Understanding Quality Upgrading Dynamics: China's Automobile Industry

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Motivation

- One challenge facing firms in developing countries is the difficulty in escaping the "low-quality trap"
- Empirically we see many “successes” and “failures” — Why?
  - E.g. Japanese electronics/cars in the 1970s and 1980s
- Multiple factors could drive the quality upgrading process:
  - Rising demand for quality (due to rising income)
  - Competition from foreign firms
  - Technology transfer from foreign firms
  - Spillovers from upstream industries
  - Various government policies . . .
- Research Agenda: To understand the role by the driving forces in shaping industrial quality upgrading dynamics in emerging markets

This Project: China's Automobile Industry

- Setting: China's automobile industry (2004-2015)
- Descriptive evidence: significant quality upgrading and catch-up
  - Leverage a rich set of vehicle attributes & user experience measures
- Descriptive analysis on various underlying mechanisms
  - (1) rising income; (2) knowledge transfer; (3) industrial linkage
- A structural model of HH demand for quality and firm competition
  - Recover the demand and cost parameters:
    - Consumers' willingness to pay for various car attributes
    - Firms' incentives and costs of improving quality
  - Rationalize the observed patterns of sales and quality upgrading
- Counterfactual exercises:
  - Quantify the importance of different forces for quality improvement and how different forces interact with one another
- Today: Descriptive analysis on technology transfer from foreign firms

"Quid Pro Quo" and Technology Transfer

- "Quid pro quo", or market-for-technology policy
  - In 1994, China imposed an ownership restriction that limited foreign carmakers to owning no more than a 50-percent share of any local venture
  - In April, the Chinese government promised to lift the restriction by 2022
- Different views on the policy
  - Some think it will facilitate knowledge transfer from global carmakers and help domestic brand grow
  - Some think it may deter entry of foreign firms or cause them to withhold technologies for IPR concerns
- We analyse the impact of this policy and assess the implications of allowing full foreign ownership

Literature

- Technology innovation and quality upgrading:
  - Market size and competition effects: Aghion et al. (2018)
  - Income-based quality choice: Bastos et al. (2018)
  - Knowledge spillovers: Buera and Oberfield (2016)
  - Input linkages and endogenous quality: Goldberg et al. (2010), Fieler et al. (2018)
- Technology transfers to developing countries
  - Effects of FDI entry: Aitken and Harrison (1999), Javorcik (2004)
  - Qui Pro Quo: Holmes et al. (2015)
- Market structure, competition and endogenous products
  - Endogenous products: Berry and Waldfogel (1999, 2010), Crawford (2011), Sweeting (2012), Fan (2013), Wang (2016), Fan and Yang (2016)
  - Optimal industrial policy: Igami and Uetake (2016), Chen and Lawell (2017)

Outline

Data

- **Vehicle quality measures**
  - Trim-level attributes from online sources (2004-2015)
    - includes over 100 vehicle specifications and features
  - Scores from JD Power's Initial Quality Studies (2009-2015)
    - Measured by the number of problems experienced per 100 vehicles during the first 90 days of ownership $\rightarrow$ lower score higher quality
- **Vehicle registration/license data (2009-2015)**
  - Universe of license registrations: month and city of registration, brand and model name, major attributes—transmission type, fuel type, engine size
- **Household survey data (2009-2015)**
  - 20036 household-year observations are matched with the license data in first/alternative choice models

List of Vehicle Attributes — Safety Features

Safety measures (安全性)			
Number of airbags (total 7)		Number of safety features (total 16)	
airbag_prime	主驾驶安全气囊	tyrePressure	胎压监测装置
airbag_secondary	副驾驶安全气囊	zeroTyrePressure	零胎压继续行驶
sideAirbag_front	前排侧气囊	safeBeltAlert	安全带未系提示
sideAirbage_rear	后排侧气囊	childSeats	ISOFIX儿童座椅接口
headAirbag_front	前排头部气囊(气帘)	engine_antiTheft	发动机电子防盗
headAirbag_rear	后排头部气囊(气帘)	centralLocking	车内中控锁
kneeAirbag	膝部气囊	ABS	ABS防抱死
		EBD_CBC	制动力分配(EBD/CBC等)
		EBA_BAS_BA	刹车辅助(EBA/BAS/BA等)
		ASR_TCS_TRC	牵引力控制(ASR/TCS/TRC等)
		ESC_ESP_DSC	车身稳定控制(ESC/ESP/DSC等)
		HAC	上坡辅助
		autoHold	自动驻车
		HDC	陡坡缓降
		airSuspension	空气悬架
		VGRS	可变转向比

List of Vehicle Attributes — Comfort Features

Convenience measures (易操作性) / Functionality (功能性)	
Number of convenience features (total 10)	
functionalSteeringWheel	多功能方向盘
cruise	定速巡航
parkingRadar_front	前驻车雷达
parkingRadar_rear	后驻车雷达
parkingVideo	倒车视频影像
autoPCScreen	行车电脑显示屏
autoWindow_front	前电动车窗
autoWindow_rear	后电动车窗
remoteKey keylessStart	遥控钥匙 无钥匙启动系统

List of Vehicle Attributes — Convenience Features

Comfort measures (舒适性)	
Number of comfort features (total 8)	
sunRoof	电动天窗
adjSeatsHeight	座椅高低调节
adjSeatsAuto_prime	主驾驶座电动调节
adjSeatsAuto_secondary	副驾驶座电动调节
heatingSeats_front	前排座椅加热
heatingSeats_rear	后排座椅加热
centralLED	中控台彩色大屏
rearAirConditioner	后排独立空调

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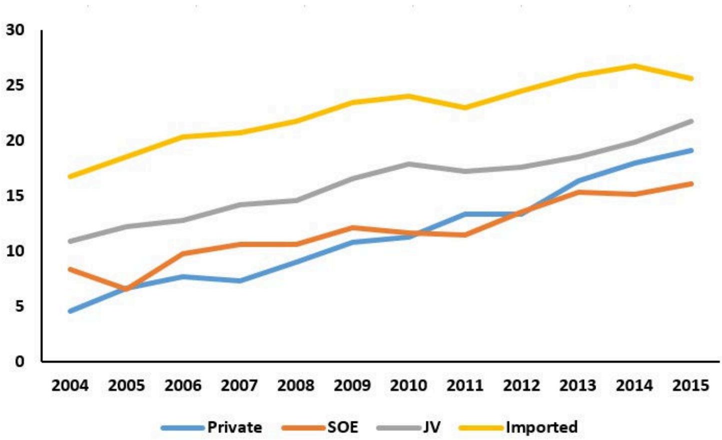
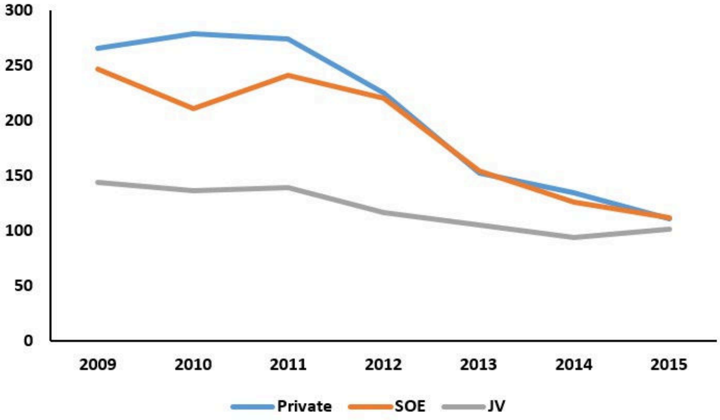
Descriptive Evidence for Quality Upgrading

Figure: Time trends in number of features by ownership types



Descriptive Evidence for Quality Upgrading

Figure: Time trends in IQS score by ownership types



Descriptive Evidence for Quality Upgrading

	(1) lnSafety	(2) lnSafety	(3) ln_ConvPlsComf	(4) ln_ConvPlsComf	(5) lnIQS	(6) lnIQS
Year	0.0600***	0.0477***	0.0481***	0.0372***	-0.0695***	-0.0599***
	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.009)
Private*Year	0.0412	0.00343	0.0809***	0.0191	-0.108***	-0.0867***
	(0.023)	(0.015)	(0.023)	(0.019)	(0.015)	(0.022)
SOE*Year	0.0440*	0.0318	0.0485**	0.0109	-0.0581***	-0.0173
	(0.020)	(0.035)	(0.019)	(0.030)	(0.017)	(0.044)
N	1985	941	1985	940	1724	893
adj. R^2	0.24	0.22	0.14	0.11	0.45	0.27

- Omitted group is the JVs
- Odd columns include all models; even columns include a balanced sample of models that exist for all years
- Catch-up (on observables) seem to be driven by model entry and exit

model entry and exit firm level analysis: average portfolio and dispersion

Outline

Technology Transfer: an Overview

- Technology transfer: foreign firms $\rightarrow$ JVs $\rightarrow$ domestic firms
- Hence, we examine technology transfer in two steps:
  1. Transfer from foreign firms to JVs: whether foreign firms bring their technologies to the JVs
  2. Transfer from JVs to SOEs: whether a SOE picks up technologies from various JVs it partners with
- Technology transfer is not just narrowly limited to access to technology, but also includes know-hows in:
  - how to produce a features more cheaply or customize it
  - how to design the car to work better with the technology

Summary Statistics of Technology Adoption

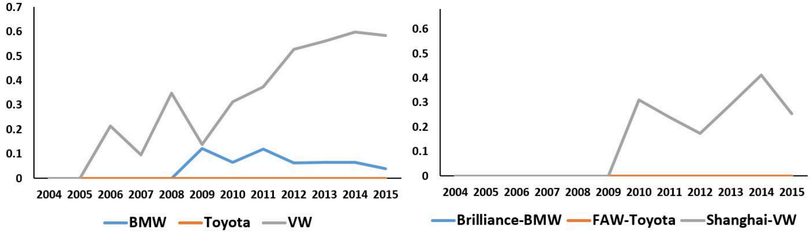
- We look at leader-follower patterns for four technologies
  - Dual-clutch transmission (DCT)
  - Turbocharged petrol engines (Turbo)
  - Gasoline direct injection (GDI)
  - Variable gear-ratio steering (VGRS)

Table: Summary statistics for JV technology adoptions

	count	mean	mean('15)	Foreign adopted	JV adopted
DCT	7376	.08	.15	2006	2009
Turbo	7373	.26	.48	2004	2004
GDI	7376	.24	.44	2004	2004
VGRS	7376	.03	.07	2004	2005

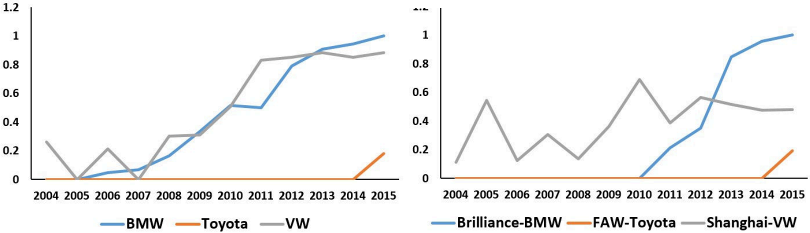
Descriptive Evidence: DCT

Figure: Adoption of DCT by three foreign firms and their JVs



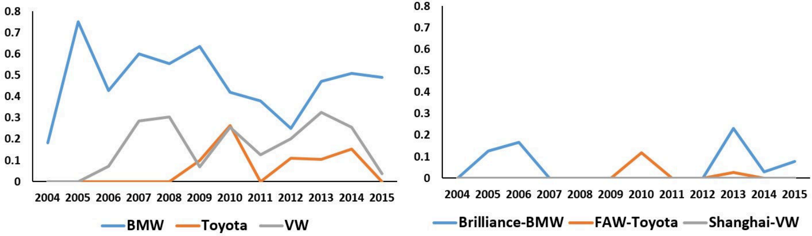
Descriptive Evidence: Turbo

Figure: Adoption of Turbo by three foreign firms and their JVs



Descriptive Evidence: VGRS

Figure: Adoption of VGRS by three foreign firms and their JVs



Descriptive Regression: Set-up

- We estimate the following regression, separately for each technology:

$$JVAdoption_{it} \quad = \quad \beta_0 + \beta * ForeignAdoption_{it} + \lambda_t + \lambda_s + \varepsilon_{it}$$

  - Each observation is at the trim-year level
  - $JVAdoption_{it}$ takes value 1 if trim i has the technology in year t
  - $ForeignAdoption_{it}$ takes value 1 if (any trim under) the foreign partner has adopted the technology by year t
  - λ_t controls for technology-specific time trend
  - λ_s controls for each segment's average propensity to adopt the technology

- We also look at different lags after foreign partners' first adoption:

$$JVAdoption_{it} \quad = \quad \beta_0 + \sum_{\tau} \beta^{\tau} * ForeignAdoption_{it}^{t-\tau} + \lambda_t + \lambda_s + \varepsilon_{it}$$

Descriptive Regression: Results

	(1) DCT	(2) Turbo	(3) GDI	(4) VGRS
FAdopted	0.142***	0.234***	0.164***	0.0542***
	(0.00706)	(0.0130)	(0.0163)	(0.00500)
Observations	6083	6080	6083	6083
R-squared	0.128	0.245	0.247	0.124
Year FE	Yes	Yes	Yes	Yes
Segment FE	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

- JV trims are more likely to adopt each technology when the foreign partner has adopted it
- Impact of foreign adoption appears significant when compared to average adoption rate of each technology

Descriptive Regression: Results

	(1) DCT	(2) Turbo	(3) GDI	(4) VGRS
FAdoptedSameYear	0.0312*	0.0875***	0.0878***	0.0756***
	(0.0163)	(0.0227)	(0.0218)	(0.0139)
FAdopted1To3Years	0.0189*	0.190***	0.139***	0.0214***
	(0.0115)	(0.0156)	(0.0170)	(0.00765)
FAdopted3YearsPlus	0.219***	0.332***	0.376***	0.0681***
	(0.00823)	(0.0152)	(0.0191)	(0.00601)
Observations	6083	6080	6083	6083
R-squared	0.168	0.264	0.293	0.129
Year FE	Yes	Yes	Yes	Yes
Segment FE	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Endogenous firm quality

- Positive correlation in JVs' and foreign partners' adoptions could be driven by
  - Technology transfer from foreign firms to JVs
  - Positive correlation between in quality of foreign firms and JVs
- The key empirical challenge is to separate firm-wide learning from intrinsic firm quality
  - This is challenging because both show up as earlier adoptions
  - Controlling for firm fixed effect does not work well because zero "first difference" before treatment
- Our solution: use within-firm variations between technologies

Estimation Framework

- We estimate the following regression:

$$\begin{aligned} JV\,Adoption_{ifkt} \quad &= \quad \alpha + \sum_{k'} \beta_{k'} Foreign Adoption_{fkt} * \mathbb{1}(k = k') \\ &\quad + X_{ift}\gamma + \lambda_{ft} + \lambda_{kt} + \lambda sk + \varepsilon_{ifkt} \end{aligned}$$

  - Each observation is at the trim-year-technology level
  - We pool four technologies in one regression and allow a separate coefficient for each technology
  - We control for firm-year fixed effects, which are common to all technologies
- Implicit assumptions:
  - Changes in adoption rates common to all technologies are driven by firm quality or other shocks
  - Additional technology-specific change is driven by technology transfer
- We scale the adoption dummies to equalize the average "adoption rates" of four technologies

Results

	(1) Adopted	(2) Adopted	(3) Adopted	(4) Adopted
FAdoptedDCT	0.469***	0.358***	0.371***	0.371***
	(0.0220)	(0.0233)	(0.0236)	(0.0234)
FAdoptedTurbo	0.234***	0.119***	0.266***	0.266***
	(0.0258)	(0.0268)	(0.0277)	(0.0275)
FAdoptedGDI	0.180***	0.0798**	0.250***	0.250***
	(0.0325)	(0.0326)	(0.0349)	(0.0345)
FAdoptedVGRS	0.428***	0.283***	0.279***	0.279***
	(0.0219)	(0.0232)	(0.0235)	(0.0233)
Observations	30412	30412	30412	30412
R-squared	0.153	0.204	0.244	0.257
Firm FE	No	Yes	Yes	No
Firm-year FE	No	No	Yes	Yes
Trim Characteristics	No	No	No	Yes

Standard errors in parentheses

$^{*}\ p < .1$, $^{**}\ p < .05$, $^{***}\ p < .01$

Coefficients need to be scaled back for proper interpretation

Scaling parameters for four technologies are 3.3, 1, 1.1, 7.9, respectively

We control for tech-year and tech-segment fixed effects in all columns

Permutation test

- We use a permutation test to further assess the statistical significance of the estimates. We
  - randomly assign a placebo foreign partner to each of the 20 JVs
  - repeat the estimation under the placebo firm linkages
  - repeat the test 100 times, plot the estimates, and see where our original estimates stand in the distribution
- The p-values of our original estimates are 0.02, 0.04, 0.02, and 0.05, respectively

JV-SOE Transfer: Set-up

- The equation has exactly the same form:

$$
\begin{aligned}
SOEAdoption_{ifkt} \quad &= \quad \alpha + \sum_{k'} \beta_{k'} JVAdoption_{fkt} * \mathbb{1}(k = k') \\
&\quad + X_{ift}\gamma + \lambda_{ft} + \lambda_{kt} + \lambda sk + \varepsilon_{ifkt}
\end{aligned}
$$

- We differ from the previous set-up in the following ways
  - We replace VGRS with the following technologies
    - Emergency Brake Assist (EBA)
    - Acceleration Skip Control (ASR)
    - Electronic Stability Control (ESC)
  - Each SOE may have multiple JVs from technology transfer is possible
  - We experiment with different boundaries of learning
    - from any models by affiliated JVs
    - only from models of the same vehicle type
    - only from models in the same segment

JV-SOE Transfer: Results

	(1) HasTech	(2) HasTech	(3) HasTech	(4) HasTech
JVTechDCT	0.403***	0.172***	0.129*	0.166**
	(0.0627)	(0.0664)	(0.0673)	(0.0667)
JVTechTurbo	0.0152	-0.143**	-0.163***	-0.131**
	(0.0547)	(0.0590)	(0.0600)	(0.0595)
JVTechStraight	0.230***	0.0633	-0.0550	-0.0272
	(0.0564)	(0.0605)	(0.0616)	(0.0612)
JVTechEBA	0.134**	0.00626	-0.0563	-0.0146
	(0.0522)	(0.0570)	(0.0571)	(0.0567)
JVTechASR	0.124**	-0.00365	-0.0596	-0.0119
	(0.0547)	(0.0595)	(0.0601)	(0.0598)
JVTechESC	0.104*	-0.0314	-0.0951	-0.0425
	(0.0558)	(0.0604)	(0.0612)	(0.0609)
Observations	20480	20480	20480	20480
R-squared	0.0977	0.125	0.171	0.186
Firm FE	No	Yes	Yes	No
Firm-year FE	No	No	Yes	Yes
Trim Characteristics	No	No	No	Yes

Standard errors in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$
Coefficients need to be scaled back for proper interpretation
Scaling parameters are 22, 2.1, 9, 1, 1.5, 1.6, respectively
We control for tech-year and tech-segment fixed effects in all columns

Technology Transfer: Conclusions

- We find foreign brands are more likely to adopt technologies their JV partners have adopted, especially after a lag of three years
  - This suggests foreign firms are not completely withholding technologies for IPR concerns
- We find no evidence for technology transfer from JVs to SOEs. This negative result could arise in two opposite scenarios
  - There is little technology transfer. JVs are successful in protecting their know-hows
  - There is industry-wide transfer through channels such as personnel movement and upstream linkage
- Scrapping ownership restriction may not have a very dramatic impact

Outline

Structural Model: Overview

Demand side: micro BLP

- A model of household purchasing decisions of cars, incorporating:
  - Quality attributes and household preference heterogeneity
- Estimation: constrained MLE

Supply side: endogenous price and quality

- Timing assumptions:
  1. Take the set of products offered as exogenously given
  2. A firm chooses the number of safety and comfort features for all its models to maximize profits under rational expectation of quality and pricing decisions by all firms
  3. Conditioning on the choices of features, each firm sets prices as under Bertrand-Nash competition to maximize static profits
- Marginal costs: FOC from static maximization
- Fixed costs: FOC from optimal product choice

jump to results

Demand

- A model of household purchasing decisions of cars, incorporating:
  - Quality attributes and household preference heterogeneity
- Utility of individual i in market (province-year) m buying model j:

$$u_{mij} = \mu_{mij} + \delta_{mj} + \varepsilon_{mij},$$

where μ_{mij} takes one of the following 2 specifications (abbrev. m)

$$\begin{aligned}
\mu^1_{ij} &= -\frac{\alpha_1}{y_i}P_j + \beta_1 FS_i log(Size_j) + \beta_2 Kid_i * Safety_j \quad \text{(Spec 1)} \\
\mu^2_{ij} &= -\frac{\alpha_1}{y_i}P_j + \beta_1 FS_i log(Size_j) + \beta_2 Kid_i Safety_j \quad \text{(Spec 2)} \\
&\quad + \beta_3 * ln(y_i) Safety_j + \beta_4 * ln(y_i) CC_j
\end{aligned}$$

  - y: income; FS: family size; Kid: dummy for having kids
- We specify product-market specific utility as: ▸ variable definitions

$$\begin{aligned}
\delta_{mj} &= \alpha P_j + \gamma_1 ln(FC_{mj}) + \gamma_2 ln(Power_j) \\
&+ \gamma_3 Safety_j + \gamma_4 CC_j + \rho_j + \omega_m + \xi_{mj}
\end{aligned}$$

Supply: Endogenous Price and Quality Choice

Timing assumptions:

1. Take the set of products offered as exogenously given
2. A firm chooses the number of safety and comfort features for all its models to maximize profits under rational expectation of quality and pricing decisions by all firms
3. Conditioning on the choices of features, each firm sets prices as under Bertrand-Nash competition to maximize static profits

In equilibrium:

- No firm has incentive to unilaterally deviate in prices, holding features constant
- No firm has incentive to unilaterally deviate in quality after considering price responses by rivals

Supply: Marginal Costs

- The annual national profit for firm f is (suppress subscript t):

$$\pi_f = \sum_{m=1}^{\mathrm{M}} \sum_{j \in \mathcal{F}} (\mathrm{p}_j^0 - \mathrm{T}_j(\mathrm{p}_j^0) - \mathrm{mc}_j)\mathrm{M}_m \mathrm{s}_{mj} = \sum_{j \in \mathcal{F}} (\mathrm{p}_j^0 - \mathrm{T}_j(\mathrm{p}_j^0) - \mathrm{mc}_j)\mathrm{S}_j$$

- Each firm chooses $\{\mathrm{p}_j^0, j \in \mathcal{F}\}$ to maximize its total profits details:

$$S_j(1 - \frac{\partial \mathrm{T}_j}{\partial \mathrm{p}_j^0}) + \sum_{r \in \mathcal{F}} (\mathrm{p}_r^0 - \mathrm{T}_r - \mathrm{mc}_r)\frac{\partial \mathrm{S}_r}{\partial \mathrm{p}_j^0} = 0, \forall j$$

$$\Rightarrow \mathrm{p}^0 = \mathrm{mc} + \mathrm{T} + \Delta^{-1}[\mathrm{S}(1 - \frac{\partial \mathrm{T}}{\partial \mathrm{p}^0})].$$

  - Δ is a J by J matrix, whose (j, r)th term is $-\frac{\partial \mathrm{S}_r}{\partial \mathrm{p}_j^0}$ if r and j are produced by the same firm, and 0 otherwise
  - Explicitly modeling the taxes: $\mathrm{T}_j = \mathrm{p}_j^0 - \mathrm{p}_j^f = \mathrm{p}_j^0 - \frac{\mathrm{p}_j^0 * (1 - t_j^c)}{1 + t_j^{va} + t_j^s}$

- Parameterize the marginal costs (baseline spec):

$$\begin{aligned} \mathrm{mc}_{tj} &= \gamma_1 * log(FC_{tj}) + \gamma_2 * log(EngineSize_{tj}) + \gamma_3(CarSize_{tj}) \\ &+ \gamma_4 * Safety_{tj} + \gamma_5 CC_{tj} + \tau_t + \chi_j + \omega_{tj}, \end{aligned}$$

Supply: Fixed Costs

- Specify fixed cost to be quadratic in the number of features X_{kjt}
  - k takes 2 values, denoting the num of safety and num of comfort/convenience features respectively
- The equilibrium condition for X_{kjt} to be optimal is given by:

$$\sum_{r \in \mathcal{F}} \left(\frac{\partial \pi_{rt}}{\partial X_{kjt}} + \sum_{g \in \mathcal{G}} \frac{\partial \pi_{rt}}{\partial p_{gt}} \frac{\partial p_{gt}}{\partial x_{kjt}} \right) = \alpha_{k0} + \alpha_{k1} * x_{kjt} + \varepsilon_{kjt}$$

  - The marginal gain from deviating from the current quality level (increase in profits) equals the change in fixed costs
  - $\mathcal{F}$ denotes the set of products by firm F, and $\mathcal{G}$ denotes all products

Estimation Procedure: Demand

Constrained MLE:

- Maximize the joint likelihood of the observed first choice in the household survey, subjected to the constraint that model-predicted market shares from pseudo-households match observed market shares
- Simulated demand from pseudo households details

Estimation steps:

1. Given a set of non-linear parameters, θ_2, calculate μ_{ij} for each pseudo household. Back out a vector of product-specific utility δ.
2. Fix δ. For the same set of θ_2, calculate μ_{ij}, now for real households in the survey data. Calculate the individual likelihood.
3. The objective function is the sum of log likelihoods of each household buying its observed choice.
4. Find θ_2 that maximize the sum of the likelihood

Estimation Results: Willingness to Pay

Table: Price equivalent of each feature at different income levels (yuan)

Income (million)	0.05	0.1	0.15	0.2	0.3
Safety, Specification I	921	1200	1400	1500	1600
Safety, Specification II	-1400	287	1800	2900	4800
CC, Specification I	4200	5500	6200	6600	7000
CC, Specification II	1500	4000	5800	7200	9200

model fit

Estimation Results: Marginal Cost

	(1) MC	(2) MC	(3) MC	(4) MC
LogFC	-0.00985	0.0209***	0.0215***	0.0199***
	(0.00949)	(0.00442)	(0.00445)	(0.00442)
LogES	0.0965***	0.0341***	0.0337***	0.0342***
	(0.00775)	(0.00394)	(0.00392)	(0.00392)
LogSize	-0.0365**	0.0739***	0.0845***	0.0781***
	(0.0176)	(0.0190)	(0.0191)	(0.0193)
Safety	0.00824***	0.00154***	0.000848	0.00159*
	(0.000412)	(0.000253)	(0.000603)	(0.000892)
CC	0.00282***	0.00469***	0.00362***	0.00247***
	(0.000505)	(0.000243)	(0.000562)	(0.000740)
SafetyJV			0.000773	
			(0.000652)	
CCJV			0.00129**	
			(0.000620)	
Safety2				0.00000135
				(0.0000401)
CC2				0.000124***
				(0.0000399)
Observations	1945	1945	1945	1945
R-squared	0.818	0.983	0.984	0.984
Model FE	No	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Segment FE	Yes	No	No	No

- Adding one safety features costs around 1540
- Adding one comfort or convenience feature costs around 4690
- Marginal cost is convex in the number of features
- Marginal cost of quality provision is higher for JVs
- Fixed cost estimation in progress

Thank You!