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SME and EV Adoption: The Role of Financial Mediation Environment

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ABSTRACT

Electric vehicle (EV) adoption is globally accelerating but remains highly uneven across economies and firms. It is primarily demand-driven in developing economies, rather than a structural shift in production. This signals the need to observe factors affecting EV adoption in production. Therefore, considering the financial environment in an economy as a mechanism, this paper develops a static theoretical model of electric vehicle (EV) adoption and compares firms in two economies. Economy H has high financial constraints due to high interest rate and a tight borrowing cap while Economy L has a lower interest rate and a comparatively relaxed borrowing cap, both with a single profit maximizing small and medium enterprise each. Using Lagrangian optimization with Karush-Kuhn-Tucker (KKT) conditions, three results are derived. First, the borrowing cap determines the level of EV adoption. Firm in economy L achieves a higher EV adoption level when the borrowing constraint binds. Second, when the borrowing constraint binds, the borrowing cap is the sole determinant of EV adoption, while the interest rate affects profitability but not adoption quantity. Third, comparative statistics confirm that a higher interest rate reduces EV adoption level and a higher borrowing cap raises EV adoption at a diminishing rate. The results suggest that expanding borrowing capacity can raise EV adoption in firms and the shadow price of borrowing constraint potentially offers a basis for targeting the most constrained firms.

Keywords: Small and Medium Enterprise (SME), Electric Vehicle (EV), Sustainability, Green Growth, Financial Constraints.

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Table 1: Full form on abbreviations used in this paper

Abbreviation	**Full Form**
EV	Electric Vehicle
SME	Small and Medium Enterprise
ICE	Internal Combustion Engine
GDP	Gross Domestic Product
R&D	Research and Development
OEM	Original Equipment Manufacturer
IEA	International Energy Agency
FOC	First-Order Condition
SOC	Second-Order Condition
KKT	Karush-Kuhn-Tucker (optimality conditions)
POT	Pecking Order Theory
EMDE	Emerging Market and Developing Economy
BMS	Battery Management System

1. INTRODUCTION

The electric vehicle (EV) transition is accelerating globally and represents one of the most consequential structural shifts in the global manufacturing industry. Recent evidence shows that electric car sales surpassed 20 million units in 2025, a twentyfold increase from 2015 and represents one-fourth of worldwide total sales of new automobiles. However, this transformation is uneven as EV adoption is not the same for all economies and all firms. There is substantial heterogeneity in barriers to adoption of EV and gains from EV transition due to varying income level and firm size [2].

China dominates the EV market with about 55 per cent of domestic car sales according to the IEA, and nearly two-thirds of global EV sales according to BloombergNEF, followed by Europe and the United States at shares of around 17 percent and 7 percent respectively [3]. Other than these three established markets, emerging economies showed a substantial growth of 80 percent in EV sales, led by Southeast Asia, Latin America, and India[1] and Vietnam, Thailand, and Brazil as among the fastest expanding markets and even in some cases demonstrating higher adoption of EV than the wealthier economies. This substantially reflects that EV is rapidly expanding in regions beyond advanced economies and in fact, driven by emerging markets.

On the demand side, EV sales in emerging markets other than China grew by around 80 per cent in 2025 and reached almost 1.2 million units and the majority of global EV market expansion through 2035 is projected to occur in Latin America, India and Southeast Asia[1]. This exhibits high latent demand for EV penetration. However, the increasing demand is almost entirely catered by imports and not by domestic production. China alone accounts for around 75 per cent of global EV production, and 55 per cent of EV sales in developing economies is facilitated by Chinese imports, with several countries in Latin America, the Middle East, and Africa importing more than 80 per cent of their EVs from China[1]. This signals that domestic manufacturing of EV is low in these economies and even in countries with specialized policy frameworks for local EV manufacturing including Thailand, Indonesia, and Brazil. A small and slowly growing local EV production as share of total sales is a pattern and not incidental. This pattern suggests that EV transition in these economies is consumption driven and does not reflect a structural industrial change.

EV adoption in production and services is heavily capital-intensive with high upfront costs. The most significant expenditure is on retooling when firms shift away from regular combustion engine compatible technology to new machinery and technology for EV compatible production. Moreover, the new methods of production require cleaner facilities, specialized equipment, and workforce retraining since competency in power electronics, battery management system, and high-voltage operations is not usually practiced in conventional automotive production[5]. Quality certification is another primary cost and it involves meeting OEM-specific standards related to battery safety, electromagnetic compatibility, and thermal performance. This certification process is expensive and lengthy [1]. These costs explain why despite increasing growth opportunities for small and medium enterprises (SMEs), EV adoption in SMEs is lagging especially if they are in a developing economy. The challenges facing an SME adopting EV are distinct from those of its conventional counterpart in a financially healthier economy, in scale and in composition.

Evidence suggests that SMEs in developing economies are price-takers and they are disadvantaged due to large and vertically integrated Chinese, Korean and Japanese firms. Therefore they often accept discounts substantially below the market prices due to limited bargaining power[6]. This means that even if the SMEs successfully retool production, their average input costs remain high. This cost disadvantage compounds the financing limit and raises the capital required. Hence these costs are a convex function of EV adoption as the costs increase with deeper EV integration.

Thus, formal finance access is among the strongest predictors of SME innovation across a broad cross-section of developing economies Ayyagari, Demirgüç-Kunt, and Maksimovic[7]. Even if the overall development progresses in the financial market, this improvement disproportionately benefit small firms although their production expansion and technology adoption is more reliant on credit access[8]. These binding credit constraints generate persistent investment distortions at the firm level[9]. Also, firms when taking investment decisions are also considering their potential benefits such as tax shield benefit of debt financing[10], may form financing preferences[11] and firm's capital structure choices alter due to financial market environment[12].

All in all, this paper acknowledges that some firms face distinct barriers to adoption of EV in comparison to bigger firms and firms in advanced economies; that have access to green finance instruments and specialized government schemes partially setting the investment costs[13]. They also benefit from secured supply contracts, especially designed assembly lines, and stronger positioning in EV value chains. It is therefore worth considering that firms in well-functioning financial markets behave differently from similar firms operating in less constrained financial environments and access to finance determines whether firms can overcome challenges in the way of EV adoption[5]. Therefore, this paper theoretically models this heterogeneity in EV engagement due to differences in access to finance.

This paper addresses the following research questions through a static theoretical model of a profit-maximisation in SMEs under two financing regimes and derives the optimality conditions using Lagrangian optimisation and KKT conditions.

1. How does the financial environment (specifically the borrowing cost and the borrowing cap faced by SMEs in an economy) determine the level of EV adoption in firms?
2. Which financing channel is potentially the binding constraint on firm-level EV engagement?

The well-established literature is available on financial constraints and firm-level innovation investment [16,8,9] does not distinguish between the two financial environment channels in determining EV adoption; (1) Interest rate (price channel) and (2) Borrowing cap (quantity channel). This paper addresses this gap by deriving a closed-form solution demonstrating that when the borrowing constraint binds, the borrowing cap determines the EV adoption level, while the interest rate affects profitability. This is policy relevant and points towards effectiveness of initiatives like credit guarantee schemes and green loan programmes at raising adoption than merely interest rate subsidies, in constrained environments.

2. METHODOLOGY

This paper demonstrates theoretical modelling as methodology, incorporating automotive SMEs that can potentially engage with EV production. EV engagement is a choice variable, and the firm's profit depends on this through the difference between revenue function and cost function, in two different economies representing different financing environments.
This paper aims at understanding whether the price or the quantity of credit is the binding constraint for potential EV adopters and the theoretical modelling approach permits this distinction and isolation for analysis by providing comparative statics ($\partial EV^*/\partial i$ and $\partial E\bar{V}/\partial\bar{B}$) that hold all other variables constant by construction. The model's closed-form results are intended to generate testable propositions especially those in constrained economies. The results show that borrowing cap predicts adoption better than the

interest rate and in future this could be tested empirically aswell using firm-level data from developing economies

2.1 ECONOMIC ENVIRONMENT

This paper compares two economies, one with high financial constraint (denoted by H) and one with low financial constraint (denoted by L). The two economies are identical and only different in terms of access to finance. Given that technology, market size, and banking sector loanable funds are constant across the two economies, the sole source of heterogeneity is access to finance for firms.

H represents a credit restricted financial market with high borrowing cost and limit to credits offered. Borrowing cost is denoted by and the limit imposed on credit per firm is $\bar{B}H$. L represents an economy with easier access to finance with low cost of borrowing (and the limit imposed on borrowing for each firm is $\bar{B}L$. The limits on credit for each borrower firm is imposed such that $\bar{B}L > \bar{B}H$ i.e. firms in L can borrow more than the firms in H.

The choice variable is the firm's EV adoption level, denoted by EV with values ≥ 0 and ≤ 1 and it represents the firm's engagement in EV as a share of the firm's production and service activity. At EV = 0 the firm is fully conventional and at EV = 1 the firm is fully EV technology oriented. The definitions of all notations used in this paper's model are given in Table 2.

Table 2: Notations and definitions

Notation	**Definition**
$EV \in [0,1]$	Adoption level of EV technology (choice variable)
R(e)	Revenue as a function of engagement
M	Market size parameter
$r \in (0,1)$	Revenue concavity parameter (diminishing returns)
C(EV)	Operating cost as a function of EV adoption
$c > 0$	Cost convexity parameter
I(EV)	Investment required for adoption of EV
S	Savings of the firm

B(EV)	Borrowing required for adoption of EV on top of S
i	Interest rate on borrowing (iH or iL)
$\bar{B}$	Borrowing cap ($\bar{B}$H or $\bar{B}$L)
π(EV)	Profit as a function of EV adoption
	Shadow price of the binding borrowing constraint
G	Government subsidy per unit of EV adoption

2.2 ASSUMPTIONS OF THE MODEL

The assumptions discussed below assist this model in generating tractable closed form solutions guided by empirical evidence.

Assumption 1

The model is static with a one-time decision period. The firm chooses its EV adoption level 'EV' on the basis of revenue, cost, and financing available within that period. Static optimization is the standard beginning for theoretical models of investment and they help in isolating the effect of financing decisions without the complexity associated with intertemporal analysis[14]. This assumption is only relaxed when the model is extended to a multi-period setting.

Assumption 2

Each of the two economies have only one representative SME. Both firms are identical in technology, production possibilities, and their product markets and heterogeneity is only due to the financial environment (ease in access to borrowing) in both the economies. This approach isolates the effect of a single source of heterogeneity while holding all other variables constant and it supports cross-country comparisons[15].

Assumption 3

EV adoption level is a continuous choice variable EV $\in$ [0, 1]. At EV = 0 the firm is fully oriented towards conventional automotive production and at EV = 1 it is fully EV compatible. EV market penetration reflects the depth of electrification that evolves over time depending on economic conditions[4,2] and therefore it works like a continuous variable, rather than as a discrete or binary.

Assumption 4

EV adoption affects revenue positively through premium contracts, increasing consumer demand, and export participation and positively affects costs (equipment, workforce training, and certification). The literature suggests that in the light of demand and supply sides, financial environment determines EV adoption level[5].

Assumption 5

Capital investment denoted by 'I(EV)' is determined by level of EV adoption. Higher integration of EV requires more capital investment. The capital-intensive nature of EV adoption is the primary driver of firms' financing needs[13,6].

Assumption 6

In Economy H, the SME faces a borrowing limit $\bar{B}H$, beyond which credit is unavailable and in Economy L, limit $\bar{B}L$ is substantially higher ($\bar{B}L > \bar{B}H$). This cap on borrowing is for credit rationing and bring the model closer to the real world scenario in which credit beyond a threshold is not extended even at a higher interest rate to avoid adverse selection[14]. Credit constraints of this form lead to persistent investment shortfalls among SMEs in developing economies[9].

Assumption 7

The interest rate on borrowing is i_H in Economy H and i_L in Economy L with $i_H > i_L$. The empirical cross-country evidence suggests that SMEs in developing economies face substantially higher borrowing costs than counterparts in advanced economies, and that this affects firms' capacity to adopt EV as EV adoption investment relies on borrowing[8].

Assumption 8

Firm's own savings denoted by S are identical across both economies. These internal funds are drawn first and borrowing is only done after exhausting S. This hierarchy of financing options is inspired by pecking order theory (POT), under which information asymmetries make borrowing costlier[11], therefore making internal funds or savings a more preferred option then debt. The sensitivity of investment to available financing options (given fixed investment opportunities) is central in the financing-constraints literature[16].

Assumption 9

The revenue function R(EV) is concave and increasing in EV: revenue rises with EV engagement, but at a diminishing rate. Early adoption enables the firms to get most accessible gains while later adoption is getting smaller gains from a shrunken pool of opportunities [17]. EV market penetration with rising motorisation rates exhibit this concavity [4].

Assumption 10

The cost function C(EV) is convex and increases in level of adoption EV; reflecting the rising marginal cost associated with deeper integration of EV. The evidence that SMEs in developing economies face higher input costs of EV integration and these costs escalate with the transition undertaken[5].

Assumption 11

Net profit is defined as π(EV) = R(EV) − C(EV) – [i × B(EV)], where i × B(EV) is the cost of debt borrowed to finance investment I(EV) on top of savings of the firm (S). The additive nature of profit function follows the standard framework that shows a firm's value dependent on its operating cash flows net of the cost of the capital[18].

Assumption 12

The model is free from additional complexities of taxation and depreciation. It is a simplifying step to isolate the effects of the financial environment[18].

2.3. FIRM'S PROFIT FUNCTION

2.3.1 REVENUE

$R(EV) = M \times EV^r$

Revenue is a power function of the adoption level with where *M* is the market size parameter and $r \in (0, 1)$ is the revenue curvature parameter and it reflects the responsiveness of revenue to EV adoption. The value of $r < 1$ shows diminishing marginal returns to EV adoption

$R'(EV) = M \times rEV^{r-1}$

This partial derivative is positive but a decreasing function of EV. This aligns with the intuition that the first units of EV adoption, such as initial establishment of initial supply contracts or substituting to EV compatible components, generate the larger revenues and with each increment in adoption, revenues get smaller. This concavity of revenue is consistent with empirical findings about EV market penetration, where the highest revenues are realised early when the pool of exploitable opportunities in EV adoption is larger[4,17].

2.2.2 COST

The cost of EV adoption is a quadratic function with $c > 0$ is the cost convexity parameter. This functional form captures the convexity in the cost of EV integration:

$C(EV) = (\frac{c}{2}) \times EV^2$

The marginal cost of adoption is $C'(EV) = c \times EV$

This is increasing in EV i.e. each additional unit of EV adoption is more costly than the previously integrated. This is due to the escalating costs of technological, regulatory, and workforce changes as the firm becomes more EV compatible.

2.2.3 BORROWING

Adoption of *EV* requires capital investment *I(EV)*. For simplification, this model assumes that the principal cost of EV adoption is the operating cost generated by changes in technology and therefore, investment is taken as equal in magnitude to the operating cost as follows:

$$I(EV) = (\frac{c}{2})\ EV^2$$

Savings '*S*' are initially used to finance this investment and then the remaining shortfall is financed by borrowing *B(EV)*.

$$B(EV) = \max\ [(\frac{c}{2})\ EV^2 - S, 0]$$

When $[(\frac{c}{2})\ EV^2 - S] < 0$, it means that investment is less than savings so the firm does not need to borrow and therefore B(EV) = 0.

In case $[(\frac{c}{2})EV^2 - S] \geq 0$, savings are less than investment so the firm borrows in this case and therefore $B(EV) = (\frac{c}{2})\ EV^2 - S > 0 < S$

The threshold adoption level 'EV_S' is at which the firm begins borrowing (after exhausting savings), is found by setting B(EV) = 0 as follows:

$$(\frac{c}{2})EV^2 - S = 0$$

$$(\frac{c}{2})\ EV^2 - S + S = 0 + S$$

$$(\frac{c}{2})\ EV^2 = S$$

$$(\frac{c}{2})\ (\frac{2}{c})EV^2 = (\frac{2}{c})\ S$$

$$EV^2 = (\frac{2S}{c})$$

Taking square root on both sides gives:

$$\sqrt{EV^2} = \sqrt{\frac{2S}{c}}$$

The adoption level EV lies within the interval [0,1] and it is a share of the firm's activity, and therefore cannot be negative. Hence, only the positive root remains as follows:

$EV_S = \sqrt{\frac{2S}{c}}$

For a check, substituting $EV_S = \sqrt{\frac{2S}{c}}$ back into the expression $(\frac{c}{2})\ EV^2 - S$ as follows:

$(\frac{c}{2}) \times (EV_S)^2 = (\frac{c}{2}) \times \left(\sqrt{\frac{2S}{c}}\right)^2$

$= (\frac{c}{2}) \times \frac{2S}{c}$

$= S$

This confirms that $(\frac{c}{2})\ (EV_S)^2 - S = S - S = 0$.

2.2.4 PROFIT

Combining functions of revenue, cost, and cost of borrowing, the net profit for a borrower firm is as follows:

$$\pi(EV) = (M) \times\ EV^{r} - (\tfrac{c}{2})\ (EV)^2 - \mathrm{i}\left((\tfrac{c}{2})\ (EV)^2 - S\right)$$

Simplifying the expression '−i' as follows:

$$= -\mathrm{i}\ (\tfrac{c}{2})\ (EV)^2 + \mathrm{Si}$$

Substituting this back into the full expression for profit gives the following function:

$$\pi(EV) = (M) \times\ EV^{r} - (\tfrac{c}{2})\ (EV)^2 - \mathrm{i}\left((\tfrac{c}{2})\ (EV)^2\right) - S\mathrm{i}$$

Factoring out the common term as follows:

$$= -(\tfrac{c}{2})\ (EV)^2\ [1 + i]$$

Substituting back into the profit function as follows:

$$\pi(EV) = -(M) \times\ EV^{r} - (\tfrac{c}{2})\ (EV)^2\ [1 + i] + \mathrm{Si}$$

This expression reflects that revenue rises concavely with EV adoption, total cost rises non-linearly with EV adoption, and this quadratic term is resized with ; higher interest rate increases the cost of each unit of EV adoption. Also, the term Si reflects the interest cost avoided due to investment financed from savings, independent of EV. The interaction between i and the quadratic cost term explains how access to finance determined by the financial environment of an economy, shapes the optimal EV adoption decision.

2.3 EV ADOPTION DECISION

In the absence of any financial friction, an unconstrained optimum serves as the benchmark level of EV adoption. The firm chooses EV level 'EV' to maximise profit 'π(EV)'.

2.3.1 FIRST ORDER CONDITION

Differentiating and setting the derivative to zero.

- Derivative of the first term w.r.t EV : $(M) \times EV^{r} = M \times rEV^{r-1}$
- Derivative of the second term w.r.t EV: $(\frac{c}{2})\ (EV)^2\ [1 + i] = -c\ (1+i) \times EV$
- Derivative of the third term w.r.t EV: Si = 0

This explains that interest (cost of borrowing) and savings of a firm are not affected by the level of EV adoption and they affect profit but do not affect EV decision.

Combining all the terms and setting FOC equal to zero as follows:

$M \times rEV^{r-1} - c(1+i)\ EV = 0$

$M \times rEV^{r-1} - c(1+i) \times EV = 0$

$M \times rEV^{r-1} = c(1+i)\ EV$

Combining the powers of EV as follows:

$= \frac{-M \times rEVr-1}{EVr-1}$

$Mr = c(1+i) \times EV^{2-r}$

Isolating EV^{2-r}:

$(EV^{2-r}) = \frac{Mr}{c(1+i)}$

$(EV^{2-r})^{1/(2-r)} = \left(\frac{Mr}{c(1+i)}\right)^{1/(2-r)}$

$EV = \left(\frac{Mr}{c(1+i)}\right)^{1/(2-r)}$

Optimal EV adoption level is: $EV^* = \left[\left(\frac{Mr}{c(1+i)}\right)^{1/(2-r)}\right]^{2-r}$

For checking, substituting this optimal EV level back into the FOC as follows:

$c(1+i) \times (EV^*)^{2-r} = c(1+i)^{2-r}$

$= c(1+i) \cdot \left(\frac{Mr}{c(1+i)}\right)$

$= Mr$

2.3.2 OPTIMAL EV ADOPTION IN BOTH ECONOMIES

Firm in economy H faces the profit function is as follows:

$\pi(EV) = MEV^r - (c/2)\,(1+i_H)\,EV^2 + S\,i_H$

Derivative of $\pi(EV)$ w.r.t EV = $MrEVr^{-1}$

$= -c(1+i_H)\,EV$

Derivative of $S\,i_H$ w.r.t. EV = 0

Summing all three gives:

$= MrEVr^{-1} - c(1+i_H)\,EV + 0$

$= MrEVr^{-1} - c(1+i_H)\,EV$

Setting the FOC to Zero:

$MrEV^{r-1} - c(1+i_H)\,EV = 0$

$MrEV^{r-1} = c(1+i_H)\,EV$

Solving for EV gives:

$Mr = c(1+i_H)\,EV^{2-r}$

$Mr/\,c(1+i_H) = EV^{2-r}$

$EV_H^* = \left(\frac{Mr}{c(1+i)}\right)^{1/(2-r)}$

A firm in economy L faces the same revenue and cost structure as Economy H and only the interest rate is different. The profit function is as follows:

$\pi(EV) = MEV^r - (c/2)\,(1+i_L)\,EV^2 + S\,i_L$

The derivative of all terms in the profit function w.r.t EV is as follows:

1. $Mr\,EV^{r-1}$
2. $-c(1+i_L)\,EV$
3. 0

Summing all three gives:

$= MrEVr^{-1} - c(1+i_L)\ EV + 0$

$= MrEVr^{-1} - c(1+i_L)\ EV$

Setting the FOC to Zero:

$MrEV^{r-1} - c(1+i_L)\ EV=0$

$MrEV^{r-1} = c(1+i_L)\ EV$

Solving for EV gives:

$Mr = c(1+i_L)\ EV^{2-r}$

$$(EV2\ -\ r)^{1/2-r} = \left(\frac{Mr}{c(1+iL)}\right)^{1/2-r}$$

$$= EV^*_L = \left(\frac{Mr}{c(1+iL)}\right)^{1/2-r}$$

Assuming that γ = 1/2-r for simplicity; the optimal EV allocation in economy H (high constraint) is as follows:

$$=EV^*_H = \left(\frac{Mr}{c(1+iH)}\right)^{\gamma}$$

And EV adoption level in economy L (low constraint) is below:

$$=EV^*_L = \left(\frac{Mr}{c(1+iL)}\right)^{\gamma}$$

Since interred rate in H > interest rate in L , $EV_H < EV_L$

This supports this paper's proposition that holding market size, technology, and all other features constant, a higher cost of borrowing reduces firm's investment and ability to choose optimal EV adoption level: $\partial EV^*/\partial i < 0$. This also aligns with the cross-country evidence on SME financing terms suggesting that differences in interest rate independent of any quantity rationing lead to differences in borrowing and investment[19].

2.3.3 SECOND ORDER CONDITION

The second derivative of π(EV) is as follows:

$Mr(r-1) \times EV^{r-1-1} - c(1+i)$

$Mr(r-1) \times EV^{r-2} - c(1+i)$

For economy L:

$Mr(r-1) \times EV^{r-1-1} - c(1+ i_l)$

$Mr(r-1) \times EV^{r-2} - c(1+ i_l)$

For economy H:

$Mr(r-1) \times EV^{r-1-1} - c(1+ i_H)$

$Mr(r-1) \times EV^{r-2} - c(1+ i_H)$

Since $r \in (0, 1)$, the term $(r - 1)$ is negative, therefore the first term is negative for all firms adopting EV technology and the second term $-c(1+i)$ is also negative. Hence $d^2\pi/dEV^2 < 0$. This reflects the concavity of $\pi(EV)$.

2.4 MAXIMIZED PROFIT

The profit function is:

$$\pi(EV) = -(M) \times EV^r - (\frac{c}{2})(EV)^2 [1 + i] + Si$$

The FOC gives the following relationship:

$$M \times rEV^{r-1} = c(1+i) EV$$

Manipulating the FOC gives the following expression:

$$M(EV)^r = (\frac{c(1+i)}{2})(EV)^2$$

Substituting this into the profit function as follows:

$$\pi(EV) = (\frac{c(1+i)}{2})(EV)^2 - c/2 (EV)^2 (1+i) + Si$$

Factoring out $c (EV)^2 (1+i)$ gives:

$$\pi(EV) = c (EV)^2 (1+i) (\frac{1}{r} - \frac{1}{2}) + Si$$

The profit function simplifies to:

$$\pi(EV) = c (EV)^2 (1+i) (\frac{2-r}{2r}) + Si$$

The value of $(\frac{2-r}{2r})$ is strictly positive and greater than 1 because $2-r > r$ as $r < 1$. This supports that $\pi^* >$ Si whenever firm adopts EV* and chooses EV = 0 if profit does not improve. The revenue concavity parameter r approaches 1 (less concave), the coefficient $(\frac{2-r}{2r})$ approaches , shrinking the effect of $(EV^*)^2$ term relative to the constant Si.

2.5 SHADOW PRICE OF DEBT

The shadow price of the constraint is central to this model and the Lagrange multiplier considering the borrowing cap provides a direct indicator of financial environment.

Since $B(EV) = (\frac{c}{2})\ EV^2 - S$, the constraint $B(EV) \leq$ can be restated as:

$(\frac{c}{2})EV^2 - S \leq$ for economy H

$(\frac{c}{2})EV^2 - S \leq$ for economy L

Solving for EV gives:

$EV^2 \leq (\frac{2\ (S + B_H)}{c})$ for economy H and $EV^2 \leq (\frac{2\ (S + B_H)}{c})$ for economy L

$$EV_H = (\frac{2\ (S + B_H}{c})$$

This is the feasible limit on adoption of EV in economy H with borrowing cost. Similarly, feasible limit of EV adoption in economy L is as follows:

$$EV_L = (\frac{2\ (S + B_L\ )}{c})$$

Since $B_L > B_H$ by assumption, it also translated into $EV_L > EV_H$. This follows the credit-rationing in which lenders refuse to lend beyond the threshold at even higher rates because higher rates would worsen the pool of borrowers through adverse selection[14].

2.6 THE LANGRANGIAN AND KKT CONDITIONS

The firm in economy H solves:

$$\max\ \pi(EV) = MEV^r - (\frac{c\ (1 + i_H)}{2})\ EV^2 + Si_H \quad \text{subject to: } EV \leq EV_H \text{ and } EV \geq 0$$

Firm in economy L solves:

$$\max\ \pi(EV) = MEV^r - (\frac{c\ (1 + i_L)}{2})\ EV^2 + Si_L \quad \text{subject to:} EV \leq EV_L \text{ and } EV \geq 0$$

Setting up the lagrange with multiplier $\lambda \geq 0$ to the upper constraint, gives the following function:

For economy L (low constrained):

$(EV, \lambda) = \pi(EV) + \lambda (EV_L - EV)$

$(EV, \lambda) = MEV^r - (\frac{c(1 + i_L)}{2}) EV^2 + Si_L + \lambda(EV_L - EV)$

For economy H (high constrained):

$(EV, \lambda) = MEV^r - (\frac{c(1 + i_H)}{2}) EV^2 + Si_H + \lambda(EV_H - EV)$

The Karush-Kuhn-Tucker (KKT) conditions are:

(i) $dL/dEV = MrEV^{r-1} + (-c(1+i)EV) + 0 + (-)\lambda$

$= MrEV^{r-1} - c(1+i) EV - \lambda = 0$

(ii) $\lambda \geq 0$

(iii) $\lambda(EV_{H,L} - EV) = 0$

(iv) $EV \leq EV_{H, L}$

2.6.1 NON-BINDING CONSTRAINT

If the constraint is not binding then for Economy H the condition $EV^*_H \leq E\overline{V}_H$ holds and $\lambda = 0$. The unconstrained optimum for economy H is:

$dL/dEV = MrEV^{r-1} - c(1+i_H) EV - = 0$

$MrEV^{r-1} - c(1+i_H) EV - 0 = 0$

$MrEV^{r-1} - c(1+i_H) EV = 0$

$EV\_unconstrained_H = [\frac{Mr}{c(1+iH)}]^{1/(2-r)}$

In this case the firm in Economy H is not credit rationed in terms of quantity but faces an EV adoption level less than what is adopted by economy L.

Similarly, for economy L in non-binding ($EV^*_L \leq EV_L$):

$EV\_unconstrained_L = [\frac{Mr}{c(1+iL)}]^{1/(2-r)}$

2.6.2 BINDING CONSTRAINT

If the firm is bound by the borrowing cap then we have the following expression:

$dL/dEV = MrEV^{r-1} - c(1+i) EV - \lambda = 0$

Substituting the binding constraint value of EV into this gives:

$dL/dEV = Mr - c(1+i_{H,L})\, EV_{H,L} - \lambda = 0$

Isolating gives:

$Mr\, EV_{H,L}^{r-1} - c(1+i_{H,L})\, EV_{H,L} = \lambda$

The multiplier explains the change in profit of the firm with an incremental unit of borrowing capacity. A large indicates that the marginal return to relaxing the credit constraint is large relative to the cost of the credit itself and this aligns with the evidence that binding credit constraints generate investment shortfalls despite profitable investment opportunities.

$EV_{L,H} = \sqrt{2(S + B_{L,H})/c}$

This is the *maximum* adoption level that firms in each Economy L and H *can finance* given the borrowing cap in economy L and H and , respectively.

2.7 PROFIT GAP BETWEEN ECONOMIES

The derivations establish that the credit constraint binds in *both* economies L and H i.e. EV*H > EVH and EV*L > EVL. Firm in each operates at its own feasibility ceiling and the *actual* profit earned by each firm is therefore π_H *and* π_L .This profit is evaluated at the adoption ceiling. The profit gap between the two economies is accordingly defined as:

$\Delta\pi = \pi_L(EV_L) - \pi_H(EV_H)$

$\pi(EV) = MEV^r - \frac{c}{2} EV^2 (1 + i_H) + Si$

Profit for firm in economy H is:

$\pi(EV_H) = MEV^r{}_H - \frac{c}{2} EV^2{}_H (1 + i_H) + Si_H$

And for economy L is:

$\pi(EV_L) = MEV^r{}_L - \frac{c}{2} EV^2{}_L (1 + i_L) + Si_L$

Substituting into the profit gap equation gives:

$\Delta\pi = MEV^r{}_L - MEV^r{}_H - \frac{c}{2} EV^2{}_L (1 + i_L) - \frac{c}{2} EV^2{}_H (1 + i_H) + Si_L - Si_H$

By grouping we get three pairs as follows:

$\Delta\pi = \Delta R + \Delta C - \Delta I$

Pair 1 ΔR : reflects difference in revenues.

If economy L adopts EV more, then gap widens in revenues since a larger output of EV technology generates more revenue.

Pair 2 ΔC: reflects difference in cost of capital

If economy L's EV adoption is higher, cost term is larger in absolute terms than economy H's.

Pair 3 ΔI: reflects the interest cost differential on savings between the two economies

Since S is same for both economies and $i_H > i_L$ and $Si_H > Si_L$, so ΔI = SiL − SiH < 0 and therefore this narrows the profit gap slightly.

$\Delta\pi = \Delta R + \Delta C + \Delta I$

2.8 Comparative Statics

$EV = \left(\frac{Mr}{c(1+i)}\right)^{\gamma}$ given that $\gamma = 1/(2 - r)$

2.8.1 Interest rate

$EV^* = \left(\frac{Mr}{c}\right)^{\gamma} \times (-\gamma(1+i)^{-\gamma-1})$

$(-\gamma/(1+i)) = EV^*$ therefore, by substituting, and simplifying we get:

$= -[(-\gamma/(1+i))]\ EV^* < 0$

Every increase in the interest rate reduces the optimal EV adoption level by $[(-\gamma/(1+i)]$.

2.8.2 BORROWING GAP

Differentiating EV adoption ceilings for economy H $= \bar{EV}_H = \sqrt{[2(S + \bar{B}_H)/c]}$ and for economy L $= \bar{EV}_L = \sqrt{[2(S + \bar{B}_L)/c]}$ w.r.t. borrowing cap as follows:

$\frac{\partial \bar{EV}_{H,L}}{\partial \bar{B}_{H,L}} = ½[2(S + \bar{B}_{H,L})/c]^{-1/2} \times \partial/\partial\bar{B}_H[2(S + \bar{B}_{H,L}□)/c]$

Since $= 1/\sqrt{[2(S + \bar{B})/c]} = 1/EV$

$\partial \bar{EV}_{H,L}□/\partial\bar{B}_{H,L} = 1/\bar{B}_{H,L} \times 1/c$

The effect is diminishing in $E\bar{V}$ is due to $\bar{B}$

3. RESULTS

3.1 DETERMINATION OF EV ADOPTION

The comparative statics show that the relaxation of borrowing cap $\bar{B}$ raises the EV adoption ceiling $E\bar{V}$, while reducing the interest rate i raises the optimal level of EV adoption EV*. Both of them deal with different objectives.

This section shows that both the channels are not symmetric and the borrowing cap exclusively determines the level of EV adoption while the interest rate is not significant in determining this. However, the interest rate does matter for profitability.

The constrained solution:

When the firm's unconstrained EV* is higher than the feasible $E\bar{V}$, the borrowing constraint $()\cdot EV^2 - S \leq \bar{B}$ binds with equality.

Solving for EV gives EV adoption level in a financial constrained environment as below:

$$E\bar{V} = \sqrt{[2(S + \bar{B})/c]}$$

This expression demonstrated that the savings stock S, the borrowing cap $\bar{B}$, and the cost convexity parameter c play roles while the interest rate i, the market size M, or the revenue curvature r are absent.

Differentiating $E\bar{V}$ with respect to financial parameters as below also confirms this:

$$\partial EV / \partial B = 1/cEV > 0$$

$$\partial EV / \partial i = 0$$

The first expression shows that when the borrowing cap rises, it increases EV adoption but at a diminishing rate. Since with each additional unit of borrowing increases adoption by less. The second expression shows that interest rate does not significantly affect $E\bar{V}$.

Proposition

If the borrowing constraint binds such that $EV^* > E\bar{V}$. Then:

(i) The borrowing cap raises EV adoption at a diminishing rate.

(ii) The interest rate does not effect on EV adoption.

(iii) The adoption gap between Economy L and Economy H is as follows:

$$E\bar{V}_L - E\bar{V}_H = \sqrt{[2(S + \bar{B}_L) / c]} - \sqrt{[2(S + \bar{B}_H) / c]}$$

This gap depends only on the cap difference and is independent of the interest rate differential.

Intuition:

The result shows that when a firm cannot borrow beyond $\bar{B}$, the binding constraint on its behavior is the credit availability policy and not simply the price of borrowing i.e. lowering the interest rate makes borrowing cheaper but does not increase borrowing. It is in fact the expansion of the borrowing limit that gives the firm opportunity to borrow it did not previously have.

In such a regime policy that governs credit-quantity such as green loan program and credit guarantee scheme, becomes more relevant for a higher EV adoption while decreasing the interest rate improves profitability. This sheds light on access to capital in terms of quantity and not merely price and is important for policy in developing economies aiming at economy-wide EV market expansion and environmental impact.

3 DISCUSSION

This paper advances literature through a closed-form theoretical model, that demonstrates that the binding constraint in credit-constrained SMEs is the quantity of credit available, and not interest rate. This distinction in channels of financing constraints at the firm level is the paper's contribution.

The model establishes that the binding constraint applies in *both* economies: $EV^*_H > EV_H$ and $EV^*_L > EV_L$ and firm in Economy L adopts more than firm in Economy H but adoption is less than EV*L. This result is structural, not parametric. The unconstrained optimum $EV^* = \gamma\left[\frac{Mr}{c(1+i)}\right]$ is determined by market parameters (M, r) and interest rate (i). The ceiling $EV = \sqrt{\frac{2(S+B_{H,L})}{c}}$ is determined by financial variables savings and borrowing (S, B̄) and cost convexity (c). These two quantities vary across economies and investment opportunities (signalled by EV*) are also different (may be greater) from available credit (signalled by EV). This aligns with work by Stiglitz and Weiss[14], suggesting that quantity limits on credit affect the equilibrium outcome instead of interest rate differences.

Holmstrom and Tirole[20] extend this to a general equilibrium framework, showing that pledge-able collateral restricts the aggregate investment. The ceiling $EV = \sqrt{\frac{2(S+B_{H,L})}{c}}$ is the firm-level, closed-form expression of this restriction.

The profit gap (Δπ) comprises of change in revenue component (ΔR), capital cost component (ΔC) and savings dependent investment component (ΔI). Each component has a different effect on profit gap driven from a different assumption. ΔR is a positive determinant. Since B̄L > B̄H and $EV = \sqrt{\frac{2(S+B_{H,L})}{c}}$ is strictly increasing in B̄, this gives $EV_L > EV_H$ given that $r \in (0,1)$. This implies that $EV_L^r > EV_H^r$ and if multiplied with market parameter M > 0, gives ΔR > 0. Brown, Fazzari, and Petersen[21] suggest that financing constraints primarily reduce the *level* of innovation investment by reducing the scale or potential of firms and not by merely raising a firm's marginal cost. So, ΔR in this paper, represents that the gap arises in revenues of firm in Economy L (generating revenue MEV_L^r) and of firm in Economy H (generating MEV_H^r solely due to the adoption-level difference.

The effect of difference in capital cost on profit gap depends on two forces operating in opposite directions. $EV_L > EV_H$ means Economy L has a larger cost base decreasing the profit gap. However, since $i_L < i_H$, the financing multiplier in Economy L $(1+i_L)$ is smaller leading to a positive gap in cost of capital component (ΔC) since there is lower financing cost in L per unit of borrowing. The net sign depends on whether the aggregate cost of capital dominates or the lower price of borrowing dominates depending on the magnitudes of $\bar{B}_H$, $\bar{B}_L$, i_H, and i_L. The effect of ΔI is unconditionally negative. As $\Delta I = S(i_L - i_H) < 0$, this shows that S reduces the firm's net borrowing, so the firm in Economy H pays more interest than Economy L on the same savings stock.

In the binding case as follows:

$$\lambda = M \cdot r \cdot EV^{r-1}_{H,L} - c(1+i_{H,L}) \cdot EV_{H,L} > 0$$

λ is the slope of the profit function π(EV) at the ceiling and the second-order condition, $d^2\pi/dEV^2 < 0$ establishes that π is globally concave, so the firm is on the rising part of its profit curve whenever it is operating below EV*. The shadow price is therefore positive. λ measures the marginal profit value of one additional unit of EV adoption at the current ceiling. It is *not* the marginal profit value of one additional unit of borrowing capacity ($\partial\pi/\partial\bar{B}$). The two are related by the chain rule: $\partial\pi/\partial\bar{B} = \lambda \cdot \partial EV/\partial\bar{B} = \lambda/(c \cdot EV)$.

Kaplan and Zingales[22] argue that the appropriate indicator of a firm's financing constraint is the wedge between the shadow values of internal and external funds. In the present model, this wedge is exactly λ in the binding case: the firm would pay up to λ per unit of additional EV adoption capacity, but the market will not supply that capacity beyond $EV_{H,L}$. Whited and Wu[23] show empirically that this shadow cost is economically large and persistent for small, asset-poor firms — consistent with the model's prediction that $\lambda > 0$ whenever $EV^* > EV$, which is the condition characterising credit-constrained SMEs.

This model derives the interest-rate channel; $\partial EV^*/\partial i < 0$, this is a *price effect*. A higher i raises the per-unit cost of borrowing, shrinking the profit-maximising EV adoption level. This channel operates even in the absence of a borrowing ceiling. The borrowing-cap channel has a quantity effect > 0. Increasing $\bar{B}$ directly raises the borrowing-cap. This allows the firm to finance a higher level of EV adoption. The derivative also exhibits that as the borrowing cap increases, additional units of borrowing produce smaller increases in adoption. This is the concavity of $\bar{B}$.

Comparing the two economies, Economy H is disadvantaged due to higher interest rate hindering EV adoption and lower borrowing cap. This cross-country comparison confirms that both the cost of borrowing and availability of credit affect SME investment in EV adoption[8,19].

4 Policy Implications

Since change in revenue ($\Delta R > 0$) is the only sign-guaranteed component of profit gap Δπ, policies aimed at expanding the borrowing including credit guarantees, specialized credit platforms, broad collateral categories, may assist SMEs in EV adoption. Furthermore, the highest returns to credit lending schemes are for the most severely constrained firms who have the lowest level of EV adoption. Therefore, such firms can be targeted with specialized credit schemes. Also, the estimated shadow price λ for a given SME may be used as a basis for credit allocation and financial mobilization policy Holmstrom and Tirole[20].

4.1 Limitations and Future Research

This model has multiple simplifying features, binding its scope. Firstly, the framework is static due to the one-time EV adoption decision by firms. This is distant from the dynamic real-world aspects of investment, learning-by-doing, technology updates, and evolving financing environment. A multi-period or dynamic programming setting may allow a better analysis of time-wise credit constraints effects on EV adoption.

Moreover, each economy is represented by a single, homogeneous firm. However, SMEs differ substantially in productivity, collateral, risk profiles and several other aspects. A model with firm heterogeneity may advance richer distributional predictions.

Also, future research could use firm-level panel data from developing economies to empirically infer the effect of financing constraints on EV or green technology adoption. Furthermore, the model does not consider government subsidies, tax incentives, and supply-side factors while these are significant determinants of EV adoption.

5. CONCLUSION

This paper develops a static theoretical model to the effect of the financial environment on electric vehicle adoption among small and medium enterprises. The model establishes that when the borrowing constraint is binding, it is the borrowing cap rather than the interest rate that exclusively determines the level of EV adoption. Interest rate influences profitability without altering the adoption quantity. This distinction between the interest channel (price channel of credit) and the borrowing cap (quantity channel of credit) is the paper's central analytical contribution. The shadow price of the borrowing constraint offers a firm-level measurement of financing restriction and a potential indicator for targeting suitable firms for credit allocation policies. Comparative statistics confirm that expanding borrowing capacity raises EV adoption but at a diminishing rate and a lower interest rate raises the unconstrained optimum. These results together suggest that, in economies where borrowing caps are binding constraint rather than the interest rates, quantity-based policy instruments (beyond interest rate subsidies alone), including credit guarantees and green lending programmes may be more effective in raising firm-level EV adoption. Future research using firm-level panel data from developing economies could test these propositions empirically.

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