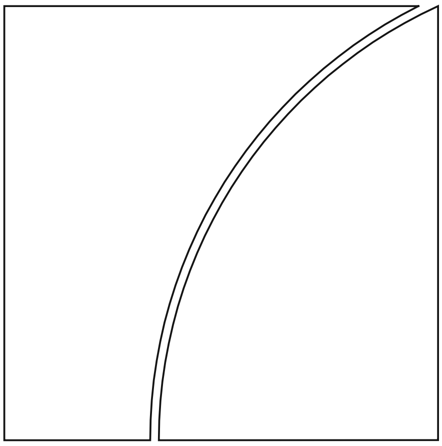

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Imitation and the diffusion of innovation

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Abstract

Why would a market leader choose not to patent an innovation? We study Samsung's decision to forgo patent protection for dual SIM technology in the Indian mobile handset market. Using a structural model of demand and supply estimated on quarterly product-level data from the Indian mobile handset industry, we document that rival firms' dual SIM products generated a *preference discovery externality.* Rival firms' widespread adoption of the dual SIM technology allowed consumers to discover the value of the technology, also benefiting Samsung itself. Counterfactual simulations show that a patent would have suppressed this externality, reducing Samsung's equilibrium profits despite holding monopoly rights. Voluntary non-patenting was therefore privately optimal. Our findings shed light on wider debates about open-sourcing in software and other markets.

Keywords: innovation, patenting, telecom, preference discovery

JEL codes: L13, O33, O34, L63

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[†] Bank for International Settlements. Email: vatsala.shreeti@bis.org. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank for International Settlements. We thank Jon Frost, participants at the 23rd ZEW conference on ICT and at APIOC Seoul for comments.

1 Introduction

When a firm develops a new technology, it must decide whether to protect it from rivals or allow it to diffuse freely through the market. This decision is central to many contemporary debates in technology policy and industrial organization. The rise of open-source artificial intelligence models, such as Meta's LLaMA, alongside proprietary alternatives like OpenAI's GPT series, has reignited longstanding debates about the strategic value of openness versus protection (Arrow, 1962; Scotchmer, 1991; Boldrin and Levine, 2008). Similar tensions arise in pharmaceuticals, where firms choose between patenting and allowing generic entry (Williams, 2013; Chaudhuri et al., 2006), in software, where open-source and proprietary licenses coexist (Lerner and Tirole, 2002) and in standard-setting, where firms may voluntarily share essential patents (Shapiro, 2000). Despite its prevalence, the question of when and why it can be *profitable* for an innovator to forgo protection of its innovation remains empirically underexplored.

In this paper, we propose and quantify a mechanism—*preference discovery*—that can rationalize an innovator's decision to allow imitation by its competitors. The core idea is that when competitors adopt a new technology, they introduce it to consumer segments and price points that the innovator may not serve directly. This expanded product variety generates information about the technology's value: consumers who would never have encountered the innovation through the innovator alone learn about it through imitators' products. Willingness to pay for the innovation increases as a result, ultimately expanding the market in ways that benefit the innovator. Preference discovery is distinct from, and complementary to, other explanations for tolerating imitation, such as costly enforcement (Lanjouw and Schankerman, 2001), network effects (Katz and Shapiro, 1985), or deterring entry into adjacent markets (Gallini, 1984).

We study this mechanism empirically in the context of the Indian mobile handset market, focusing on the introduction of dual subscriber identity module (SIM) functionality—a product feature that allows consumers to use two different telecommunications operators on a single device. Samsung introduced the first dual SIM handset in India in 2007. Shortly after, dozens of competing firms, including small Indian brands with no

R&D capability, rapidly adopted the feature with no intellectual property disputes. By 2016, 44 out of 46 companies in the Indian market offered dual-SIM phones, and these devices accounted for 94% of handset sales by volume. Despite holding patents related to dual-SIM technology, Samsung chose not to enforce them, a decision that our analysis rationalizes through the preference discovery mechanism.

This setting is well-suited for studying the role of preference discovery and market expansion following an innovation for several reasons. First, dual SIM technology is a discrete, observable product characteristic, which makes it straightforward to track adoption across firms and time. Second, the market features a large number of heterogeneous firms, ranging from multinationals with substantial R&D to local brands that began as resellers of unbranded Chinese handsets, providing rich variation in the timing and extent of adoption. Third, the rapid and widespread adoption of the technology by competitors allows us to estimate how imitation shaped consumer preferences over time.

To quantify the effects of imitation, we estimate a structural model of demand and supply for mobile handsets. On the demand side, we estimate a nested logit model (Berry, 1994) with dual SIM and non-dual SIM nests, allowing the mean utility of the dual SIM feature to vary over time through a log-quarter interaction. On the supply side, we model firm behavior as a two-stage game: firms first decide whether to offer products with the dual SIM technology, and then in the second stage, set prices competitively. In the second stage, we model multiproduct Bertrand-Nash pricing with a log-linear marginal cost function that also allows dual-SIM production costs to evolve over time. We estimate demand and supply jointly using GMM with BLP-style instruments (Berry et al., 1995), applied to quarterly product-level data from the International Data Corporation (IDC) covering 15,397 product-quarter observations between 2007 and 2016.

Our structural estimates deliver three key findings. First, consumer willingness to pay (WTP) for dual-SIM was significantly negative at the start of the sample (−$74 in 2007) and crossed into positive territory around 2011 (at 95% confidence interval between 2010Q3–2011Q3). The crossover coincides with the period in which imitators' products reached majority market share, consistent with preference discovery. Second, the marginal cost premium for dual SIM production fell by 47% over the sample, from a 63% cost premium above non-dual SIM phones in 2007 to 14% *below* non-dual SIM costs by 2016, consistent with learning-by-doing and scale economies enabled by broad market adoption. Third, the preference discovery externality, the portion of WTP growth attributable to imitators' market presence, was large enough that a patent enforcing Samsung's monopoly over dual-SIM would have *reduced* the rate at which consumer preferences evolved, leaving Samsung worse off despite its monopoly position.

These findings contribute to several literatures. We contribute to the economics of innovation and intellectual property (Scotchmer, 1991; Boldrin and Levine, 2008; Williams, 2013) by providing, to our knowledge, the first structural estimate of a preference discovery externality that rationalizes voluntary non-patenting. We contribute to the empirical industrial organization literature on demand estimation (Berry, 1994; Berry et al., 1995; Nevo, 2001) by demonstrating how a time-varying product feature coefficient can identify the evolution of consumer preferences for a new technology. We also contribute to the literature on technology diffusion in emerging markets (Chaudhuri et al., 2006) by documenting the mechanism through which low-cost imitators can accelerate the adoption of an innovation by expanding consumer awareness.

The remainder of the paper is organized as follows. Section 2 describes the data and institutional setting. Section 3 presents the structural model. Section 4 discusses estimation. Section 5 reports the results. Section 6 presents counterfactual simulations. Section 7 concludes.

2 Data and Institutional Setting

2.1 Data Sources

We use quarterly product-level data from the International Data Corporation (IDC) covering the Indian mobile handset market from 2007Q1 to 2016Q4. Each observation is a handset model-quarter pair. A model is defined by its brand, screen size, operating system, communication technology (2G, 2.5G, 3G, or 4G), camera megapixels, dual-SIM functionality, memory capacity and hardware type (full touchscreen or not). For each model-quarter, we observe unit sales and average selling price. We convert all prices to constant 2010 US dollars using the IMF consumer price index series for India and a fixed exchange rate of 45.73 INR/USD. The raw dataset contains 24,681 product-quarter observations across 83 firms and 40 quarterly markets. To reduce noise from very small niche products that contribute little to identification, we drop observations with market shares below 0.01%, yielding a final estimation sample of 15,397 product-quarter observations across 74 firms.

2.2 Summary Statistics

Table 1 reports summary statistics for the estimation sample. The average handset price is \$80, with substantial dispersion (standard deviation \$108) reflecting the coexistence of budget feature phones priced under \$10 and premium smartphones exceeding \$1,000. Feature phones constitute 71% of product-quarter observations but this share declines from 89% in 2007 to 51% in 2016, mirroring the smartphone transition. Dual SIM products account for 71% of observations overall but this masks dramatic time variation: from less than 1% in 2007 to 97% by 2016.

Table 1: Summary statistics — estimation sample

Variable	Mean	Median	SD	Min	Max
Price (2010 USD)	79.7	40.9	108.1	5.9	1,066
Market share (%)	0.099	0.042	0.194	0.010	4.82
Screen size (inches)	2.48	2.00	1.50	0	6.50
Dual SIM (%)	70.6				
Feature phone (%)	71.2				
3G capable (%)	19.9				
4G capable (%)	6.2				
Products per quarter	385	406	114	116	551
Firms per quarter	37	39	9	16	45

N = 15,397 product-quarters. Products with market share < 0.01% excluded.

2.3 The Indian Handset Market

India's mobile handset market experienced rapid growth and structural transformation during our sample period. By 2016, 50 brands offered 1,850 distinct models, up from fewer than 20 brands in 2007. The market segments sharply between feature phones that are basic devices capable of voice calls, text messaging, and limited internet browsing and smartphones with touchscreens, app ecosystems and high-speed data connectivity. Average prices declined from $150 in 2007 to $70 by 2016 as competition intensified and manufacturing costs fell.

2.4 Dual SIM Technology and its diffusion

A dual SIM device allows a consumer to maintain two active connections, typically with different telecom operators, on a single handset. This feature is especially valuable in India's competitive telecom market, where consumers routinely optimize across operators' pricing plans for voice, data, and roaming services.

Samsung and Spice simultaneously introduced the first dual-SIM handsets in India in 2007Q3. The technology diffused rapidly: by volume, dual-SIM devices grew from 0.2% of unit sales in 2007 to 94% by 2016 (Table 2). By the end of our sample, 44 of 46 active firms offered dual-SIM products, and only premium devices (notably Apple's iPhone) lacked the feature.

Table 2: Dual-SIM adoption over time

	2007	2009	2011	2013	2015	2016
DS share of products (%)	0.8	16.7	60.0	81.4	93.2	96.9
DS share of unit sales (%)	0.2	8.2	48.7	78.7	89.7	94.2
Firms offering DS	2	7	20	36	41	44
Total active firms	16	29	36	41	43	44

Two features of this diffusion pattern are central to our analysis. First, dual SIM devices were consistently cheaper than non-dual-SIM devices because the premium segment of the market (e.g., Apple, high-end Samsung) was slow to adopt the feature. The technology was largely targeted at price-sensitive consumers who optimize across operators' plans. Second, the firms that drove adoption were predominantly small Indian brands (Micromax, Karbonn, Lava, Intex, Spice), many of which began as importers of unbranded Chinese handsets and invested little in R&D. Samsung, by contrast, is a vertically integrated original equipment manufacturer with substantial global patent holdings related to dual SIM technology. Despite holding these patents, Samsung did not enforce them in India, creating the natural experiment that motivates our analysis.

2.5 Samsung as the innovator

Although Samsung and Spice introduced dual SIM handsets simultaneously, we view Samsung as the innovator for several reasons. First, Samsung is an original design manufacturer with global R&D investments, whereas Spice and other Indian firms primarily imported and rebranded devices. Second, Samsung holds registered patents related to dual SIM implementation in multiple jurisdictions, including in the United States, South Korea and the European Union. These patents cover key aspects of dual SIM operation such as dual SIM dual-standby (DSDS) management, SIM card selection interfaces, and power management for multi-SIM devices (e.g., US 8,463,279; US 8,755,803). Notably, Samsung filed and obtained dual SIM patents in these jurisdictions but did not file analogous patents in India, where the core dual SIM concept was implemented using widely available MediaTek chipsets. A search of Google Patents and the Indian Patent Office database reveals no dual SIM patents held by Samsung in India, nor by Indian firms such as Spice, Micromax, or Karbonn during our sample period. This asymmetry, patenting abroad but not in India, is consistent with a strategic decision to permit imitation in the Indian market. Samsung's dual SIM phones were on average two to four times more expensive than those of Indian competitors (Table 3), consistent with the difference between quality differentiation by an innovator versus price competition by imitators.

Table 3: Average price of dual SIM (DS) phones: Samsung vs. Indian firms (2010 USD)

Year	Samsung	Indian firms
2007	\$272	\$304
2008	\$325	\$136
2009	\$239	\$87
2010	\$160	\$64
2011	\$73	\$44
2012	\$69	\$33
2013	\$67	\$40
2014	\$65	\$35
2015	\$73	\$44
2016	\$113	\$27

Indian firms: Micromax, Spice, Karbonn, Lava, Intex, Onida, Meridian, Maxx.

3 Model

This section presents a structural model of demand and supply that allows us to recover (i) the evolution of consumer preferences for dual SIM technology, (ii) marginal costs and their trajectory, and (iii) the fixed costs of offering dual SIM products.

3.1 Demand

We model the demand for mobile handsets using a discrete choice framework (Berry, 1994; Nevo, 2001). A market is defined as a quarter $t \in \{1, \dots, 40\}$ spanning 2007Q1–2016Q4. Each consumer i chooses among J_t handsets or an outside option (not purchasing). Consumer i's indirect utility from purchasing handset j produced by firm f in quarter t is

$$u_{ijt} = \beta x_{jt} + \alpha p_{jt} + \Big(\theta_1 + \theta_2 \ln t\Big) \mathbb{1}_{\mathrm{DS},j} + \lambda_f + \lambda_t + \xi_{jt} + \epsilon_{ijt}, \tag{1}$$

where x_{jt} is a vector of observed characteristics (screen size, feature phone indicator, 3G/4G generation, and network coverage interacted with generation), p_{jt} is the real price in 2010 USD, λ_f and λ_t are firm and year fixed effects, ξ_{jt} is an unobserved product-level demand shock, and ϵ_{ijt} is an idiosyncratic taste shock distributed Type I extreme value.

The key specification choice is the time-varying dual SIM premium $(\theta_1 + \theta_2 \ln t)\mathbb{1}_{\mathrm{DS},j}$. The parameter θ_1 captures the baseline utility of dual SIM at $t = 1$ (2007Q1), and θ_2

governs how this premium evolves. The preference discovery hypothesis predicts $\theta_1 < 0$ (initial unfamiliarity with the technology) and $\theta_2 > 0$ (preferences grow as market exposure accumulates). The log-quarter functional form implies concave preference growth, consistent with a learning process that exhibits diminishing returns. The crossover quarter at which WTP turns positive is $t^* = e^{-\theta_1/\theta_2}$.

We adopt a nested logit structure (Berry, 1994) with two nests: dual SIM ($g = 1$) and non-dual SIM ($g = 0$) to capture the empirically important pattern that consumers substitute more readily within technology categories than across them. This yields the estimating equation

$$\ln s_{jt} - \ln s_{0t} = \beta x_{jt} + \alpha\, p_{jt} + \Big(\theta_1 + \theta_2 \ln t\Big) \mathbb{1}_{\text{DS},j} + \rho \ln \tilde{s}_{j|g,t} + \lambda_f + \lambda_t + \xi_{jt}, \qquad (2)$$

where s_{0t} is the outside-option share, $\tilde{s}_{j|g,t} \equiv s_{jt}/S_{g,t}$ is product j's share within its nest, and $\rho \in (0, 1)$ is the nesting parameter. When $\rho = 0$ the model reduces to standard logit; as $\rho \to 1$, within-nest products become perfect substitutes.

3.2 Supply

We model the supply side as a two-stage game. In the second (pricing) stage, firms set prices simultaneously given their product portfolios. In the first (product choice) stage, firms decide which products to offer with dual-SIM functionality, anticipating the pricing equilibrium.

3.2.1 Pricing

Each multiproduct firm f chooses prices for its product set $\mathcal{J}_{ft}$ to maximize variable profits under Bertrand-Nash competition:

$$\max_{\{p_j\}_{j\in\mathcal{J}_f}} \sum_{j\in\mathcal{J}_f} (p_j - c_j) \cdot s_j(\mathbf{p}).$$

The first-order conditions yield the standard markup equation:

$$\mathbf{c} = \mathbf{p}^* - \Big(\Omega \odot \Delta(\mathbf{p}^*)\Big)^{-1} \mathbf{s}(\mathbf{p}^*), \tag{3}$$

where Ω is the ownership matrix ($\Omega_{jk} = 1$ if products j and k are produced by the same firm) and Δ is the matrix of demand derivatives $\partial s_j / \partial p_k$. Under the nested logit, the own-price derivative is

$$\frac{\partial s_j}{\partial p_j} = \alpha\, s_j \left(\frac{1}{1-\rho} - \frac{\rho}{1-\rho} \tilde{s}_{j|g} - s_j \right),$$

which depends on α and ρ nonlinearly, linking the demand and supply sides of the model.

3.2.2 Marginal Cost

We parameterize the marginal cost function in logs to ensure positivity:

$$\ln c_{jt} = \beta^c x_{jt} + (\gamma_1 + \gamma_2 \ln t)\, \mathbb{1}_{\text{DS},j} + \kappa_f + \kappa_t + \omega_{jt}, \tag{4}$$

where x_{jt} includes the same product characteristics as in the demand equation, κ_f and κ_t are firm and year fixed effects, and ω_{jt} is the structural supply-side error. The parameters (γ_1, γ_2) are of central interest: $\gamma_1 > 0$ implies that dual SIM components carry a cost premium, and $\gamma_2 < 0$ implies that this premium declines over time through learning-by-doing or scale economies. The multiplicative cost premium at quarter t is $\exp(\gamma_1 + \gamma_2 \ln t)$.

3.2.3 Product choice and fixed costs

Introducing dual SIM functionality in a handset involves a fixed cost F^{DS}_{jft} that is observed by the firm but not by the econometrician. A firm will include dual SIM in product j if and only if the incremental variable profit exceeds this fixed cost. This revealed preference condition yields upper and lower bounds on F^{DS}_{jft} via moment inequalities (Pakes et al, 2015), which we use to characterize the distribution of fixed costs without imposing a parametric assumption on their distribution.

For a product *with* dual SIM, the equilibrium condition implies:

$$F_{jft}^{\text{DS}} \leq E_{\xi,\omega}\Big[\pi_{ft}(\text{with DS}) - \pi_{ft}(\text{without DS})\Big], \tag{5}$$

providing an upper bound. For a product *without* dual-SIM, the analogous condition provides a lower bound. Together, these inequalities identify the distribution of fixed costs without imposing distributional assumptions.

4 Estimation

4.1 Market size and outside option

We define the market size as one-eighth of the total adult working population in a given year. This implicitly assumes that consumers make a purchase decision once every two years, choosing between buying a new device and the outside option of no purchase. We obtain data on the adult working population from the World Bank. Using this, we compute product-level market shares as the ratio of total sales of each product to the market size. Products with market shares below 0.01% are dropped from the sample to reduce noise from very small niche products, yielding a final estimation sample of 15,397 product-quarter observations across 40 markets. The outside option of not purchasing a new handset accounts for approximately 81% of the potential market, implying that 19% of the working-age population purchases a new phone each year.

4.2 Demand moments and instruments

Both price and the within-nest share $\ln \tilde{s}_{j|g,t}$ are endogenous. Prices correlate with the unobserved demand shock ξ_{jt} because firms observe demand conditions when setting prices. Within-nest shares correlate with ξ_{jt} because a product with high unobserved quality mechanically attracts a larger fraction of its nest's sales.

To address price endogeneity we use BLP-style instruments (Berry et al., 1995): for each product, the sum of characteristics of other products sold in the same market.

These instruments shift prices through competitive interactions without entering demand directly. We apply principal component analysis to reduce the nine raw instrument columns to two principal components that capture 98.2% of the instrument variation, mitigating concerns about weak instruments in the presence of many covariates. For instrumenting $\ln \tilde{s}_{j|g,t}$, we follow Berry (1994) and instrument with the log count of other products in the same nest, $\ln(1+n_{-j,g,t})$, where $n_{-j,g,t}$ is the number of competing products in nest g at time t. A larger nest mechanically dilutes each product's within-nest share but is uncorrelated with any individual product's demand shock.

4.3 Joint Demand and Supply Estimation

The structural parameters are estimated jointly using demand and supply moments. On the demand side, the estimating equation (2) provides moment conditions of the form $E[Z_d'\xi_{jt}] = 0$, where Z_d contains the exogenous characteristics and excluded instruments. On the supply side, marginal costs are recovered from the Bertrand-Nash first-order conditions (3), and the log-linear cost equation provides additional moment conditions $E[Z_s'\omega_{jt}] = 0$.

We stack the demand and supply moments into a joint GMM objective:

$$\hat{\boldsymbol{\theta}} = \arg\min_{\boldsymbol{\theta}} \begin{pmatrix} Z_d'\boldsymbol{\xi} \\ Z_s'\boldsymbol{\omega} \end{pmatrix}' \begin{pmatrix} \hat{\Omega}_d & 0 \\ 0 & \hat{\Omega}_s \end{pmatrix}^{-1} \begin{pmatrix} Z_d'\boldsymbol{\xi} \\ Z_s'\boldsymbol{\omega} \end{pmatrix}, \tag{6}$$

where $\hat{\Omega}_d$ and $\hat{\Omega}_s$ are the demand and supply weighting matrices. The price coefficient α and nesting parameter ρ enter the supply-side moments nonlinearly through the markup formula. The remaining demand parameters $(\beta, \theta_1, \theta_2)$ and cost parameters $(\beta^c, \gamma_1, \gamma_2)$ are linear conditional on (α, ρ) and are recovered in closed form via IV-GMM.

Standard errors for the full parameter vector, including α and ρ, are computed using the GMM sandwich formula. For the nonlinear parameters, we construct the Jacobian of the stacked moment conditions numerically via central finite differences; for the linear parameters, the Jacobian is available analytically. The resulting variance-covariance matrix is heteroskedasticity-robust.

4.4 Fixed Cost Estimation

Introducing the dual SIM feature to a handset involves a fixed cost. Each firm observes the realization of the fixed cost associated with adding the dual SIM feature to the set of products it sells. Firms have complete information about the fixed costs of adding the dual SIM feature to their handsets and decide which subset of their products will include it. We also assume that firms know the distribution of marginal cost and demand shocks and can therefore compute the expected profit associated with each possible choice.

A subgame perfect Nash equilibrium implies that given the product choices with dualsim characteristic and pricing decisions of competing firms, a firm does not find it profitable (in expectation over demand and supply) to deviate from its choice of products and prices. These equilibrium decisions lend themselves to moment inequalities, which can allow us to estimate bounds for the fixed costs of each product (Fan and Yang (2020), Eizenberg (2014), Pakes et al (2015), Eisenberg, Estay and Mohapatra (2025)).

For a firm (f) producing a subset of handsets with the dual SIM characteristic, consider a product (j) that includes dual SIM. Conditional on the choices of rival firms, the expected profit from the observed product set (π_{ft}) must weakly exceed the expected profit from a counterfactual product set in which product (j) does not include the dual SIM characteristic $\pi_{ft}^{no,ds}$.

$$\begin{aligned} & E_{\xi,\omega}\pi_{ft}(\mathcal{J}_{ft}, \mathcal{J}_{-ft}, j \text{ with dualsim}) - F_{jft}^{ds} \geq E_{\xi,\omega}\pi'_{ft}(\mathcal{J}_{ft}, \mathcal{J}_{-ft}, , j \text{ no dualsim}) \\ \Longrightarrow\ & F_{jft}^{ds} \leq E_{\xi,\omega}\pi_{ft}(\mathcal{J}_{ft}, \mathcal{J}_{-ft}, j \text{ with dualsim}) - E_{\xi,\omega}\pi'_{ft}(\mathcal{J}_{ft}, \mathcal{J}_{-ft}, , j \text{ no dualsim}) \end{aligned} \tag{7}$$

Inequality 7 provides an upper bound for handsets offered in the market with dual SIM capabilities.

For a firm (f) producing a subset of handsets with the dual SIM characteristic, consider a product (j) that does not have the dual SIM feature. Conditional on the choices of rival firms, the expected profit from the observed product set (π_{ft}) must weakly exceed the expected profit from a counterfactual product set in which product (j) includes the dual SIM characteristic (π'_{ft}).

$$\begin{aligned} E_{\xi,\omega}\pi_{ft}(\mathcal{J}_{ft},\mathcal{J}_{-ft},j \text{ no dualsim}) &\geq E_{\xi,\omega}\pi'_{ft}(\mathcal{J}_{ft},\mathcal{J}_{-ft},j \text{ with dualsim}) - F^{ds}_{jft} \\ \implies F^{ds}_{jft} &\geq E_{\xi,\omega}\pi'_{ft}(\mathcal{J}_{ft},\mathcal{J}_{-ft},j \text{ with dualsim}) - E_{\xi,\omega}\pi_{ft}(\mathcal{J}_{ft},\mathcal{J}_{-ft},j \text{ no dualsim}) \end{aligned} \tag{8}$$

Inequality 8 provides a lower bound for handsets offered in the market with dual SIM capabilities.

Given the demand and supply estimates, we estimate the fixed cost of offering the dual SIM feature using the moment inequality approach of Pakes et al (2015). For each product-quarter observation, we compute the counterfactual Bertrand-Nash equilibrium that would obtain if the product's dual SIM status were switched, holding all rival products fixed. The difference between observed and counterfactual variable profits provides bounds on the unobserved fixed cost F^{DS}_{jft}.

The counterfactual equilibrium requires recomputing market shares and prices under the alternative product configuration. For a product switching from dual SIM to non-dual SIM, the mean utility changes by $-(\hat{\theta}_1 + \hat{\theta}_2 \ln t)$, and the marginal cost changes by removing the dual-SIM cost premium $\exp(\hat{\gamma}_1 + \hat{\gamma}_2 \ln t)$. We then solve for the new Bertrand-Nash pricing equilibrium and compute the resulting variable profit for the firm. The computation is repeated for every product in every quarter, yielding a distribution of fixed cost bounds across the sample.

5 Results

5.1 Demand estimates

Table 4 reports the demand estimates from the joint demand and supply nested logit specification. The mean price coefficient $\hat{\alpha} = -2.528$ is negative and precisely estimated ($t = -12.94$), confirming that consumers dislike higher prices. The nesting parameter $\hat{\rho} = 0.84$ (SE $= 0.015$, $t = 54.4$) is well inside the unit interval, validating the nested logit structure: products within the same dual-SIM nest are substantially closer substitutes than products across nests.

The dual SIM preference coefficients $\hat{\theta}_1$ and $\hat{\theta}_2$ are, respectively, negative and positive, implying that the mean utility premium of dual-SIM handsets evolves as $-1.869 + 0.652 \ln t$. This is negative in early quarters and turns positive at the crossover quarter $\hat{t}^* = e^{1.869/0.652} \approx 17.6$, corresponding to the first quarter of 2011. The result captures a preference discovery dynamic: dual SIM handsets were initially penalised by consumer unfamiliarity relative to established single-SIM devices, but as rival firms introduced competitively priced dual SIM products across market segments, consumers developed a robust preference for the feature. Both coefficients are highly significant.

To interpret the estimates in dollar terms, we compute the willingness to pay (WTP) for the dual SIM feature at each quarter as $\text{WTP}_t = (\hat{\theta}_1 + \hat{\theta}_2 \ln t)/|\hat{\alpha}| \times 100$, where the factor of 100 rescales from the price units used in estimation (hundreds of 2010 USD) to dollars. Table 5 reports the WTP trajectory. At the start of the sample (2007Q1), consumers' WTP for dual SIM is $-\$73.9$ (95% CI: $[-\$108, -\$40]$), reflecting an initial aversion to an unfamiliar technology. By 2011Q1 the WTP is approximately zero ($-\$0.9$, 95% CI: $[-\$4.5, \$2.7]$), and by 2016Q4 it reaches $+\$21.2$ (95% CI: $[\$10.8, \$31.5]$). The crossover date is precisely estimated at 2011.15 (SE $= 0.31$ years; 95% CI: $[2010.5, 2011.8]$), coinciding with the period in which dual SIM handsets achieved majority market share in India.

Among the remaining characteristics, 3G and 4G functionality command the largest premiums ($\hat{\beta}_{3G} = 4.473$, $\hat{\beta}_{4G} = 5.682$), consistent with the value placed on data connectivity over our sample period. Screen size carries a positive premium ($\hat{\beta}_{\text{screen}} = 0.562$), while feature phones are valued less than smartphones ($\hat{\beta}_{\text{fphone}} = -0.939$).

5.2 Marginal cost estimates

Table 6 reports the estimates from the supply equation. The dual SIM cost premium is governed by $\hat{\gamma}_1 = 0.489$ and $\hat{\gamma}_2 = -0.152$. Because the specification is in logs, the multiplicative cost premium at quarter t is $\exp(\hat{\gamma}_1 + \hat{\gamma}_2 \ln t)$. At $t = 1$ (2007Q1) this implies a premium of $e^{0.489} \approx 1.63$, meaning dual SIM marginal costs were approximately 63% above non-dual SIM costs at the outset. By $t = 25$ (2013Q1) the premium falls to

Table 4: Demand estimates — nested logit, joint demand and supply

Variable	Estimate	Std. Error	t-stat
Nonlinear parameters			
Price (α)	-2.528^{***}	0.195	-12.94
Nesting parameter (ρ)	0.840^{***}	0.015	54.44
Linear parameters (conditional on α, ρ)			
Dual SIM (θ_1)	-1.869^{***}	0.445	-4.20
Dual SIM $\times \ln t$ (θ_2)	0.652^{***}	0.154	4.23
Screen size	0.562^{***}	0.021	26.90
Feature phone	-0.939^{***}	0.060	-15.54
3G	4.473^{***}	0.128	34.93
4G	5.682^{***}	0.168	33.89
Firm FEs		Yes (73)	
Year FEs		Yes (9)	
N (product-quarters)		15,397	
Markets (quarters)		40	

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. Robust SEs from GMM sandwich formula.

Price scaled by 100; units are hundreds of 2010 USD. Products with share $< 0.01\%$ dropped.

Crossover quarter: $t^* = e^{|\theta_1|/\theta_2} \approx 17.6$ (2011Q1).

Table 5: Willingness to pay for dual SIM (2010 USD)

Quarter	t	WTP (\$)	SE (\$)	95% CI
2007Q1	1	-73.9	17.6	$[-108.3, \ -39.5]$
2009Q1	9	-17.3	4.5	$[\ -26.1, \ -8.5]$
2010Q1	13	-7.8	2.6	$[\ -12.9, \ -2.7]$
2011Q1	**17**	$\mathbf{-0.9}$	**1.8**	$[\ \mathbf{-4.5}, \ \mathbf{2.7}]$
2012Q1	21	4.6	2.1	$[\ 0.5, \ 8.7]$
2013Q1	25	9.1	2.8	$[\ 3.6, \ 14.5]$
2015Q1	33	16.2	4.2	$[\ 8.0, \ 24.4]$
2016Q4	40	21.2	5.3	$[\ 10.8, \ 31.5]$

WTP $= (\hat{\theta}_1 + \hat{\theta}_2 \ln t)/|\hat{\alpha}| \times 100$. SEs via delta method.

Crossover: $t^* = 17.6 \Rightarrow$ year 2011.15 (SE $= 0.31$; 95% CI: $[2010.5, 2011.8]$).

$\exp(0.489 - 0.152 \times \ln 25) \approx 1.01$—essentially parity with non-dual SIM devices. By $t = 40$ (2016Q4) it reaches $\exp(0.489 - 0.152 \times \ln 40) \approx 0.86$, meaning dual SIM components have become 14% *cheaper* than single SIM equivalents, consistent with large-scale adoption and learning-by-doing in manufacturing. Both parameters carry the expected sign and are statistically significant at the 1% level.

The overall cost decline from 2007 to 2016 represents a 47% reduction in the dual SIM cost multiplier. This trajectory is consistent with the rapid diffusion of dual SIM chipsets from specialised component suppliers (e.g., MediaTek) that lowered unit costs through economies of scale.

Among the other cost determinants, 3G and 4G technology do not significantly increase marginal costs ($\hat{\beta}^c_{4G} = 0.875$, $t = 14.1$), while screen size raises marginal cost ($\hat{\beta}^c_{\text{screen}} = 0.751$) and feature phones have substantially lower marginal costs than smartphones ($\hat{\beta}^c_{\text{fphone}} = -1.199$). The mean implied margin across all products is 6.6%.

Table 6: Marginal cost estimates: supply equation (log-MC)

Variable	Estimate	Std. Error	t-stat
Dual SIM (γ_1)	0.489^{***}	0.167	2.93
Dual SIM $\times \ln t$ (γ_2)	-0.152^{***}	0.054	-2.83
Screen size	0.751^{***}	0.019	39.70
Feature phone	-1.199^{***}	0.044	-27.33
3G	-0.237^{***}	0.062	-3.81
4G	0.875^{***}	0.062	14.07
Coverage	2.275^{***}	0.108	21.04
Firm FEs		Yes (73)	
Year FEs		Yes (9)	
Positive MC (%)		99.2%	
Mean margin		6.6%	

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. Robust SEs from GMM sandwich formula. Dependent variable: $\ln(c_{jt})$. DS cost multiplier: $\exp(\gamma_1 + \gamma_2 \ln t)$.

5.3 Preference discovery and cost decline

Figure 1 summarises the two central findings of the paper. The blue curve plots the estimated willingness to pay for the dual-SIM feature over time, computed as $\text{WTP}_t = (\hat{\theta}_1 + \hat{\theta}_2 \ln t)/|\hat{\alpha}| \times 100$. Consumer WTP was approximately $-\$17$ at the start of 2009, crossed zero in early 2011, and rose to +\$21 by the end of 2016. The red curve plots the dual-SIM cost multiplier $\exp(\hat{\gamma}_1 + \hat{\gamma}_2 \ln t)$, which fell from 1.17 in 2009 to 0.93 by 2016—indicating that dual SIM components went from being a cost premium to a cost *discount* relative to single SIM equivalents. The two trends, rising consumer valuation and falling production costs, jointly explain why dual SIM handsets came to dominate the Indian market.

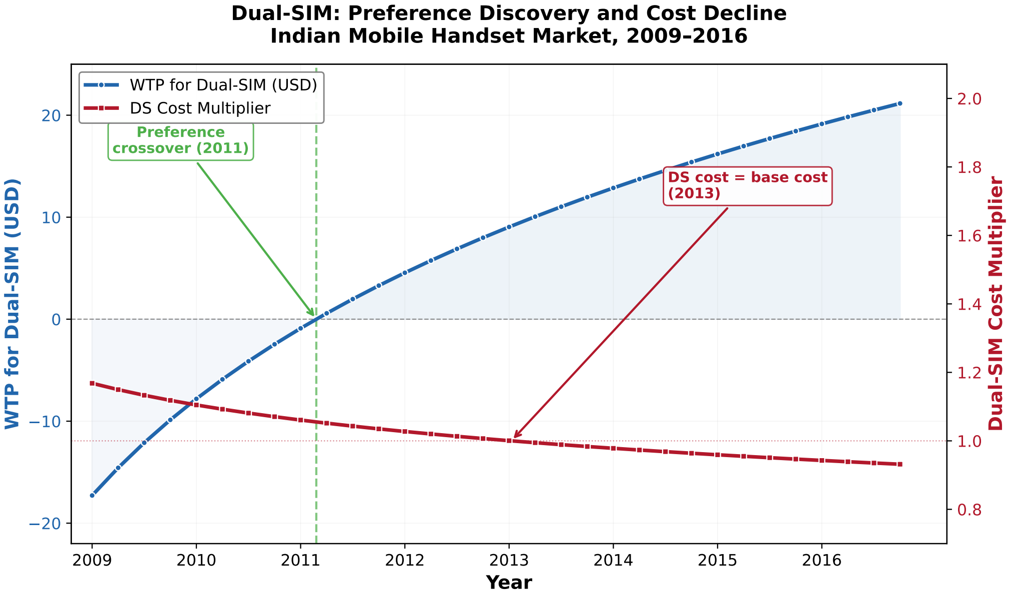


Figure 1: Willingness to pay for dual SIM and dual SIM cost multiplier, 2009–2016. The blue curve (left axis) shows the estimated WTP in 2010 USD. The red curve (right axis) shows the multiplicative cost premium $\exp(\hat{\gamma}_1 + \hat{\gamma}_2 \ln t)$. The green dashed line marks the preference crossover at 2011.

5.4 Firm-level cost heterogeneity

The aggregate cost decline documented above masks important heterogeneity across firms that is central to the preference discovery mechanism. Figure 2 plots the estimated marginal cost advantage of each major dual SIM producer relative to Samsung, computed as the difference between Samsung's average MC and each competitor's average MC for dual SIM products in each year.

We document three patterns. First, Indian firms (Micromax, Karbonn, Spice, Lava, and Intex) enjoyed substantial cost advantages over Samsung throughout the sample, consistent with their business model of importing low-cost chipsets and assembling budget handsets with minimal R&D overhead. At the start of the sample, this advantage exceeded \$200 per handset. Second, the cost advantage narrowed sharply between 2008 and 2011, reaching a minimum around the time of the preference crossover. This convergence reflects Samsung's rapid movement down the cost curve as dual SIM chipsets became commoditized and Samsung scaled its own dual SIM production. Third, after 2011, the cost advantage widened again as Samsung shifted its dual SIM product mix toward higher-end smartphones while Indian firms continued to serve the budget segment.

This U-shaped pattern in relative costs is consistent with the preference discovery narrative. In the early period (2007–2010), imitators' low production costs enabled them to introduce dual SIM products at price points that Samsung could not profitably serve. These low-cost products exposed a broad consumer base to the technology, generating the preference discovery externality that ultimately benefited Samsung. The cost convergence around 2011, precisely when consumer WTP crossed into positive territory, suggests that learning-by-doing and scale economies in dual SIM manufacturing were shared across the industry, consistent with a common upstream technology (e.g., MediaTek chipsets) rather than firm-specific process innovation. The subsequent divergence reflects Samsung's strategic repositioning toward premium dual SIM smartphones, a segment made viable precisely because imitators had established consumer demand for the feature.

5.5 Own-price elasticities

Own-price elasticities in the nested logit model are given by

$$\eta_{jj} = \frac{\alpha\, p_{jt}}{1-\rho}\Big(1 - \rho\, \tilde{s}_{j|g,t} - (1-\rho)\, s_{jt}\Big). \tag{9}$$

The mean own-price elasticity across all products is -12.5 (median -6.4), with the 10th and 90th percentiles at -29.2 and -2.3. Dual SIM products have a mean elasticity of -8.0, while non-dual SIM products average -23.5, reflecting the latter group's smaller market shares and higher price sensitivity. These elasticities are on the higher end of those reported in the mobile handset literature but are consistent with the large number

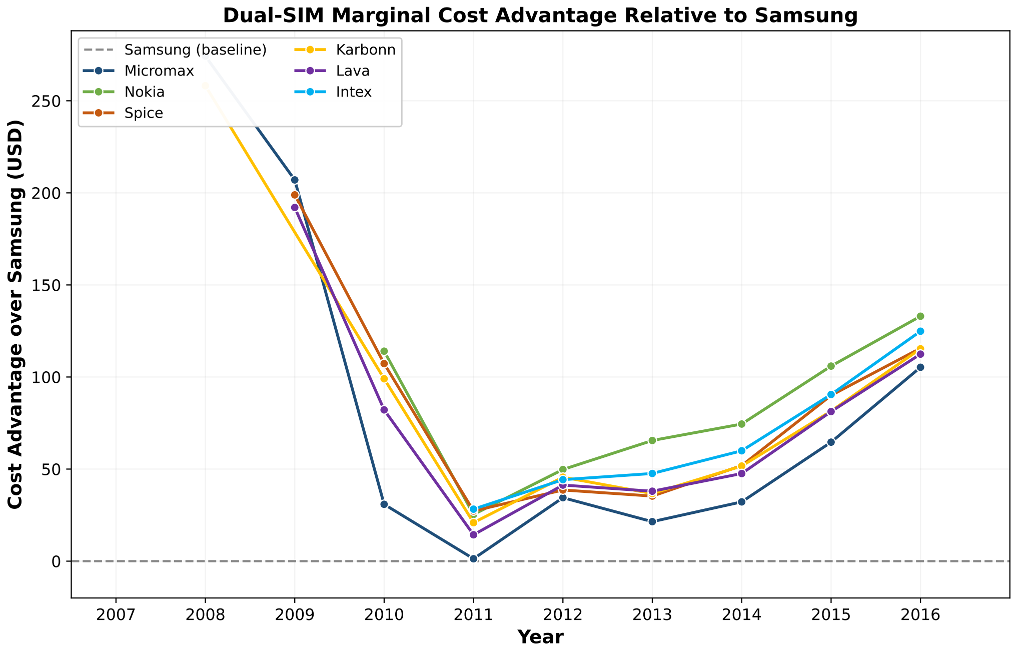


Figure 2: Dual SIM marginal cost advantage of competing firms relative to Samsung, by year. Each line plots Samsung's average MC minus the competitor's average MC for dual SIM products (positive values indicate the competitor produces more cheaply). The dashed grey line at zero represents Samsung's own cost level.

of close substitutes available in the Indian market and the relatively low switching costs for consumers.

5.6 Fixed cost estimates

Using the demand and supply estimates, we recover bounds on the fixed cost of including dual SIM functionality through the moment inequality approach described in Section 3. For each product-quarter observation, we compute the counterfactual variable profit that the firm would earn if the product's dual SIM status were switched (from dual SIM to non-dual SIM, or vice versa), holding all other products and rival decisions fixed. The difference between observed and counterfactual variable profits provides the revealed preference bound on the fixed cost.

Specifically, for a product observed *with* dual SIM, the upper bound on the fixed cost is the incremental variable profit from including the feature: $\hat{F}_{jft}^{\text{DS},UB} = E[\pi_{ft}(\text{with DS}) - \pi_{ft}(\text{without DS})]$. For a product observed *without* dual SIM, the lower bound is the incremental variable profit that the firm chose *not* to capture: $\hat{F}_{jft}^{\text{DS},LB} = E[\pi'_{ft}(\text{with DS}) -$

π_{ft}(without DS)]. The counterfactual profits are computed by re-solving the Bertrand-Nash pricing equilibrium under the alternative product configuration.

Table 7 reports the distribution of estimated fixed cost bounds. The median upper bound is approximately \$654,000, while the median lower bound is approximately \$208,000. These magnitudes are economically plausible for a product-level fixed cost that encompasses retooling, component sourcing, firmware development, and testing for dual SIM compatibility. The wide range across products reflects substantial heterogeneity in the incremental profitability of dual SIM across market segments: budget feature phones in competitive segments have small incremental profits (and thus low implied fixed costs), while premium smartphones in less contested segments command larger incremental profits.

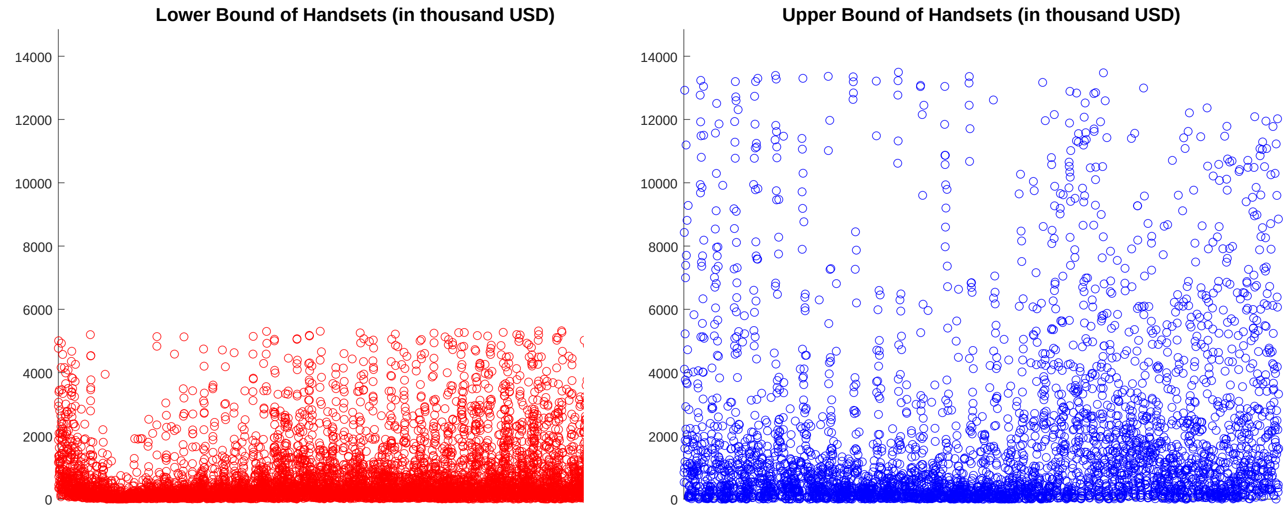
Figures 3a and 3b plot the lower-bound and upper-bound fixed cost estimates against time, respectively. Both panels show a declining trend over the sample period, consistent with the falling marginal cost premium documented above and with the standardization of dual SIM chipsets by suppliers such as MediaTek. This declining fixed cost rationalizes the rapid adoption of the feature even by small firms with limited R&D budgets.

Table 7: Fixed cost estimates (thousands of 2010 USD)

	5th percentile	Median	95th percentile
Lower bound	25	208	2,693
Upper bound	27	654	8,305

Bounds from moment inequalities (equations 5).

Lower bound from products without DS; upper bound from products with DS.



(a) Lower bounds (products without DS)

(b) Upper bounds (products with DS)

Figure 3: Fixed cost estimates over time (thousands of 2010 USD). Panel (a) shows lower bounds from products observed without dual SIM; panel (b) shows upper bounds from products observed with dual SIM.

6 Counterfactual Simulations

The preceding sections established two key facts: (i) consumer willingness to pay for dual SIM was initially negative and grew to positive over time, and (ii) the marginal cost of producing dual SIM handsets declined substantially. We now ask the central question: what would have happened to Samsung's profits if it had enforced patent protection on dual SIM technology in India, thereby preventing rival firms from offering dual SIM handsets?

6.1 Preference discovery decomposition

Our demand estimates parameterise the dual SIM preference as $\beta_{\text{DS}} + \beta_{\text{DS}} \times \log(t)$, where t indexes quarters. This specification captures the time trend in preferences but does not distinguish between two potential drivers of preference growth: (i) the entry of additional dual SIM firms, which exposes more consumers to the technology and generates a preference discovery externality, and (ii) an autonomous time trend reflecting learning from usage or media exposure.

To decompose these channels, we first estimate unrestricted quarter-specific dual SIM preferences by replacing the parametric dual SIM terms with 40 quarter-specific interactions $\text{DS}_j \times \mathbf{1}(t' = t)$ for each quarter t. This yields a nonparametric series $\hat{\beta}_t^{\text{DS}}$ that traces the evolution of dual SIM preferences without imposing a functional form on time.

We then regress these quarter-specific preferences on the number of firms offering dual-SIM handsets and a log-time trend:

$$\hat{\beta}_t^{\text{DS}} = \gamma_0 + \gamma_1 N_t^{\text{DS}} + \gamma_2 \log(t) + \varepsilon_t \tag{10}$$

where N_t^{DS} is the number of unique firms selling at least one dual SIM handset in quarter t, which ranges from zero in 2007Q1 to 38 by 2015Q3.

Table 8: Preference discovery decomposition

	Coefficient	Std. Error
Constant (γ_0)	-1.394^{**}	(0.643)
No. of dual-SIM firms (γ_1)	0.072^{***}	(0.026)
$\log(t)$ (γ_2)	-0.245	(0.390)
R^2	0.435	
Observations	40	

Table 8 reports the results. The coefficient on the number of dual SIM firms is positive ($\hat{\gamma}_1 = 0.072$), indicating that each additional firm entering the dual SIM segment raises consumer valuation of the technology. The coefficient on the log-time trend is negative ($\hat{\gamma}_2 = -0.245$), implying that, after controlling for the number of dual SIM firms, there is no autonomous improvement in consumer preferences over time. This finding is striking: it suggests that *all* of the observed preference growth for dual SIM technology is attributable to the entry of rival firms, not to an exogenous time trend.

6.2 Samsung Patent Counterfactual

We use the decomposition in equation (10) to construct a counterfactual in which Samsung enforces patent protection on dual SIM technology in India, preventing all rival firms from offering dual SIM handsets. Under this scenario, the number of dual SIM firms is set to $N_t^{\text{DS}} = 1$ for all quarters (Samsung only). We then compute counterfactual dual SIM preferences as:

$$\hat{\beta}_t^{\text{DS,CF}} = \hat{\gamma}_0 + \hat{\gamma}_1 \times 1 + \hat{\gamma}_2 \log(t) \tag{11}$$

To trace the profit implications, we adjust mean utilities for each product accordingly. For non-Samsung dual SIM products, we remove the dual SIM utility component and reassign them to the non-dual SIM nest. For Samsung's dual-SIM products, we replace the status quo preference with the counterfactual preference $\hat{\beta}_t^{\text{DS,CF}}$, which is uniformly lower. We then recompute nested logit market shares under the new mean utilities and calculate Samsung's variable profits in each quarter.

Figure 4 reports the quarterly difference in Samsung's variable profits between the status quo (no patent) and the counterfactual (patent enforcement). In every quarter, the profit difference is positive, meaning Samsung earns *more* under the status quo than under the patent counterfactual. The total cumulative difference over the sample period is approximately \$2.6 billion.

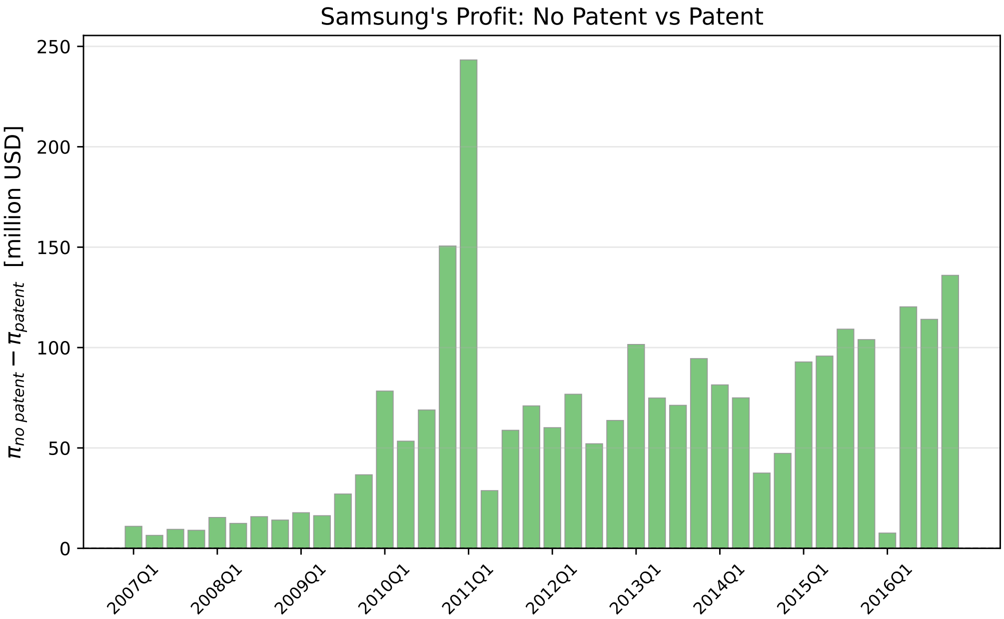


Figure 4: Samsung's quarterly profit difference: no patent minus patent counterfactual (million USD). Positive values indicate Samsung benefits from not enforcing patent protection.

The pattern in Figure 4 is informative. Even in early quarters (2007–2009), when consumer WTP for dual SIM is negative and Samsung has few dual SIM products, the profit difference is positive. This occurs because the existence of a separate dual-SIM nest reduces competitive pressure in the non-dual SIM nest where Samsung's products primarily compete. Under patent enforcement, rival firms' dualSIM products would be forced back into the non-dual SIM nest, intensifying within-nest competition and reducing Samsung's market shares.

As the market matures (2010 onward), the profit advantage of the status quo grows substantially, reaching \$100–\$140 million per quarter by 2015–2016. By this point, the preference discovery externality is in full effect: rival firms' dual SIM offerings have educated consumers about the technology's value, and Samsung, now offering dual SIM in the majority of its product line, captures a large share of the resulting demand growth.

These results provide a quantitative rationalisation for Samsung's observed strategy. Patent enforcement would have eliminated the preference discovery externality generated by rival firms' imitation. Although a patent would have granted Samsung a temporary monopoly on dual SIM, the monopoly would have been over a technology that consumers had not yet learned to value. The "value of imitation," in this context, is precisely the preference discovery that rivals' entry generated and that Samsung ultimately benefited from more than any individual imitator.

7 Conclusion

When firms innovate, they do not always seek to protect their innovations through patents, licensing, or other forms of intellectual property enforcement. In this paper, we provide quantitative evidence for a mechanism that can rationalize this behavior: preference discovery. Using the introduction of dual SIM handsets in the Indian mobile phone market as our empirical setting, we estimate a structural model of demand and supply that allows us to recover consumer preferences, marginal costs, and the fixed costs of adopting the innovation. We find that consumer willingness to pay for dual SIM technology was initially negative (−\$74 in 2007) and crossed into positive territory around 2011, precisely as imitation by rival firms made the technology ubiquitous. By 2016, WTP had risen to +$21 per handset.

On the supply side, the marginal cost premium for dual SIM production declined by 47% over the sample period, from a 63% cost premium in 2007 to 14% below non-dual SIM costs by 2016. This cost decline, combined with the growing consumer valuation, made dual SIM the dominant technology in the market.

Our findings carry implications beyond the specific market we study. In any setting where an innovation takes a form that many firms can adopt, and where consumer preferences for the innovation are still evolving, preference discovery may play an important role in shaping the innovator's optimal strategy. Identifying the conditions under which preference discovery dominates the costs of lost market power remains a promising direction for future research.

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