.346^{***}	0.479^{***}	0.075^{***}
	(0.018)	(0.061)	(0.020)	(0.012)
Log pack size	0.185^{***}	2.884^{***}	4.146^{***}	-1.140^{***}
	(0.041)	(0.487)	(0.029)	(0.017)
Median own-price elasticity	-0.21	-3.23	-4.64	-1.38
State FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Type × Family FE	Yes	Yes	Yes	Yes
Scanner observations	22,793	22,793	22,793	22,793
Panel observations	—	—	107,840	107,840
Log-likelihood	—	—	$-11{,}332.99$	$-12{,}894.55$
R^2	0.276	0.276	—	—
Within R^2	0.030	0.030	—	—

Notes: Standard errors in parentheses. Scanner standard errors are clustered by state × month. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$. The price entry is the signed coefficient, $-\alpha$, on price in dollars. In column 4, the trimmer and blades coefficients are monthly flow utilities, the pack-size coefficient is a one-time purchase-occasion term, and the elasticity is the short-run elasticity holding beliefs fixed.

have the same signs as the IV estimates and are somewhat larger.

Allowing households to be forward-looking changes this picture substantially. With $\beta = 0.95$ (column 4), α falls to 0.107 and the median short-run own-price elasticity is -1.38.[13] The fall in α from column 3 to column 4 reflects how the static and dynamic versions of the model explain the same purchase pattern. When $\beta = 0$, a household that does not buy when prices are high is responding to price. When $\beta = 0.95$, it may instead be holding stock bought earlier at a lower price and have no need to buy. Because stock explains part of this pattern, a smaller price coefficient is needed to fit it. This agrees with Hendel and Nevo (2006), who find that static estimates overstate own-price elasticities when consumers hold inventory.

The magnitudes of the characteristic coefficients in column 4 are smaller than in column 3

[13]The short-run elasticity holds households' beliefs about future prices fixed, so a price change affects choices only through current utility. Conditional on a household's state, it then takes the static logit form $-\alpha p_j(1 - s_j)$.

for a different reason. At $\beta = 0.95$, the coefficients on the trimmer and the number of blades are monthly flow utilities, received while the household holds stock, rather than one-time values. Gowrisankaran and Rysman (2012) make the same point for durable goods: because the flow from a camcorder lasts indefinitely, the dynamic coefficients on characteristics should be roughly $1-\beta$ times their static counterparts. In my setting the flow lasts only while the stock lasts. If a pack lasts T months, its flow is worth $(1-\beta^T)/(1-\beta)$ times the monthly flow, so the dynamic coefficients should be roughly $(1-\beta)/(1-\beta^T)$ times their static counterparts. This ratio is larger than $1-\beta$ and approaches it only as T becomes large. Moreover, T varies across households and packs, since it depends on pack size and the consumption rate.

8 Counterfactual Analysis

8.1 Price Counterfactuals

To understand how compatibility affects substitution, I begin by using the model to estimate elasticities and diversion ratios. For the former, I measure both short-run and long-run elasticities. Short-run elasticities refer to demand changes following price increases that households see as one-time or temporary. This short run exercise raises prices in each month while holding households' beliefs about future inclusive-values fixed, so that a household making a discrete-choice in period t behaves as if prices have risen in only t, and not $t+1, t+2, ...$ as well. The long run exercise re-solves beliefs at the new prices, and simulates the panel forward, so that household decisions reflect that prices have risen in every future period as well. I split price increases into razor packs and cartridge packs; each simulation raises the prices of all of a line's razor packs, or all of its cartridge packs, by 1%, and measures changes in quantities in the number of packs sold. Table 8 reports the results for the largest lines in each compatibility family.

There are a few notable patterns. First, in the short run exercise, cartridge elasticities lie between -1.4 and -2.3, and razor elasticities are close to one. This ordering partly reflects market shares; short-run elasticities are effectively static logit elasticities, therefore the own-price elasticity is roughly proportional to own shares, and cartridge packs generally have higher shares than razor packs.

The comparison between the short and long run is more informative since it captures households' forward-looking behavior. Once households can foresee price rises in addition to current prices, households may be less willing to delay purchases leading to lower elasticities, or they may substitute to the outside option entirely since they perceive the change as a more permanent price increase. The results show a mix of these two behaviors. For Family

Table 8: Own-Price Elasticities for a 1% Price Increase

	Cartridges		Razors	
Family	Short run	Long run	Short run	Long run
Family D	−2.14	−2.51	−1.15	−1.15
Family M	−2.27	−3.06	−1.17	−1.10
Family P	−1.55	−1.64	−1.30	−1.61
Family R	−2.11	−2.02	−1.01	−1.01
Family T	−1.42	−1.52	−1.11	−1.14

Notes: Counterfactual simulations are compared against a common baseline simulation. Results are presented for the largest line, by baseline volume, of each compatibility family. Changes in quantities are measured in packs.

R, the long-run cartridge elasticity of −2.02 is slightly smaller than the short-run one of −2.11. For Family D it rises from −2.14 to −2.51, and for Family M from −2.27 to −3.06, while those of Families P and T increase a little. The gap is thus largest where the installed base is largest. This may be because Families D and M offer larger varieties compared to Family R, so that households have more within-family products to substitute to. Indeed, the diversion ratios show precisely this pattern in Table 9 below. Razor elasticities, by contrast, barely change between the short and long run for most families, since a razor pack is bought only once. I find that razor packs have elasticities near one while elasticities of cartridge packs are much larger. Therefore, consistent with Hartmann and Nair (2010), this can be interpreted as evidence of the razors-and-blades pricing strategy, where razors are priced on the relatively inelastic region of the demand curve and blades are priced on the relatively elastic region, effectively a strategy which sells cheap razors to build an installed base and generate revenue in the aftermarket.

Table 9 reports diversion ratios from the short-run exercise in a line's cartridges. The diversion ratios to "No purchase" are all larger than 90%, suggesting the majority of lost demand corresponds to households delaying their purchase: since the increase lasts one month, a household that still has cartridges can postpone its purchase until prices return to normal. Among the products households switch to, however, compatibility plays an important role as shown by the fact that most of the substitution goes to other lines in the same family, consistent with the reduced form results presented in Section 4. For instance, for the largest line of Family M the diversion ratio to cartridges of other Family M lines is 0.053, against 0.001 to other families' razors. The same pattern holds for Families D and R. The diversion from the largest line of Family P goes mostly to razors of other Family P lines, though cartridges of other Family P lines capture more diversion than rival razors. Panel B

Table 9: Diversion Ratios of Each Family's Largest Line After a 1% Price Increase in Cartridge Packs

	Other lines, same family		Other families		
Price increase on	Cartridges	Razors	Cartridges	Razors	No purchase
A. Temporary increase (short run)					
Family D cartridges	0.022	0.002	0.000	0.004	0.972
Family M cartridges	0.053	0.003	0.000	0.001	0.942
Family P cartridges	0.011	0.017	0.000	0.008	0.964
Family R cartridges	0.028	0.000	0.000	0.003	0.968
Family T cartridges	0.008	0.001	0.000	0.010	0.981
B. Permanent increase (long run)					
Family D cartridges	−0.122	−0.029	0.213	0.050	0.888
Family M cartridges	−0.181	−0.049	0.168	0.052	1.010
Family P cartridges	−0.018	−0.130	0.720	0.054	0.375
Family R cartridges	0.003	−0.015	0.119	0.056	0.837
Family T cartridges	0.014	−0.366	0.121	0.130	1.102

Notes: Each entry is the diversion ratio from the treated line's cartridge packs to the column's products: the change in their purchases, in cartridges (a razor pack's cartridges included), divided by the decrease in the treated line's, when the treated line's cartridge prices rise by 1%. The treated lines are each listed family's largest line. "Other lines, same family" excludes all of the treated line's own products, including its razor packs. Panel A: the increase lasts one month, with beliefs held fixed. Panel B: the increase is permanent, beliefs are re-solved at the new prices, and the panel is simulated forward so that stocks and handle ownership adjust. "No purchase" is the part of the decline not replaced by any other purchase. A negative entry means the column's purchases fall as well, in which case "No purchase" can exceed one.

shows that once households expect the increase to persist, the diversion moves away from the family: purchases of the family's razors fall, since the family's handle is less valuable to own when the treated line's cartridges will remain more expensive, and other families' razors and cartridges gain. The contrast between the two panels shows why a dynamic model is needed. A static model cannot distinguish a temporary price increase from a permanent one, so it cannot separate households that delay their purchase from those that change what they buy. The contrast also shows why households must be able to replace their base goods. A model in which households choose a base good once and never replace it would miss the long-run shift to other families entirely.

8.2 Compatibility Counterfactuals

The substitution patterns at the line level estimated in the previous section show how compatibility leads consumers to substitute within family. This is suggestive that consumers generally benefit from greater levels of compatibility. As mentioned previously, compat-

ibility, manifested in this market through the connectors between handles and cartridges, shapes demand in two ways. The first is market expansion: a handle that fits more cartridges gives its owner more choices, which makes it more valuable to own and keep using and can draw new buyers to the firm's system. The second is cannibalization: owners can substitute among all the cartridges that fit their handle, so a newly compatible line draws sales from the firm's existing lines. In this section, I examine how counterfactual compatibility regimes would have shaped demand through these two channels.

Within-Firm Compatibility. I first look at the effect of *increasing* within firm compatibility through Families D and M, which are owned by the same firm; I ask what a shared connector would have done to demand for both. Family D provides access to cheaper cartridges for Family M holders, while Family D holders gain access to higher quality cartridges, so that there may be a significant increase in variety for the joint installed base which can be accessed by owning only one handle. On the other hand, the two families' products may cannibalize each others' sales to a greater degree due to this increase in ability to substitute between the two products.

Figure 3 shows the market-expansion channel at work: the combined Family D–M installed base grows at the expense of rival systems, suggesting it steals significantly from rivals. Indeed, Panel A of Table 10 shows that rivals' sales revenue decreases by 71.1% overall. Despite this sharp drop, rivals' losses account for only a small part of the merged family's increase in purchases. Most of its increase is additional tied razor purchasing: households whose handle now fits more cartridges spend more of their months with compatible cartridges in stock rather than stocked out. Family D gains a large increase in sales, likely because Family D's cartridges, which cost considerably less than Family M's as shown in Table 1, are sold only to a shrinking base of Family D handles in the baseline and in the counterfactual are available to every Family M owner.

Panel B of Table 10 helps to better understand this tradeoff. The total change in packs describes the extensive margin; the first three columns measure the total change in packs purchased in the counterfactual. The next three columns describe the intensive margin effects; they measure the total number of cartridges purchased on a per-1000-month basis. These figures show that the cannibalization channel is also present. Family M holders shift toward the cheaper Family D cartridges: in the counterfactual, they buy 228.2 packs of Family D cartridges per 1,000 handle-months, and their purchases of Family M cartridges fall from 83.1 to 67.0 packs, a decrease of 19.4%. Putting these together, the rate at which Family M holders purchase Family M cartridges falls, and the majority of their cartridge purchases have shifted to Family D; Family D is therefore cannibalizing Family M sales.

If cannibalization dominated, purchases would mainly shift from one family to the other, and at least one family would lose sales. Instead, total sales of both families rise. Family M owners buy 2.1% more packs of Family M cartridges in total, because there are more of them, and Family D owners add 3.8 million packs of Family M cartridges, while sales of Family D cartridges rise sharply. Purchases by Family D and M owners rise by 462.5%, so market expansion strongly dominates cannibalization.

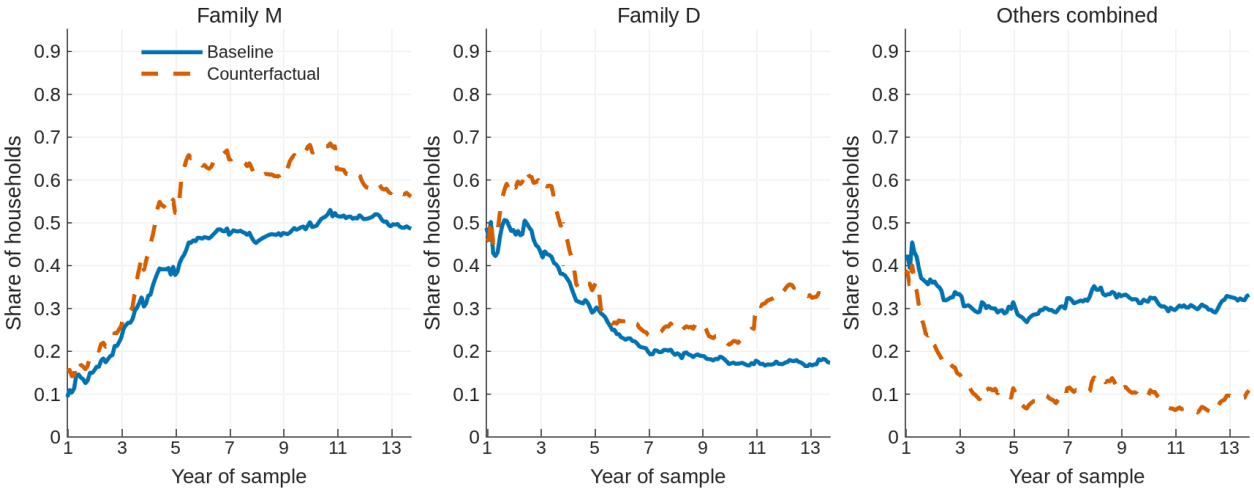
I measure the change in consumer welfare by the projection-weighted average of each household's compensating variation in its first month,

$$CV = \frac{\delta^c_{it_{i0}}(\Omega_{it_{i0}}) - \delta^b_{it_{i0}}(\Omega_{it_{i0}})}{\alpha}, \tag{20}$$

where t_{i0} denotes the market corresponding to household i's first month.[14] Because prices are held fixed, no household is made worse off. Households gain whichever handle they start with, and owners of rival systems gain as well, because the combined system is a better option when they next replace their handle. The mean compensating variation across all households is \$22.72.

These gains in units need not raise the firm's revenue. Because Family M owners shift toward cheaper Family D cartridges, the firm could earn less per cartridge even as unit sales rise, which may help explain why Family M was not released as compatible with Family D.

Figure 3: Installed Base After Compatibility Changes: Families D and M made compatible



Notes: The figure reports the share of projection-weighted household-months by the line of the handle held, in the baseline (solid) and counterfactual (dashed). Households with no handle remain in the denominator but are not plotted. Families other than Families D and M are combined in the last plot.

[14]The long-run impact of a counterfactual must be measured at a particular point in time and I use each household's first month to do so.

Table 10: Family-level effects: Family M and Family D made compatible

	Razor packs		Cartridge packs		Change at baseline-		Revenue ($M)			CV
Family	Baseline	% change	Baseline	% change	empty	stocked	Baseline	Change	% change	($/hh)
A. Effects by family										
Family M	421	118.1	4,562	84.8	3,938	427	88.2	79.9	90.6	22.25
Family D	179	600.1	1,650	1,580.1	25,516	1,625	22.5	243.5	1,082.8	37.94
Others combined	486	−76.0	1,237	−69.3	−1,131	−95	17.0	−12.1	−71.1	–
Total	1,086	110.7	7,448	390.4	28,323	1,957	127.7	311.3	243.7	22.72

B. Decomposition of the change in packs	Packs (000)			Per 1,000 handle-months		
	Baseline	Change	% change	Baseline	Counterf.	% change
Cross-compatible purchases						
Family M handle holders buying Family D cartridges	0	15,869	–	0.0	228.2	–
Family D handle holders buying Family M cartridges	0	3,772	–	0.0	85.9	–
	0	19,641	–	0.0	173.1	–
Families D and M, total						
Family M handle holders buying Family M cartridges	4,562	95	2.1	83.1	67.0	−19.4
Family D handle holders buying Family D cartridges	1,650	10,199	618.2	52.1	270.0	418.1
Family D and M razor packs	600	1,571	261.7	4.7	17.0	261.7
	6,812	31,506	462.5	78.7	337.8	329.1
Rival families	1,722	−1,226	−71.2	41.7	34.4	−17.4
Total	8,534	30,280	354.8	66.8	303.6	354.8

Notes: Razor and cartridge packs are in thousands of 4-pack equivalents. The changes at baseline-empty and baseline-stocked observations split the change in total packs by whether the observation (household-month) corresponds to an out-of-stock month in the baseline. In Panel B, each purchase is classified by the handle the household holds at the start of the month of purchase, on the baseline and in the counterfactual separately. Each un-labelled row below a rule is a subtotal. Per 1,000 handle-months divides each row's 4-pack equivalents by the projection-weighted household-months holding the corresponding handle on that simulation: Family M handles for rows of Family M handle holders, Family D handles for rows of Family D handle holders, either for the two subtotals, any other handle or none for rival families, and all household-months for razor packs and the Total.

Compatibility among more similar products. The previous exercise shows that connecting Families D and M increases their combined demand by giving handle owners access to cartridges at different price and quality levels. I therefore ask whether making similar lines compatible also expands demand by more than it cannibalizes sales between them. Separating these products could lead to relatively lower cannibalization, but it also affects the variety of cartridge choices available to each handle owner less than in the previous exercise.

To do this, I consider the effect of removing Line M-2 from the rest of Family M, since Line M-2 is significantly less differentiated from the rest of Family M than any product in Family D. In this case, Line M-2 handles can no longer fit the other Family M lines' cartridges, and the other Family M handles can no longer use Line M-2's, so both parts of the former family become less valuable to own. Table 11 shows that both lose sales. The remaining Family M loses 11.2% overall or 3.6% on a per-month basis, while Line M-2 loses 49.7% overall or 8.9% on a per-month basis. Razor pack sales of both lose a combined 27.7% since each handle is now less valuable to own.

Figure 4 shows the evolution of the Family M and split-Line M-2 installed base. To make clear the difference between the two, Line M-2 is plotted separately from the remaining

Family M. The loss is largest for Line M-2, whose share of handle ownership roughly halves. Interestingly, Line M-2 seems to have been responsible for a majority of Family M's growth after its launch, as revealed in both the baseline and counterfactual installed base time series for Family M. Rival systems recover only a small part of the lost purchases with a 16.2% increase in their sales; most of the loss is a decrease in the total demand. In fact, on a per-month basis rivals are purchased 0.2% less, reflecting the 22.8% decrease in total demand.

The extent of cannibalization depends on the relative price of cartridges that fit the same handle, as Table 12 shows. Family D cartridges are much cheaper than Family M cartridges, with a price per cartridge 0.68 times that of Family M, whereas Line M-2 cartridges are priced close to those of the rest of Family M, with a relative price of 1.09. To test whether this difference drives the results, I rerun the Line M-2 counterfactual while varying the price of all Line M-2 packs, and compare purchases when the two parts of the family are compatible with purchases when they are not, at the same prices. When Line M-2 is priced at 0.6 times its observed level, its relative price of 0.65 is close to that of Family D, and the two experiments give results in the same direction: Family M owners buy fewer of their own cartridges when the products are compatible, 19.1% fewer when Families D and M are compatible and 1.8% fewer when Line M-2 is compatible with the rest of Family M. At observed prices, owners of both handles buy more of their own cartridges under compatibility, 2.2% and 7.6% more. At 1.4 times its observed level, the direction reverses: owners of other Family M handles buy 2.6% more of their own cartridges under compatibility, while owners of Line M-2 handles buy 4.3% fewer Line M-2 cartridges, as some switch to the now cheaper cartridges of the rest of Family M. Cannibalization therefore falls on whichever line is more expensive.

Together, the two exercises show that, at fixed prices, making a firm's products compatible raises demand for them by more than it cannibalizes sales between them. This holds both when the products differ substantially in price and quality, as Families D and M do, and when they are similarly priced, as Line M-2 and the rest of Family M are. In both cases, the gain comes mainly from handle ownership: a handle that fits more cartridges is more valuable to own, so more households buy and keep one. Cannibalization arises mainly when compatible cartridges differ substantially in price, and it falls on the more expensive line. Demand-side cannibalization is therefore unlikely to explain why firms keep their products incompatible; such decisions more likely reflect pricing, entry, or strategic motives, which are outside the scope of this analysis.

Figure 4: Installed base by handle, remove Line M-2 from Family M.

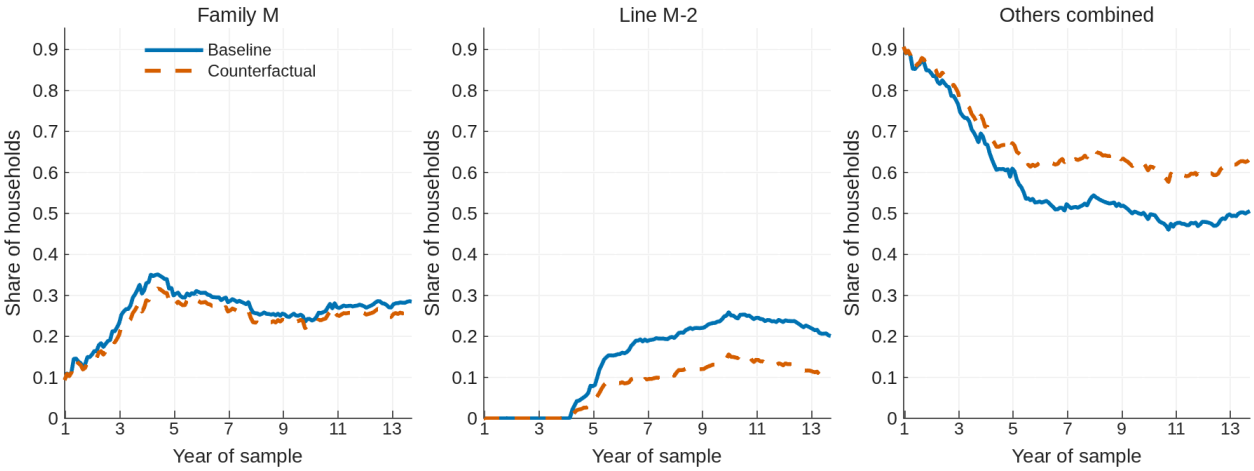


Table 11: Family-level effects: Line M-2 split from Family M

	Razor packs		Cartridge packs		Change at baseline-		Revenue ($M)			CV
Family	Baseline	% change	Baseline	% change	empty	stocked	Baseline	Change	% change	($/hh)
A. Effects by family										
Family M	240	−13.8	2,824	−36.6	−983	−82	52.2	−17.5	−33.6	−3.28
Line M-2	181	−46.2	1,738	−79.2	−1,324	−136	36.1	−26.4	−73.3	−9.53
Others combined	664	23.7	2,887	14.5	506	70	39.5	6.4	16.3	–
Total	1,086	3.7	7,448	−26.7	−1,802	−148	127.7	−37.5	−29.4	−1.76

B. Decomposition of the change in packs	Packs (000)			Per 1,000 handle-months		
	Baseline	Change	% change	Baseline	Counterf.	% change
Cross-compatible purchases						
Family M handle holders buying Line M-2 cartridges	1,019	−1,019	−100.0	29.8	0.0	−100.0
Line M-2 handle holders buying Family M cartridges	806	−806	−100.0	38.9	0.0	−100.0
	1,824	−1,824	−100.0	33.2	0.0	−100.0
Family M and Line M-2, total						
Family M handle holders buying Family M cartridges	2,018	−227	−11.2	59.1	57.0	−3.6
Line M-2 handle holders buying Line M-2 cartridges	719	−357	−49.7	34.7	31.6	−8.9
Family M and Line M-2 razor packs	421	−117	−27.7	3.3	2.4	−27.7
	4,983	−2,525	−50.7	90.8	57.3	−36.9
Rival families	3,551	576	16.2	48.7	48.6	−0.2
Total	8,534	−1,949	−22.8	66.8	51.5	−22.8

Notes: Razor and cartridge packs are in thousands of 4-pack equivalents. The changes at baseline-empty and baseline-stocked observations split the change in total packs by whether the observation (household-month) corresponds to an out-of-stock month in the baseline. Family M excludes Line M-2 throughout. In Panel B, each purchase is classified by the handle the household holds at the start of the month of purchase, on the baseline and in the counterfactual separately. Each un-labelled row below a rule is a subtotal. Per 1,000 handle-months divides each row's 4-pack equivalents by the projection-weighted household-months holding the corresponding handle on that simulation: Family M handles for rows of Family M handle holders, Line M-2 handles for rows of Line M-2 handle holders, either for the two subtotals, any other handle or none for rival families, and all household-months for razor packs and the Total.

Table 12: Cannibalization and the Relative Price of Compatible Cartridges

	Relative price	Own-line purchases (% change)	
		Family M holders	Other holders
Families D and M compatible	0.68	−19.1	435.3
Line M-2 compatible, priced at			
0.6 × observed	0.65	−1.8	20.8
0.8 × observed	0.87	1.2	14.4
1.0 × observed	1.09	2.2	7.6
1.2 × observed	1.30	2.5	1.4
1.4 × observed	1.52	2.6	−4.3

Notes: California and Florida, 2007–2019, forward simulated. Each entry compares purchases when the two sets of products are compatible with purchases when they are not, at the same prices: the percentage change in the 4-pack equivalents of cartridges of their own family or line bought by household-months that hold the same handle in both simulations. In the first row, the compatible case is the counterfactual and other holders hold a Family D handle; in the remaining rows, the compatible case is the baseline at the stated Line M-2 cartridge price, the incompatible case is the split at the same price, Family M excludes Line M-2, and other holders hold a Line M-2 handle. The relative price is the average price per cartridge of the other holders' cartridges divided by that of Family M's (including Line M-2 in the first row, excluding it in the others), each weighted by its observed purchases.

9 Conclusion

This paper studies how compatibility restrictions shape demand in the market for razors and replacement cartridges. Compatibility affects demand through two channels. First, it can expand the market: a handle that fits more cartridge lines is more valuable to own, attracting households from rival systems and making the existing owners less likely to switch away. Second, it can intensify cannibalization: compatible lines compete for the same owners' purchases, so a new line can take sales away from existing lines. The descriptive evidence shows that compatibility shapes both adoption and substitution. For example, when Line M-2 was introduced with cartridges that fit existing handles, households that owned a compatible handle were 39 percentage points more likely to adopt it, and three quarters of this gap came from owners who initially bought cartridges alone. Within a family, households shift purchases toward cartridges from other compatible lines when their own line becomes more expensive.

To measure the balance between these two channels, I estimate a dynamic model in which households choose each month whether to buy a razor pack, a cartridge pack, or nothing, and form expectations about future product offerings through inclusive values. I estimate the model with a nested fixed-point algorithm and use it to simulate demand under

alternative price and compatibility scenarios. The price counterfactuals show that when a line's cartridges become more expensive temporarily, most purchases that switch go to another line that fits the same handle rather than to a rival family, as in the reduced-form evidence. When the increase is permanent, households instead shift away from the family, as its handle becomes less attractive and fewer households buy or keep one. The compatibility counterfactuals, which hold prices fixed, show that compatibility within a firm expands demand for the affected lines by more than it cannibalizes sales between them. Making Families D and M compatible, for example, draws households from rival systems and leads existing owners to buy more cartridges, which outweighs the sales Family M loses to the cheaper Family D cartridges. The experiments separating Line M-2 from Family M show that this result does not depend on how differentiated products are. These experiments remove the competition between two similar sets of products, yet demand is still lower for both.

These results have two implications. First, for firms, making more cartridges fit a handle makes it more attractive and raises the number of households that own it, and this gain is large relative to the sales lost to cannibalization. Cannibalization alone therefore does not explain why firms sell several incompatible families, which suggests that these decisions reflect pricing or strategic considerations. Second, for policies that encourage firms to make more compatible products, the results suggest that expansion effects are substantial, and existing consumers stand to benefit through more frequent consumption, and the overall market also expands through new consumers' purchases.

The analysis also has limitations. First, it takes prices as given: the counterfactuals measure how demand responds to a new choice set at existing prices, rather than at the prices firms would choose under the new arrangement. It also takes the timing of product introductions as given. In the razor market, firms commonly introduce a new family well before the connector on an existing family loses patent protection. Keurig, a maker of single-serve coffee brewers, offers a contrasting case: after the patents on its pod design expired, it introduced a brewer designed to reject unlicensed pods, but the new system did not restore control over the interface. Understanding these considerations, including why firms introduce new families while existing connectors are still protected and how they set prices around these launches, requires modeling firms' entry, compatibility, and pricing decisions. Developing this supply-side model is my ongoing work.

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A Household Panel: Sample Construction

This appendix describes the treatment of inactive periods and reports household demographics for the final sample.

Inactive periods. I classify a household as active in a given month if it makes at least one purchase of any product recorded in the panel, and as inactive otherwise. An inactivity spell is a run of more than two consecutive inactive months. Households that never have such a spell are retained in full. For households that do, I retain observations from active purchasing periods and exclude the subsequent spell of prolonged inactivity. During such spells the household records no purchases in any category, so the absence of razor or cartridge purchases is uninformative about its shaving choices and more likely reflects purchases that went unrecorded than a decision not to buy.

Household demographics. Table A.1 reports the demographic composition of the final sample.

Table A.1: Household Demographics

Age of male head		Education of male head	
Under 35	2.3	High school or less	30.9
35–44	11.9	Some college	29.1
45–54	18.5	College graduate	27.5
55–64	26.7	Post-graduate	12.5
65 and over	40.7		
Household income		Race	
Under $30,000	13.9	White	87.8
$30,000–59,999	33.7	Black	5.9
$60,000–99,999	32.2	Asian	2.4
$100,000 and over	20.1	Other	3.9

Notes: Percentages of the 6,053 households in the final sample, measured in each household's most recent panel year. Source: NielsenIQ Homescan Consumer Panel.

B Cartridge Purchases Without an Observed Handle

I treat a cartridge purchase as evidence that the household already owns a compatible handle. The alternative is that the household buys cartridges in anticipation of a handle it has not yet purchased. If this were common, cartridge purchases made before any compatible handle is observed would typically be followed, within a short period, by a razor-pack purchase from the same family.

Table B.1 shows that they are not. The unit of observation is a cartridge purchase made at any point in the household's panel history, including the burn-in period, without a previously observed razor pack from the same family. Of these purchases, 85.4% are never followed by a razor-pack purchase from that family during the sample. Among the 14.6% that are, the median time to the razor-pack purchase is 22 months and the mean is 32 months. Delays of this length are hard to reconcile with anticipatory purchasing. They are more consistent with a handle acquired before the household entered the panel or through a purchase not recorded in the panel.

If households bought cartridges in anticipation of a handle, these purchases should also be concentrated in periods when cartridges are on sale. They are not: 14.0% of these cartridge purchases are made on sale, compared with 18.8% of all cartridge purchases in the sample.

Anticipation or a mistaken purchase is most plausible when a cartridge purchase is followed by a matching razor pack within one month. This occurs for 732 of 109,059 cartridge purchases.

Table B.1: Razor-Pack Purchases Following a Cartridge Purchase Without an Observed Handle

Panel A. Later purchase of a matching razor pack		
	Cartridge purchases	Share (%)
No	63,777	85.4
Yes	10,915	14.6
Total	74,692	100.0
Panel B. Months to matching razor pack (10,915 purchases)		
Mean	32.0	
Median	22	
Interquartile range	[8, 46]	
Panel C. Share bought on sale (%)		
Cartridge purchases without an observed handle	14.0	
All cartridge purchases	18.8	

Notes: The unit of observation is a cartridge purchase made without a previously observed razor pack from the same product family. Purchases from the full panel history, including the burn-in period, are included. Panel A reports whether the purchase is followed by a razor-pack purchase from the same family during the sample. Panel B reports the time to that razor-pack purchase, in months, among purchases with a later matching razor-pack purchase. Panel C reports the share of purchases recorded as bought on sale.

C Scanner Data: Construction of Market Shares

Aggregation. The NielsenIQ Retail Scanner data report weekly unit sales and prices by store and UPC. I aggregate UPCs to products (product type, product line and pack size) and store–weeks to state–months. Units are summed; the price of a product in a market is the unit-weighted mean price across stores and weeks, deflated to 2019 dollars.

Store coverage. The scanner data cover a subset of stores, so unit sales understate total sales. For each market m and year y, I compute the ratio of total purchases of tied-razor products by all panel households, weighted by projection factors, to total units recorded in the scanner data,

$$M_{my} = \frac{Q_{my}^{\text{panel}}}{Q_{my}^{\text{scanner}}}. \tag{21}$$

Because M_{my} is noisy in market–years with few panel purchases, I smooth it by regressing $\log M_{my}$ on market and year fixed effects, weighting by the number of purchasing panel households, and use the fitted value. Store coverage is $\kappa_{my} = \min\{1/\widehat{M}_{my},\, 1\}$.

Sample households. Scanner sales include purchases by all households, whereas the market size counts only households that have one male of shaving age. I therefore scale scanner units by ϕ_{my}, the share of projection-weighted panel purchases in market m and year y made by one-adult-male households. The market share of product j in market m and month t is

$$s_{jmt} = \frac{q_{jmt}\,\phi_{my}/\kappa_{my}}{H_{my}}, \tag{22}$$

where q_{jmt} is scanner unit sales in packs and H_{my} is the sum of projection factors of sample households.

D Cartridge Stock When Households Switch Families

The model assumes that a household discards its cartridge stock when it buys a razor pack from a different family. Table D.1 examines how much stock this assumption affects. Panel A compares razor pack purchases within the household's family with purchases that change its family. Households that switch families are much more likely to hold no cartridges at the time of purchase, 70.4% compared with 47.4%, and hold less stock on average. Panel B reports the purchases that require stock to be discarded. They account for 14.9% of razor pack purchases, and the median household in this group discards 2.17 cartridges. The distribution has a long right tail: at the 95th percentile, a household discards 19.1 cartridges. The assumption therefore affects a minority of purchases, and in most of them the amount discarded is small.

Table D.1: Cartridge Stock at Razor Pack Purchases

	Within family	Change of family
A. Stock held at purchase		
Razor pack purchases	3,014	2,673
Share holding no stock	0.474	0.704
Mean stock (cartridges)	3.74	1.69
Mean stock (months of consumption)	16.4	8.8
B. Purchases requiring stock to be discarded		
Number of purchases	846	
Share of razor pack purchases	0.149	
Median stock discarded (cartridges)	2.17	
75th percentile	6.08	
95th percentile	19.1	

Notes: Razor pack purchases by households with an observed handle. Stock is the household's cartridge inventory at the time of purchase, constructed as described in Section 3. Months of consumption divides stock by the household's cartridge consumption rate. A purchase requires stock to be discarded if the family purchased is different from the held family. Panel B statistics are computed over purchases that require discarding; the share is relative to all 5,687 razor pack purchases.