Essays on Luxury brand strategies for second-hand market using blockchain technology

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4.1 Theoretical contributions

This thesis contributes to two main streams of literature: the second-hand luxury market and the use of blockchain technology for luxury brand authentication (Shen et al., 2020, 2021). While prior studies have explored these topics separately, they have not examined the simultaneous impact of blockchain on brand exclusivity and profitability in the second-hand luxury market.

Essay one uses a single-period game-theoretic analytical model to analyse brand-appropriate strategies for blockchain technology in the second-hand market, considering factors such as the social value attached to knowingly purchasing counterfeits, the brand's aspirational value, and status utility. Our findings offer valuable insights for luxury brand managers regarding the role of blockchain technology, luxury identity, and product quality in preserving brand exclusivity and the circumstances under which the second-hand platform can impact the brand's aspirational value.

Building on essay one, essay two proposes second-hand platform strategy implications for the luxury brand. A single-period game-theoretic analytical model is proposed to examine two benefits of blockchain implementation. The first benefit is product authentication captured through changes in status utility. The second benefit is product ownership record desirability captured through gains in utility. Furthermore, the allure of a luxury brand is magnified by its impressive resale value, underscoring its significant asset value. This symbiotic relationship between the prices of new offerings and their resale values not only enhances the brand's appeal but also raises the price bar for the entire collection (Kapferer & Bastien, 2012). Essay two suggests that focusing on a specific timeframe characterized by neutral market sentiment towards luxury brands can help in decoupling the relationship between new product price and resale value, thereby being helpful in gaining insights into a clearer understanding of the second-hand market. The findings in the study can serve as a stepping stone for further research in developing effective strategies for luxury second-hand markets.

4.2 Limitations and future research directions

While these essays provide valuable insights, there are some limitations that present opportunities for future research. First, it is important to acknowledge that this study assumed consumer product valuations are heterogeneously distributed with a uniform distribution, which may not accurately reflect societal wealth distribution. Future research could explore the impact of different income levels on consumer valuation of luxury brands. Second, with sustainability becoming an increasingly important factor for both consumers and companies, it would be valuable for future research to examine brand strategies that appeal to environmentally conscious consumers (Feng et al., 2020; Klaus & Tynan, 2022)

Third, luxury brands have observed that young consumers value access to luxury more than owning them permanently (Luxe Digital, 2022). This shift has prompted luxury brands like Kering to offer rental services (Feng et al., 2020; Chitrakorn, 2021). Fourth, , as the luxury industry (valued at $1319B in 2022) increasingly enters the sharing economy, it is crucial to determine the optimal strategy for luxury brand in engaging with second-hand platform and rental platform (Cisse, 2020; Feng et al., 2020). Fifth, in addition to second-hand and rental markets, luxury brands are expanding into the metaverse to target new consumer demographics like gamers, warranting analysis of these strategies together (Girod, 2023).

Sixth, luxury brands are interested in emerging markets like India and China, where the number of millionaires is projected to grow by 105% and 97% by 2026, respectively (Schorrocks et al., 2022). Despite Balenciaga and Reliance Brands Limited has signed a partnership deal (D’Souza, 2022), brands in India need to comply with regulatory requirements, such as sourcing at least 30% of the value of goods locally (DPIIT, 2020). Additionally, these brands will face tough competition from homegrown luxury brands like Sabyasachi and Heaven Gaia, which resonate with their culture. Considering these complexities alongside second-hand opportunities could provide impactful insights.

Chapter 5 Proofs of the results in Chapter 2 and 3

5.1 List of Appendix for chapter 2

Appendix A: Summary of Notations

Table A.1: Parametric notations

Notations	Definitions	Parametric Ranges
$p_{\alpha j}$	Price of player α in case *j*. Where *j*= b1, b2, c1, c2, c3 & c4 and α= B, S & C	$[0,\infty)$
λ	Second-hand product quality	$[0,1]$
δ	Counterfeit product quality	$[0,1]$
μ	Reselling utility gain sensitivity parameter	$[0,1]$
γ	Consumer’s perception about quality of product	$[0,1]$
i	Brand Identity/ Luxury identity	$[0,1]$
S	Second-hand Platform acquisition cost	$[0,\infty)$
a	Authentication cost	$[0,1]$
$T_{\alpha j}$	Consumer valuation threshold for player *α* for case *j*	$[0,1]$
$\pi_{\alpha j}$	Profit for player *α* for case *j*	$(-\infty,\infty)$
SU_{Bj}	Exclusivity of a luxury product for case *j*	$(-\infty,\infty)$
CW_j	Consumer welfare function for case *j*	$(-\infty,\infty)$

Table A.2: Utility functions $\left(U_{\alpha j}\right)$ expressions. Where *j*= b1, b2, c1, c2, c3 & c4 and α= B, S & C

Cases	Luxury Brand product (B)	Second-hand product (S)	Counterfeit product (C)	Non-Buyers (N)
b1	$v-p_{Bb1}+\frac{1}{2}i\left(T_{Cb1}+1\right)$	NA	$\delta v-p_{Cb1}+\frac{1}{2}i\left(T_{Cb1}+1\right)$	$\frac{iT_{Cb1}}{2}$
b2	$v-p_{Bb2}+\frac{1}{2}i\left(T_{Sb2}+1\right)$	NA	NA	$\frac{iT_{Bb2}}{2}$
c1	$v-p_{Bc1}+\frac{1}{2}i\left(T_{Cc1}+1\right)+\mu p_{Sc1}$	$v((1-\gamma)\delta+\gamma)-p_{Sc1}+\frac{1}{2}i\left(T_{Cc1}+1\right)$	$\delta v-p_{Cc1}+\frac{1}{2}i\left(T_{Cc1}+1\right)$	$\frac{iT_{Cc1}}{2}$

c2	$v-p_{\mathrm{Bc2}}+\frac{1}{2}i\left(T_{\mathrm{Sc2}}+1\right)+\mu p_{\mathrm{Sc2}}$	$\lambda v-p_{\mathrm{Sc2}}+\frac{1}{2}i\left(T_{\mathrm{Sc2}}+1\right)$	NA	$\frac{iT_{Sc2}}{2}$
c3	$v-p_{\mathrm{Bc3}}+\frac{1}{2}i\left(T_{\mathrm{Cc3}}+1\right)+\mu p_{\mathrm{Sc3}}$	$v\lambda-p_{\mathrm{Sc3}}+\frac{1}{2}i\left(T_{\mathrm{Cc3}}+1\right)$	$\delta v-p_{Cc3}+\frac{1}{2}i\left(T_{\mathrm{Cc3}}+1\right)$	$\frac{iT_{Cc3}}{2}$
c4	$v-p_{\mathrm{Bc4}}+\frac{1}{2}i\left(T_{\mathrm{Sc4}}+1\right)+\mu p_{\mathrm{Sc4}}$	$v\lambda-p_{\mathrm{Sc4}}+\frac{1}{2}i\left(T_{\mathrm{Sc4}}+1\right)$	NA	$\frac{iT_{Sc4}}{2}$

Table A.3: Profit function $\left(\pi_{\alpha j}\right)$ expression. Where *j*= b1, b2, c1, c2, c3 & c4 and α= B, S & C

Cases	**Luxury Brand product (B)**	**Second-hand product (S)**	**Counterfeit product (C)**
b1	$p_{\mathrm{Bb1}}\left(1-T_{\mathrm{Bb1}}\right)$	NA	$\left(p_{Cb1}-\delta\right)\left(T_{\mathrm{Sb1}}-T_{\mathrm{Cb1}}\right)$
b2	$\left(p_{\mathrm{Bb2}}-a\right)\left(1-T_{\mathrm{Bb2}}\right)$	NA	NA
c1	$p_{Bc1}\left(1-T_{Bc1}\right)$	$\left(p_{Sc1}-\lambda\right)\left(T_{Bc1}-T_{Sc1}\right)$	$\left(p_{Cc1}-\delta\right)\left(T_{Sc1}-T_{Cc1}\right)$
c2	$\left(p_{Bc2}-a\right)\left(1-T_{Bc2}\right)+a\left(T_{Bc2}-T_{Sc2}\right)$	$\left(p_{Sc2}-a-\lambda\right)\left(T_{Bc2}-T_{Sc2}\right)$	NA
c3	$p_{Bc3}\left(1-T_{Bc3}\right)+\left(p_{Sc3}-\lambda\right)\left(T_{Bc3}-T_{Sc3}\right)-S$		$\left(p_{Cc3}-\delta\right)\left(T_{Sc3}-T_{Cc3}\right)$
c4	$\left(p_{Bc4}-a\right)\left(1-T_{Bc4}\right)+\left(p_{Sc4}-a-\lambda\right)\left(T_{Bc4}-T_{Sc4}\right)-S$		NA

Table A.4: Exclusivity $\left(SU_{Bj}\right)$ expression of luxury product. Where *j*= b1, b2, c1, c2, c3 & c4

Case	**Calculation for Exclusivity**
b1	$\int_{T_{\mathrm{Cb1}}}^{1}\frac{1}{2}i\left(T_{\mathrm{Cb1}}+1\right)dv$
b2	$\int_{T_{\mathrm{Bb2}}}^{1}\frac{1}{2}i\left(T_{\mathrm{Bb2}}+1\right)dv$
c1	$\int_{T_{\mathrm{Cc1}}}^{1}\frac{1}{2}i\left(T_{\mathrm{Cc1}}+1\right)dv$
c2	$\int_{T_{\mathrm{Sc2}}}^{1}\frac{1}{2}i\left(T_{\mathrm{Sc2}}+1\right)dv$
c3	$\int_{T_{\mathrm{Cc3}}}^{1}\frac{1}{2}i\left(T_{\mathrm{Cc3}}+1\right)dv$
c4	$\int_{T_{\mathrm{Sc4}}}^{1}\frac{1}{2}i\left(T_{\mathrm{Sc4}}+1\right)dv$

Table A.5: Luxury consumer welfare function $\left(CW_j\right)$. Where *j*= b1, b2, c1, c2, c3 & c4

Case	Expression
b1	$\int_{T_{Bb1}}^{1}\left(\frac{1}{2}\left(i+2v-2p_{Bb1}+iT_{Cb1}\right)\right)dv$
b2	$\int_{T_{Bb2}}^{1}\left(\frac{1}{2}\left(i+2v-2p_{Bb2}+iT_{Bb2}\right)\right)dv$
c1	$\int_{T_{Bc1}}^{1}\left(\frac{1}{2}\left(i+2v-2p_{Bc1}+2\mu p_{Sc1}+iT_{Cc1}\right)\right)dv$
c2	$\int_{T_{Bc2}}^{1}\left(\frac{1}{2}\left(i+2v-2p_{Bc2}+2\mu p_{Sc2}+iT_{Sc2}\right)\right)dv$
c3	$\int_{T_{Bc3}}^{1}\left(\frac{1}{2}\left(i+2v-2p_{Bc3}+2\mu p_{Sc3}+iT_{Cc3}\right)\right)dv$
c4	$\int_{T_{Bc4}}^{1}\left(\frac{1}{2}\left(i+2v-2p_{Bc4}+2\mu p_{Sc4}+iT_{Sc4}\right)\right)dv$

Appendix B: Equilibrium expressions

Table B.1: Equilibrium Outcomes

Case	Notation	Expression
b1	p^*_{Bb1}	$\frac{4+i-(2+i)\delta}{8-2\delta}$
	p^*_{Cb1}	$\frac{\left(i^2(-1+\delta)+8\delta-2i(6+(-9+\delta)\delta)\right)\left(8\delta+i(-4+7i(-1+\delta)+2\delta(3+\delta))\right)}{16(2+i)^2(-4+\delta)^2(1-\delta)\delta}$
b2	p^*_{Bb2}	$\frac{(2+2a+i)}{4}$
c1	p^*_{Bc1}	$\frac{\left(8\gamma^3(-1+\delta)^2\mu-2\delta(3+\delta(-2+\mu)+2\lambda(1+\mu))-\gamma^2(-1+\delta)(8+i(1+\mu)+2\delta(-2+9\mu)-4\mu(2+\lambda+\lambda\mu))+\gamma\left(i(-1+\delta)(1+\mu)+4\delta^2(-2+3\mu)-4(2+\lambda+\lambda\mu)+2\delta\left(9-5\mu-2\lambda\left(-1+\mu^2\right)\right)\right)\right)}{\left(4\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)+\gamma(-1+\delta)(-1+3\mu)\right)\right)\right)}$
	p^*_{Sc1}	$\frac{i\gamma(-1+\gamma+\delta-\gamma\delta)+2(\gamma(-1+\delta)-\delta)\left(\gamma^2(-1+\delta)+\delta+2\lambda+\gamma(1-2\delta+2\lambda\mu)\right)}{2\left(-3\delta+\gamma(-4+\delta(4-3\mu))+\gamma^2(-1+\delta)(-1+3\mu)\right)}$
	p^*_{Cc1}	$\frac{i\gamma(-1+\delta)(4+\gamma(-1+3\mu))+2\delta\left(-2(2\delta+\lambda)+\gamma^2(-1+\delta)(-2+3\mu)-\gamma(5+3\delta(-2+\mu)+2\lambda\mu)\right)}{4\left(-3\delta+\gamma(-4+\delta(4-3\mu))+\gamma^2(-1+\delta)(-1+3\mu)\right)}$
c2	p^*_{Bc2}	$\frac{4-2\lambda+6\lambda\mu-2\lambda^2\mu+2\lambda^2\mu^2-i(-1+\lambda)(1+\mu)+2a(5+\mu)(1+\lambda\mu)}{8+\lambda(-2+6\mu)}$
	p^*_{Sc2}	$\frac{i-i\lambda+2a(1+\lambda+\lambda\mu)+\lambda(3-\lambda+2\lambda\mu)}{4+\lambda(-1+3\mu)}$
c3	p^*_{Bc3}	$\frac{\left(\delta\left(-4+4\lambda-8\lambda\mu-4\lambda^2(-1+\mu)\mu+i(-1+\lambda)(2+\mu)\right)+\lambda\left(8+4\lambda^2(-2+\mu)\mu-i(-1+\lambda)(2+\mu)+4\lambda(-2+3\mu)\right)\right)}{\left(4\delta\left(-2+\lambda\left(2+\mu^2\right)\right)-4\lambda\left(-4+\lambda\left(4+\mu^2\right)\right)\right)}$
	p^*_{Sc3}	$\frac{i(\delta-\lambda)(-1+\lambda)+2\lambda(\delta(-2+2\lambda-\mu)+\lambda(4-4\lambda+\mu))}{2\delta\left(-2+\lambda\left(2+\mu^2\right)\right)-2\lambda\left(-4+\lambda\left(4+\mu^2\right)\right)}$
	p^*_{Cc3}	$\frac{\left(-2\delta\lambda\left(\delta\left(-4-\mu+\lambda\left(4+\mu^2\right)\right)+\lambda\left(8+\mu-\lambda\left(8+\mu^2\right)\right)\right)+i\left(\delta^2\left(-1+\lambda+\lambda\mu^2\right)+\lambda^2\left(-4+\lambda\left(4+\mu^2\right)\right)+\delta\lambda\left(5-\lambda\left(5+2\mu^2\right)\right)\right)\right)}{\left(4\lambda\left(-\delta\left(-2+\lambda\left(2+\mu^2\right)\right)+\lambda\left(-4+\lambda\left(4+\mu^2\right)\right)\right)\right)}$
c4	p^*_{Bc4}	$\frac{-4+4\lambda-6\lambda\mu+4\lambda^2\mu-2\lambda^2\mu^2+2a(-1+\lambda)(2+\mu)+i(-1+\lambda)(2+\mu)}{-8+2\lambda\left(4+\mu^2\right)}$
	p^*_{Sc4}	$\frac{2a(-1+\lambda)+i(-1+\lambda)+\lambda(-4+4\lambda-\mu)}{-4+\lambda\left(4+\mu^2\right)}$

Table B.2: Exclusivity $\left(SU^*_{\alpha j}\right)$ expression of a luxury product at equilibrium. Where *j*= b1, b2, c1, c2, c3 & c4 and α= B

Cases	Exclusivity of a luxury product
b1	$-\left(\frac{i(-4+i(-7+\delta))(i+2\delta)\left(i^2(-7+\delta)+8(7-2\delta)\delta-2i\left(2-9\delta+3\delta^2\right)\right)}{32(2+i)^2(-4+\delta)^2\delta^2}\right)$
b2	$\frac{16i-i(-2-2a+i)^2}{32}$

c1	$-\left(\frac{(i(i(-6\delta+\gamma^2(-1+\delta)(-1+3\mu)+\gamma(-4+4\delta-6\delta\mu))+2\delta(-2\delta+2\lambda+3\gamma^2(-1+\delta)\mu+\gamma(-3+2\delta-3\delta\mu+2\lambda\mu)))(i(-6\delta+\gamma^2(-1+\delta)(-1+3\mu)+\gamma(-4+4\delta-6\delta\mu))+2\delta(2(5\delta+\lambda)-\gamma^2(-1+\delta)(-4+9\mu)+\gamma(13-14\delta+9\delta\mu+2\lambda\mu))))}{(32\delta^2(-3\delta+\gamma(-4+\delta(4-3\mu))+\gamma^2(-1+\delta)(-1+3\mu))^2)}\right)$
c2	$-\left(\frac{i(2\lambda(1+\lambda\mu)-4a(1+\lambda+\lambda\mu)+i(2+\lambda+3\lambda\mu))(-4a(1+\lambda+\lambda\mu)+i(2+\lambda+3\lambda\mu)-2\lambda(7-2\lambda+5\lambda\mu))}{8\lambda^2(4+\lambda(-1+3\mu))^2}\right)$
c3	$-\left(\frac{(i(2\delta(\delta-\lambda)\lambda\mu(1+\lambda\mu)+i(-\delta(-1+\lambda)\lambda+\delta^2(-1+\lambda+\lambda\mu^2)-\lambda^2(-4+\lambda(4+\mu^2)))))(2\delta\lambda(\delta(8-8\lambda+\mu-3\lambda\mu^2)+\lambda(-16+16\lambda-\mu+3\lambda\mu^2))+i(-\delta(-1+\lambda)\lambda+\delta^2(-1+\lambda+\lambda\mu^2)-\lambda^2(-4+\lambda(4+\mu^2)))))}{(32\delta^2\lambda^2(\delta(-2+\lambda(2+\mu^2))-\lambda(-4+\lambda(4+\mu^2)))^2)}\right)$
c4	$-\left(\frac{i(-4a(-1+\lambda)+2\lambda\mu(1+\lambda\mu)+i(-2+\lambda(2+\mu^2)))(-4a(-1+\lambda)+i(-2+\lambda(2+\mu^2))+2\lambda(8+\mu-\lambda(8+\mu^2)))}{8\lambda^2(-4+\lambda(4+\mu^2))^2}\right)$

Table B.3. Demand $\left(D^*_{B\,j}\right)$ expression of a luxury product at equilibrium. Where *j*= b1, b2, c1, c2, c3 & c4

Cases	Demand of a luxury product
b1	$\frac{-8(\delta-2)+(\delta-1)i^2+2(\delta^2-7\delta+8)i}{4(\delta-4)(\delta-1)(i+2)}$
b2	$\frac{(2-2a+i)}{4}$
c1	$\frac{(8\gamma^3(-1+\delta)^2\mu-2\delta(3+\delta(-2+\mu)+2\lambda(1+\mu))-\gamma^2(-1+\delta)(8-4(2+\lambda)\mu-4\lambda\mu^2+i(1+\mu)+2\delta(-2+9\mu))+\gamma(i(-1+\delta)(1+\mu)+4\delta^2(-2+3\mu)-4(2+\lambda+\lambda\mu)+2\delta(9-5\mu-2\lambda(-1+\mu^2))))}{(4(-1+\gamma)(-1+\delta)(-3\delta+\gamma(-4+\delta(4-3\mu))+\gamma^2(-1+\delta)(-1+3\mu)))}$
c2	$\frac{(-4+2\lambda-6\lambda\mu-2\lambda^2(-1+\mu)\mu+i(-1+\lambda)(1+\mu)-2a(-3+\mu+\lambda(2-\mu+\mu^2)))}{(2(-1+\lambda)(4+\lambda(-1+3\mu)))}$
c3	$\frac{-\delta(4+i\mu+4\lambda\mu)+\lambda(8+i\mu+8\lambda\mu)}{4\delta(-2+\lambda(2+\mu^2))-4\lambda(-4+\lambda(4+\mu^2))}$
c4	$\frac{4+2a\mu+i\mu+4\lambda\mu}{8-2\lambda(4+\mu^2)}$

Appendix C: Notations of expressions used in intermediary calculations

Table C.1: Consumer valuation threshold $\left(T_{\alpha j}\right)$ for player α for case j. Where *j*= b1, b2, c1, c2, c3 & c4 and α= B, S & C

Cases	Notation	Expression
b1	T_{Bb1}	$\frac{p_{Bb1}-p_{Cb1}}{1-\delta}$
	T_{Cb1}	$\frac{2p_{Cb1}-i}{2\delta}$
b2	T_{Bb2}	$\frac{2p_{Bb2}-i}{2}$
c1	T_{Bc1}	$\frac{p_{Bc1}-(1+\mu)p_{Sc1}}{(1-\gamma)(1-\delta)}$
	T_{Sc1}	$\frac{p_{Sc1}-p_{Cc1}}{\gamma(1-\delta)}$
	T_{Cc1}	$\frac{2p_{Cc1}-i}{2\delta}$
c2	T_{Bc2}	$\frac{p_{Bc2}-p_{Sc2}-\mu p_{Sc2}}{1-\lambda}$
	T_{Sc2}	$\frac{2p_{Sc2}-i}{2\lambda}$
c3	T_{Bc3}	$\frac{p_{Bc3}-p_{Sc3}-\mu p_{Sc3}}{1-\lambda}$
	T_{Sc3}	$\frac{p_{Sc3}-p_{Cc3}}{\lambda-\delta}$
	T_{Cc3}	$\frac{2p_{Cc3}-i}{2\delta}$
c4	T_{Bc4}	$\frac{p_{Bc4}-p_{Sc4}-\mu p_{Sc4}}{1-\lambda}$
	T_{Sc4}	$\frac{2p_{Sc4}-i}{2\lambda}$

Table C.2 Exclusivity $\left(SU_{\alpha j}\right)$expression of a luxury product. Where *j*= b1, b2, c1, c2, c3 & c4 and α= B

Cases	Exclusivity of a luxury product
b1	$\frac{i\left(4\delta^2-(2p_{Cb1}-i)^2\right)}{8\delta^2}$
b2	$\frac{i\left(4-(2p_{Bb2}-i)^2\right)}{8}$
c1	$\frac{i\left(4\delta^2-(2p_{Cc1}-i)^2\right)}{8\delta^2}$
c2	$\frac{i\left(4\lambda^2-(2p_{Sc2}-i)^2\right)}{8\lambda^2}$

c3	$\frac{i\left(4\delta^2-\left(2p_{Cc3}-i\right)^2\right)}{8\delta^2}$
c4	$\frac{i\left(4\lambda^2-\left(2p_{Sc4}-i\right)^2\right)}{8\lambda^2}$

Table C.3: The demand $D_{\alpha j}$ for player α for case j. Where *j*= b1, b2, c1, c2, c3 & c4 and α= B, S & C

Cases	**Luxury product**	**Second-hand platform**	**Counterfeits**
b1	$1-\frac{p_{Bb1}-p_{Cb1}}{1-\delta}$	-	$\frac{p_{Bb1}-p_{Cb1}}{1-\delta}-\frac{2p_{Cb1}-i}{2\delta}$
b2	$1-\frac{2p_{Bb2}-i}{2}$	-	-
c1	$1-\frac{p_{Bc1}-(1+\mu)p_{Sc1}}{(1-\gamma)(1-\delta)}$	$\frac{p_{Bc1}-(1+\mu)p_{Sc1}}{(1-\gamma)(1-\delta)}-\frac{p_{Sc1}-p_{Cc1}}{\gamma(1-\delta)}$	$\frac{p_{Sc1}-p_{Cc1}}{\gamma(1-\delta)}-\frac{2p_{Cc1}-i}{2\delta}$
c2	$1-\frac{p_{Bc2}-p_{Sc2}-\mu p_{Sc2}}{1-\lambda}$	$\frac{p_{Bc2}-p_{Sc2}-\mu p_{Sc2}}{1-\lambda}-\frac{2p_{Sc2}-i}{2\lambda}$	-
c3	$1-\frac{p_{Bc3}-p_{Sc3}-\mu p_{Sc3}}{1-\lambda}$	$\frac{p_{Bc3}-p_{Sc3}-\mu p_{Sc3}}{1-\lambda}-\frac{p_{Sc3}-p_{Cc3}}{\lambda-\delta}$	$\frac{p_{Sc3}-p_{Cc3}}{\lambda-\delta}-\frac{2p_{Cc3}-i}{2\delta}$
c4	$1-\frac{p_{Bc4}-p_{Sc4}-\mu p_{Sc4}}{1-\lambda}$	$\frac{p_{Bc4}-p_{Sc4}-\mu p_{Sc4}}{1-\lambda}-\frac{2p_{Sc4}-i}{2\lambda}$	-

Appendix D: Summary of results threshold

Table D.1: Threshold values for section 4.1

a_{1P1}	$\frac{4(-3+\delta)\delta+2i(-3+\delta)\delta+i^2(5-6\delta+\delta^2)}{2(2+i)(-4+\delta)(-1+\delta)}$
a_{2P1}	$\frac{4\delta^3-36\delta^2+96\delta+(\delta-4)^2(\delta-1)i^2+\sqrt{2}\sqrt{(\delta-4)^2(\delta-1)(i+2)(-16(\delta-2)^2+(\delta-1)^2i^3+2(\delta^3-7\delta^2+12\delta-6)i^2+4(\delta^3-11\delta^2+28\delta-20)i)}+4(\delta-4)^2(\delta-1)i-64}{2(\delta-4)^2(\delta-1)(i+2)}$
a_{3P1}	$\frac{4\delta^3-36\delta^2+96\delta+(\delta-4)^2(\delta-1)i^2-\sqrt{2}\sqrt{(\delta-4)^2(\delta-1)(i+2)(-16(\delta-2)^2+(\delta-1)^2i^3+2(\delta^3-7\delta^2+12\delta-6)i^2+4(\delta^3-11\delta^2+28\delta-20)i)}+4(\delta-4)^2(\delta-1)i-64}{2(\delta-4)^2(\delta-1)(i+2)}$
λ_{1P2}	$\frac{(1-\gamma)(8\gamma^2(\delta-1)^2\mu+2\delta(\delta(\mu-2)+3)-\gamma(\delta-1)(10\delta\mu-4\delta+i\mu+i+8))}{4(\mu+1)(\gamma(\delta-1)-\delta)(\gamma\mu+1)}$
λ_{2P2}	$\frac{(-1+\gamma)(i^2(-1+\delta)(-3\delta+\gamma^2(-1+\delta)(-1+3\mu)-\gamma(8-5\delta+4\mu+2\delta\mu))-2i(\gamma^2(-1+\delta)(8+\delta(-7+\mu)-8\mu+\delta^2(1+\mu))+\delta(12+\delta^2(1+\mu)-2\delta(5+2\mu))+\gamma(-4(-3+\mu)+9\delta(-3+\mu)-2\delta^3(1+\mu)+\delta^2(17+3\mu)))-(4(\delta^2(5+\delta(-2+\mu)-4\mu)+2\gamma^2(-1+\delta)(2-\delta+2\mu-7\delta\mu+2\delta^2\mu)+\gamma\delta(4+\delta^2(2-5\mu)-8\mu+\delta(-6+19\mu)))))}{(4(2+i)(\gamma(-1+\delta)-\delta)(-4+\delta)(1+\mu)(1+\gamma\mu))}$
i_{1P2}	$\frac{-2\gamma(1+2\gamma)+8(-1+\gamma)\gamma\delta-4(-1+\gamma)^2\delta^2-2(-1+4\gamma)(\gamma+\delta-\gamma\delta)^2\mu}{\gamma(1+\mu)}$
f_{P4}	$i^2+i\left(\frac{-4a(\lambda-1)(\lambda(\lambda^2(1-3\mu)^2+2\lambda(\mu(\mu(2\mu+9)+14)-1)+4\mu(\mu+7)+8)+16)-4(\lambda-1)\lambda(\lambda^2((\mu-2)\mu(4\mu-1)-1)+4\lambda(\mu-1)(3\mu-1)+8(\mu-1))}{(\lambda-1)\lambda(\lambda^2(1-3\mu)^2+4\lambda(\mu(\mu+8)-1)-4(\mu-1)(\mu+3))}\right)+$ $+\left(\frac{4(\lambda^2(8+24\mu+\lambda(-5+\lambda+4\lambda^2(-1+\mu)^2\mu^2+\mu(-10+43\mu)+\lambda\mu(2+\mu(-23+24\mu))))+a^2(-32+\lambda^4(1-3\mu)^2+4\lambda(7+(-20+\mu)\mu)+8\lambda^2(1+\mu(7+(-7+\mu)\mu))+\lambda^3(-1+\mu(30+\mu(35+4(-2+\mu)\mu))))+2a\lambda(8\mu+\lambda(-6+10\mu(-1+2\mu)+\lambda^2(-1+\mu^2(-3+4(-2+\mu)\mu))+\lambda(3+\mu(-6+\mu(-17+16\mu))))))}{((-1+\lambda)\lambda(\lambda^2(1-3\mu)^2-4(-1+\mu)(3+\mu)+4\lambda(-1+\mu(8+\mu))))}\right)$
a_{P5}	$\frac{\left((-1+\lambda)\lambda(1+\mu)(4+\lambda(-1+3\mu))^2\left(-\left(\frac{(4(4+2\lambda^2(-1+\mu)\mu-i(-1+\lambda)(1+\mu)+\lambda(-2+6\mu)))}{(4+\lambda(-1+3\mu))^2}\right)+\frac{(\gamma(-8\gamma^3(-1+\delta)^2\mu+2\delta(3+\delta(-2+\mu)+2\lambda(1+\mu))+\gamma^2(-1+\delta)(8-4(2+\lambda)\mu-4\lambda\mu^2+i(1+\mu)+2\delta(-2+9\mu))+\gamma(2\delta^2(4-6\mu)-i(-1+\delta)(1+\mu)+4(2+\lambda+\lambda\mu)+2\delta(-9+5\mu+2\lambda(-1+\mu^2)))))}{(-3\delta+\gamma(-4+\delta(4-3\mu))+\gamma^2(-1+\delta)(-1+3\mu))^2}\right)\right)}{(4(-8-2\lambda(-6+7\mu+\mu^2)-\lambda^2(7-12\mu+7\mu^2+2\mu^3)+\lambda^3(3+2\mu+9\mu^2+2\mu^3)))}$

Table D.2: Threshold values for section 4.2

λ_{1P6}	$\frac{(3i^2(-1+\delta)(\delta+\gamma^2(1-3\mu)+\gamma(-4+\delta\mu))-4\delta(-2(-1+\delta)\delta+\gamma^2(-1+\delta)(-2+3(-2+\delta)\mu)+\gamma(4+\delta^2(2-3\mu)+\delta(-3+6\mu)))-2i(\delta(18-19\delta+\delta^2)+\gamma^2(-1+\delta)(2+\delta^2-6\mu+4\delta(-2+3\mu))+\gamma(8-2\delta^3-5\delta^2(-5+3\mu)+2\delta(-14+9\mu))))}{(4(2+i)(-4+\delta)\delta(1+\gamma\mu))}$

λ_{2P6}	$\frac{(i^2\left(9(-5+\delta)\delta-\gamma^2\left(11-13\delta+2\delta^2\right)(-1+3\mu)+\gamma\left(-44+\delta(52-45\mu)+\delta^2(-8+9\mu)\right)\right)+2i(\delta\left(-30+25\delta-7\delta^2\right)+\gamma^2(-1+\delta)\left(-6+18\mu+\delta^2(-3+6\mu)-2\delta(-5+9\mu)\right)+\gamma\left(-24+\delta(52-30\mu)+\delta^3(10-6\mu)+\delta^2(-41+21\mu)\right))+4\delta\left(2(17-5\delta)\delta+\gamma^2(-1+\delta)(14-30\mu+\delta(-4+9\mu))+\gamma\left(44+\delta^2(14-9\mu)+\delta(-61+30\mu)\right)\right))}{4(\delta-4)\delta(i+2)(\gamma\mu+1)}$
λ_{3P6}	$\frac{2\delta\left(-4\delta+\gamma^2(-1+\delta)(-2+3\mu)+\gamma(-5+6\delta-3\delta\mu)\right)+i\left(6\delta+\gamma^2(-1+\delta+3\mu-3\delta\mu)+\gamma(4-4\delta+6\delta\mu)\right)}{4(\delta+\gamma\delta\mu)}$
a_{1P7}	$\frac{-4i-7i^2+40\delta+2i\delta-3i^2\delta-12\delta^2-2i\delta^2+i^2\delta^2}{2(2+i)\left(-4\delta+\delta^2\right)}$
a_{2P7}	$\frac{4i+7i^2-8\delta-2i\delta-5i^2\delta+4\delta^2+2i\delta^2+i^2\delta^2}{2(2+i)\left(-4\delta+\delta^2\right)}$

Table D.3: Threshold values for section 4.3

a_{1P8}	$\frac{-2-i+i^2+\left(\frac{-i^6(-7+\delta)(-1+\delta)^2-64\delta\left(4-8\delta+3\delta^2\right)+32i\delta\left(-24+44\delta-23\delta^2+3\delta^3\right)+i^5\left(-115+218\delta-115\delta^2+12\delta^3\right)+4i^2\left(16+48\delta-144\delta^2+77\delta^3-10\delta^4+\delta^5\right)+8i^3\left(14+106\delta-263\delta^2+178\delta^3-40\delta^4+3\delta^5\right)+i^4\left(-68+357\delta-574\delta^2+373\delta^3-96\delta^4+8\delta^5\right)}{(2+i)^2\delta\left(4-5\delta+\delta^2\right)^2}\right)^{1/2}}{2(-1+i)}$
a_{2P8}	$\frac{2+i-i^2+\left(\frac{-i^6(-7+\delta)(-1+\delta)^2-64\delta\left(4-8\delta+3\delta^2\right)+32i\delta\left(-24+44\delta-23\delta^2+3\delta^3\right)+i^5\left(-115+218\delta-115\delta^2+12\delta^3\right)+4i^2\left(16+48\delta-144\delta^2+77\delta^3-10\delta^4+\delta^5\right)+8i^3\left(14+106\delta-263\delta^2+178\delta^3-40\delta^4+3\delta^5\right)+i^4\left(-68+357\delta-574\delta^2+373\delta^3-96\delta^4+8\delta^5\right)}{(2+i)^2\delta\left(4-5\delta+\delta^2\right)^2}\right)^{1/2}}{2(1-i)}$

Appendix E: Proofs

Proof of convexity of cases and equilibrium outcomes (As summarised in appendix B and notations in Appendix A): In case b1, the demand of luxury and counterfeit product is $1-T_{Bb1}$ *and* $T_{Bb1}-T_{Cb1}$, respectively. The T_{Bb1} is calculated by comparing U_{Bb1} and U_{Cb1}. Similarly, T_{Cb1} is calculated by comparing U_{Cb1} and U_{Nb1}. Then these values are substituted in π_{Bb1} and π_{Cb1}. The luxury brand and counterfeit player decide their price by maximizing profit π_{Bb1} *and* π_{Cb1}. Where $\frac{\partial^2 \pi_{\text{Bb1}}}{\partial \left(p_{\text{Bb1}}\right)^2} = \frac{2}{\delta - 1} < 0$ and $\frac{\partial^2 \pi_{\text{Cb1}}}{\partial \left(p_{\text{Cb1}}\right)^2} = 2\left(\frac{1}{\delta - 1} - \frac{1}{\delta}\right) < 0$.

In case b2, blockchain technology for authentications eliminates the threat of counterfeit presence. The brand incurs per unit authentication cost (a). The demand of luxury is $1-T_{Bb2}$. The T_{Bb2} is calculated by comparing U_{Bb2} and U_{Nb2}. Thus, luxury brand decides their price p_{Bb2} by maximizing their profit π_{Bb2}. Where $\frac{\partial^2 \pi_{\text{Bb2}}}{\partial \left(p_{\text{Bb2}}\right)^2} = -2 < 0$.

In case c1, counterfeit player strategically decides their price p_{Cc1} after observing p_{Bc1} and p_{Sc1}. Similarly, independent second-hand player decides their price p_{Sc1} after observing new product price p_{Bc1}. The demand of luxury, second-hand and counterfeit products are $1-T_{Bc1}, T_{Bc1}-T_{Sc1}$, and $T_{Sc1}-T_{Cc1}$. The T_{Bc1} is calculated by comparing U_{Bc1} and U_{Sc1}, T_{Sc1} is calculated by comparing U_{Sc1} and U_{Cc1}, and T_{Cc1} is calculated by comparing U_{Cc1} and U_{Nc1}. The luxury brand, second-hand player and counterfeit player decides their prices by maximizing their profit π_{Bc1}, π_{Sc1} and π_{Cc1}. Where $\frac{\partial^2 \pi_{\text{Bc1}}}{\partial \left(p_{\text{Bc1}}\right)^2} = \frac{-2}{(-1+\gamma)(-1+\delta)} < 0$, $\frac{\partial^2 \pi_{\text{Sc1}}}{\partial \left(p_{\text{Sc1}}\right)^2} = 2\left(\frac{1}{\gamma(-1+\delta)} + \frac{-1-\mu}{(-1+\gamma)(-1+\delta)}\right) < 0$ and $\frac{\partial^2 \pi_{\text{Cc1}}}{\partial \left(p_{\text{Cc1}}\right)^2} = 2\left(\frac{1}{\gamma(-1+\delta)} - \frac{1}{\delta}\right) < 0$.

In case c2, the independent second-hand player benefits from brand's use of blockchain technology and agrees to pay the authentication charge on its demand to luxury brand. The demand of luxury, and second-hand are $1-T_{Bc2}$ and $T_{Bc2}-T_{Sc2}$. The T_{Bc2} is calculated by comparing U_{Bc2} and U_{Sc2} and T_{Sc2} is calculated by comparing U_{Sc2} and U_{Nc2}. The luxury brand, second-hand player and counterfeit player decides their prices by maximizing their profit π_{Bc2} and π_{Sc2}. Where, $\frac{\partial^2 \pi_{\mathrm{Bc2}}}{\partial\left(p_{\mathrm{Bc2}}\right)^2} = \frac{2}{-1+\lambda} < 0$ and $\frac{\partial^2 \pi_{\mathrm{Sc2}}}{\partial\left(p_{\mathrm{Sc2}}\right)^2} = 2\left(\frac{-1}{\lambda} + \frac{1+\mu}{-1+\lambda}\right) < 0$.

In case c3, the luxury brand acquires the second-hand platform to strategically decide the resale value of their products. The demand of luxury, second-hand and counterfeit products are $1-T_{Bc3}$, $T_{Bc3}-T_{Sc3}$, and $T_{Sc3}-T_{Cc3}$. The T_{Bc3} is calculated by comparing U_{Bc3} and U_{Sc3}, T_{Sc3} is calculated by comparing U_{Sc3} and U_{Cc3}, and T_{Cc3} is calculated by comparing U_{Cc3} and U_{Nc3}. The luxury brand and counterfeit player decides their prices by maximizing their profits π_{Bc3} and π_{Cc3}. Where, $\frac{\partial^2 \pi_{\mathrm{Cc3}}}{\partial\left(p_{\mathrm{Cc3}}\right)^2} = 2\left(\frac{1}{\delta-\lambda} - \frac{1}{\delta}\right) < 0$ for $\lambda > \delta$ and $\frac{\partial^2 \pi_{\mathrm{Bc3}}}{\partial\left\{p_{\mathrm{Bc3}}, p_{\mathrm{Sc3}}\right\}^2}$ is negative definite if lemma 1 holds true.

Lemma 1 proof:

$$\frac{\partial^2 \pi_{\mathrm{Bc3}}}{\partial\left\{p_{\mathrm{Bc3}}, p_{\mathrm{Sc3}}\right\}^2} = \begin{pmatrix} \frac{2}{\lambda-1} & \frac{\mu+2}{1-\lambda} \\ \frac{\mu+2}{1-\lambda} & 2\left(\frac{\mu+1}{\lambda-1} + \frac{1}{\delta-\lambda}\right) \end{pmatrix}$$

For π_{Bc3} to be negative definite we require the first principal order of above hessian matrix negative and second principal order positive. We can observe that first principal order is always negative whereas second principal order $\left(= \frac{4(\delta-\delta_{L1})\left(\mu-2\left(-\sqrt{\lambda+1}-1\right)\right)(\mu-\mu_{L1})}{(\lambda-1)^2(\lambda-\delta)} \right)$ will be positive if conditions in lemma 1 hold true. Where, $\delta_{L1} = \frac{4\lambda^2-\lambda(\mu+2)^2+4}{4\lambda-\mu(\mu+4)}$, $\mu_{L1} = 2\left(\sqrt{\lambda+1}-1\right)$.

In case 4, The luxury brand employs blockchain to authenticate their products and owns second-hand platform to strategically decides the resale value of their products. The demand of luxury, and second-hand are $1-T_{Bc4}$ and $T_{Bc4}-T_{Sc4}$. The T_{Bc4} is calculated by comparing U_{Bc4} and U_{Sc4} and T_{Sc4} is calculated by comparing U_{Sc4} and U_{Nc4}. The luxury brand player decides his price by maximizing their profits π_{Bc4}. Where, $\frac{\partial^2 \pi_{\mathrm{Bc4}}}{\partial\left\{p_{\mathrm{Bc4}}, p_{\mathrm{Sc4}}\right\}^2}$ is negative definite if lemma 2 holds true.

Lemma 2 proof:

$$\frac{\partial^2 \pi_{\mathrm{Bc4}}}{\partial\{p_{\mathrm{Bc4}}, p_{\mathrm{Sc4}}\}^2} = \begin{pmatrix} \frac{2}{\lambda-1} & \frac{\mu+2}{1-\lambda} \\ \frac{\mu+2}{1-\lambda} & \frac{2(\lambda\mu+1)}{(\lambda-1)\lambda} \end{pmatrix}.$$

For π_{Bc4} to be negative definite we require the first principal order of above hessian matrix negative and second principal order positive. We can observe that first principal order is always negative whereas second principal order is $\frac{4-\lambda\left(\mu^2+4\right)}{(\lambda-1)^2\lambda} > 0$ for $\mu < \mu_{L2} = \frac{2\sqrt{1-\lambda}}{\sqrt{\lambda}}$.

Proof of Proposition 1:

In this proof we are comparing case b1 and b2 to find conditions when blockchain could be profitable for luxury brands. We compared $\pi^*_{Bb1}\ and\ \pi^*_{Bb2}$ and found that: $\pi^*_{Bb2} - \pi^*_{Bb1} = \frac{(a-a_{2P1})(a-a_{3P1})}{4}$. Where $a_{3P1} > 1 \forall i \in [0,1] \Rightarrow (a - a_{3P1}) < 0 \forall a \in [0,1]$ which means that $\forall a < a_{2P1} \Rightarrow \pi^*_{Bb2} > \pi^*_{Bb1}$. Table D.1 tabulates the expressions for thresholds.

Proof of Corollary 1:

In this proof we are comparing luxury product demand and prices of case b1 and b2. We compared D^*_{Bb2} and D^*_{Bb1} and found that: $D^*_{Bb2} - D^*_{Bb1} = \frac{-(a-a_{1P1})}{2}$. Where $a_{1P1} < a_{2P1}$ always, which means that $D^*_{Bb2} > D^*_{Bb1} \forall a < a_{1P1}$. Similarly, we compared p^*_{Bb2} and p^*_{Bb1} and found that: $p^*_{Bb2} - p^*_{Bb1} = \frac{a-a'}{2}$. Where $0 > a' = -\left(\frac{2\delta+i(2+\delta)}{2(4-\delta)}\right)$ which means that $p^*_{Bb2} > p^*_{Bb1}$ always. Table B.1 and B.3 tabulates the expressions used in this proof.

Proof of Proposition 2:

In this proof we are concerned when and how a luxury brand can benefit form second-hand market presence. We compared $\pi^*_{Bb1}\ and\ \pi^*_{Bc1}$ and found that: $\frac{d(\pi^*_{Bc1} - \pi^*_{Bb1})}{d\lambda} = A(\lambda - \lambda_{1P2})$, Where $0 < A = \frac{2(\mu+1)^2(\gamma(-\delta)+\gamma+\delta)^2(\gamma\mu+1)^2}{(1-\gamma)(1-\delta)\left(\gamma^2(\delta-1)(3\mu-1)+\gamma(\delta(4-3\mu)-4)-3\delta\right)^2} \Rightarrow \forall \lambda > \lambda_{1P2}$ we have $\frac{d(\pi^*_{Bc1} - \pi^*_{Bb1})}{d\lambda} > 0$.

We further tried to understand the behaviour of threshold λ_{1P2}. Part a) suggest that $\frac{d\lambda_{1P2}}{di} = -\left(\frac{(1-\gamma)\gamma(1-\delta)}{4\left(\gamma(1-\delta)+\delta\right)(1+\gamma\mu)}\right) < 0$. In part b) we found that $\frac{d\lambda_{1P2}}{d\delta} = (i - i_{1P2})B$ where

$0 < B = \frac{(1-\gamma)\gamma}{4(\gamma+\delta-\gamma\delta)^2(1+\gamma\mu)}$ and $i_{1P2} < 0$ in parametric range suggest that $\frac{d\lambda_{1P2}}{d\delta} > 0$. Table D.1 tabulates the expressions for thresholds.

Proof of Corollary 2:

In this proof we are comparing luxury product demand of case c1 and b1. We compared D^*_{Bc1} and D^*_{Bb1} and found that:

$$D^*_{Bc1} - D^*_{Bb1} = A\left(\lambda - \lambda_{2P2}\right) \text{ such that } 0 < A = \frac{-\left(\gamma(1-\delta)+\delta\right)(1+\mu)(1+\gamma\mu)}{(1-\gamma)(1-\delta)\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)\right)+\gamma^2(-1+\delta)(-1+3\mu)\right)}$$

$\because\left(-3\delta+\gamma\left(-4+\delta\left(4-3\mu\right)\right)+\gamma^2\left(-1+\delta\right)\left(-1+3\mu\right)\right) < 0 \ \forall \mu \in [0,1]$ and $\lambda_{2P2} > \lambda_{1P2}$ (checked via plotting graph). This suggest that for $\lambda > \lambda_{2P2}$, $D^*_{Bc1} > D^*_{Bb1}$. We compared p^*_{Bc1} and p^*_{Bb1} and found that: $\frac{d\left(p^*_{Bc1} - p^*_{Bb1}\right)}{d\lambda} > 0$ in the parametric region.

Proof of Proposition 3

In this proof we are concerned with finding the regions in second-hand platform acquisition cost in determining appropriate strategies for a brand who is facing the threat of counterfeits. We compared $\pi^*_{Bc3}\ and\ \pi^*_{Bb1}$ and $\pi^*_{Bc3}\ and\ \pi^*_{Bc1}$ found that:

$$\pi^*_{Bc3} - \pi^*_{Bb1} = \left(p^*_{Bc3}\left(1-T^*_{Bc3}\right) + \left(p^*_{Sc3} - \lambda\right)\left(T^*_{Bc3} - T^*_{Sc3}\right)\right) - S - \left(p^*_{\mathrm{Bb1}}\left(1-T^*_{\mathrm{Bb1}}\right)\right) = S_{1P3} - S$$

$$\pi^*_{Bc3} - \pi^*_{Bc1} = \left(p^*_{Bc3}\left(1-T^*_{Bc3}\right) + \left(p^*_{Sc3} - \lambda\right)\left(T^*_{Bc3} - T^*_{Sc3}\right)\right) - S - \left(p^*_{Bc1}\left(1-T^*_{Bc1}\right)\right) = S_{2P3} - S$$

The above two equation suggest that if $S < S_{1P3}$ then $\pi^*_{Bc3} > \pi^*_{Bb1}$ and if $S < S_{2P3}$ then $\pi^*_{Bc3} > \pi^*_{Bc1}$. Table D.1 tabulates the expressions for thresholds.

Proof of Proposition 4:

This proof aims to identify the optimal strategy regions for blockchain-enabled brands. We compared $\pi^*_{Bb2}, \pi^*_{Bc2}, and\ \pi^*_{Bc4}$ and got the following result:

$$\pi^*_{Bc2} - \pi^*_{Bb2} = A(i - i_{1P4})(i - i_{2P4}) \text{ where } 0 > A = \frac{-\left(\lambda^2(1-3\mu)^2 - 4(-1+\mu)(3+\mu) + 4\lambda\left(-1+\mu(8+\mu)\right)\right)}{16(-4+\lambda-3\lambda\mu)^2}$$

and $i_{1P4}\ and\ i_{2P4}$ are roots of f_{P4}. Such that $i_{1P4} < i_{2P4}$ always in parametric region. This suggest that

$\forall i \in \left(i_{1P4},\, i_{2P4}\right),\ \pi^*_{Bc2} > \pi^*_{Bb2}$ otherwise $\pi^*_{Bc2} < \pi^*_{Bb2}$. When we compared π^*_{Bb2} *and* π^*_{Bc4} we get following result:

$$\pi^*_{Bc4} - \pi^*_{Bb2} = \left(\left(p^*_{Bc4} - a\right)\left(1 - T^*_{Bc4}\right) + \left(p^*_{Sc4} - a - \lambda\right)\left(T^*_{Bc4} - T^*_{Sc4}\right)\right) - S - \left((p^*_{Bb2} - a)\left(1 - T^*_{Bb2}\right)\right) = S_{1P4} - S$$

This suggests that $\forall\, S < S_{1P4},\ \pi^*_{Bc4} > \pi^*_{Bb2}$ otherwise $\pi^*_{Bc4} < \pi^*_{Bb2}$.

And when we compared π^*_{Bc2} *and* π^*_{Bc4} we get following result:

$$\pi^*_{Bc4} - \pi^*_{Bc2} = \left(\left(p^*_{Bc4} - a\right)\left(1 - T^*_{Bc4}\right) + \left(p^*_{Sc4} - a - \lambda\right)\left(T^*_{Bc4} - T^*_{Sc4}\right)\right) - S - \left(\left(p^*_{Bc2} - a\right)\left(1 - T^*_{Bc2}\right) + a\left(T^*_{Bc2} - T^*_{Sc2}\right)\right)$$

$\Rightarrow \pi^*_{Bc4} - \pi^*_{Bc2} = S_{2P4} - S$. This suggest that $\forall\, S < S_{2P4},\ \pi^*_{Bc4} > \pi^*_{Bc2}$ otherwise $\pi^*_{Bc4} < \pi^*_{Bc2}$.

By comparing above results we can understand that when $S < S' = \min\{S_{1P4}, S_{2P4}\}$ then $\pi^*_{Bc4} > \pi^*_{Bb2}$ *and* $\pi^*_{Bc4} > \pi^*_{Bc2}$. When $S > S'' = \max\{S_{1P4}, S_{2P4}\}$ then $\forall i \in \left[i_{2P4}, i_{1P4}\right],\ \pi^*_{Bc2} > \pi^*_{Bb2}$ otherwise $\pi^*_{Bc2} < \pi^*_{Bb2}$. Table D.1 tabulates the expressions for thresholds.

Proof of Corollary 3:

In this proof we are comparing luxury product demand of case c2 and b2. We compared D^*_{Bc2} and D^*_{Bb2} and found that: $\dfrac{d\left(D^*_{Bc2} - D^*_{Bb2}\right)}{di} = \dfrac{1+\mu}{8 - 2\lambda + 6\lambda\mu} - \dfrac{1}{4} < 0$. Similarly, we compared p^*_{Bc2} and p^*_{Bb2} and found that: $\dfrac{d\left(p^*_{Bc2} - p^*_{Bb2}\right)}{di} = \dfrac{(1-\lambda)(1+\mu)}{8 + \lambda\left(-2 + 6\mu\right)} - \dfrac{1}{4} < 0$ in the parametric region.

Proof of Proposition 5:

In this proof, our aim is to identify potential strategies that luxury brands can use to combat counterfeits in the secondary retail market through the implementation of blockchain technology. We compared π^*_{Bc1} *and* π^*_{Bc2} and got the following result:

$\dfrac{d(\pi^*_{Bc2} - \pi^*_{Bc1})}{di} = A(a - a_{P5})$ Where, $0 < A = \frac{\lambda^2\left(2\mu^3 + 9\mu^2 + 2\mu + 3\right) + 2\lambda\left(\mu^2 + 7\mu - 2\right) + 8}{2\lambda(\lambda(3\mu - 1) + 4)^2}$ and $a_{P5} < 0$ in the parametric domain. This result suggests that $\forall a \in \left[0,1\right], \dfrac{d(\pi^*_{Bc2} - \pi^*_{Bc1})}{di} > 0$. Table D.1 tabulates the expressions for thresholds.

Proof of Corollary 4:

In this proof we are comparing luxury product demand of case c2 and c1. We compared D^*_{Bc2} and D^*_{Bc1} and found that: $\frac{d\left(D^*_{Bc2}-D^*_{Bc1}\right)}{di}=\frac{(1+\mu)\left(-6\delta+2\gamma^2(-1+\delta)(-1+3\mu)-\gamma\left(4+\lambda-3\lambda\mu+\delta(-8+6\mu)\right)\right)}{4\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)\right)+\gamma^2(-1+\delta)(-1+3\mu)\right)\left(4+\lambda(-1+3\mu)\right)}$. Upon checking the numerator, we found that:

$$\left(-6\delta+2\gamma^2(-1+\delta)(-1+3\mu)-\gamma\left(4+\lambda-3\lambda\mu+\delta(-8+6\mu)\right)\right)=A\left(\delta-\delta_1\right)<0\ \forall\,\delta\in[0,1],$$

where $0>A=2(-1+\gamma)\left(3+\gamma(-1+3\mu)\right)$ and $0>\delta_1=\frac{\gamma\left(4+\lambda-3\lambda\mu+\gamma(-2+6\mu)\right)}{2(-1+\gamma)\left(3+\gamma(-1+3\mu)\right)}\ \forall\,\mu\in[0,1]$ checked via graph. Similarly, checking the denominator of $\frac{d\left(D^*_{Bc2}-D^*_{Bc1}\right)}{di}$ we found that:

$\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)\right)+\gamma^2(-1+\delta)(-1+3\mu)\right)=A\left(\mu-\mu_1\right)<0$ where

$0>A=3\gamma\left(\gamma(-1+\delta)-\delta\right)$ and $0>\mu_1=\frac{-4\gamma(-1+\delta)+\gamma^2(-1+\delta)+3\delta}{3\gamma\left(\gamma(-1+\delta)-\delta\right)}$, and $\left(4+\lambda(-1+3\mu)\right)>0$.

$\therefore\frac{d\left(D^*_{Bc2}-D^*_{Bc1}\right)}{di}>0$.

Proof of Proposition 6:

Our goal in this proof is to identify regions where luxury brands may lose their product exclusivity due to quality of second-hand products. We compared SU^*_{Bb1} *and* SU^*_{Bc1} and found that:

$SU^*_{Bc1}-SU^*_{Bb1}=A(\lambda-\lambda_{1P6})(\lambda-\lambda_{2P6})$ such that $\lambda_{2P6}-\lambda_{1P6}=Bg(i,\delta)$

where $g(i,\delta)=\frac{-i^2(-7+\delta)+8(-3+\delta)\delta+2i\left(2-\delta+\delta^2\right)}{2(4+i)}$, $0<B=\frac{(4+i)\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)+\gamma(-1+\delta)(-1+3\mu)\right)\right)}{(2+i)(-4+\delta)\delta(1+\gamma\mu)}$ and $0>A=-\left(\frac{i(1+\gamma\mu)^2}{2\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)\right)+\gamma^2(-1+\delta)(-1+3\mu)\right)^2}\right)$ in parametric range. It suggest that $SU^*_{Bc1}>SU^*_{Bb1}$ when second-hand product quality is in the range of $\left[\lambda_{\min},\lambda_{\max}\right]$ such that if $g(i,\delta)>0$ then $\lambda_{1P6}<\lambda_{2P6}$ and if $g(i,\delta)<0$ then $\lambda_{1P6}>\lambda_{2P6}$. Table D.2 tabulates the expressions for thresholds. Table A.4 shows the calculation of exclusivity of luxury product. Table B.2 tabulates the exclusivity expression of a luxury product at equilibrium.

Proof of Corollary 5

In this proof we are comparing luxury brand exclusivity of case c1 and b1. We compared SU^*_{Bb1} *and* SU^*_{Bc1} and found that: $\frac{d\left(SU^*_{Bc1}-SU^*_{Bb1}\right)^2}{d\lambda^2}=\frac{-\left(i(1+\gamma\mu)^2\right)}{\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)\right)+\gamma^2(-1+\delta)(-1+3\mu)\right)^2}<0$.

$\frac{d\left(SU^*_{Bc1}-SU^*_{Bb1}\right)}{d\lambda}=A\left(\lambda-\lambda_{3P6}\right)$ such that $0>A=-\frac{i(1+\gamma\mu)^2}{\left(-3\delta+\gamma\left(-4+\delta(4-3\mu)\right)+\gamma^2(-1+\delta)(-1+3\mu)\right)^2}$. Furthermore, if $g(i,\delta)>0$ then $\lambda_{1P6}<\lambda_{3P6}<\lambda_{2P6}$, and if $g(i,\delta)<0$ then $\lambda_{1P6}>\lambda_{3P6}>\lambda_{2P6}$.

Proof of Proposition 7:

In this proof, our aim to check when an authentication technology will be deemed useful in increasing the exclusivity of luxury product. We compared SU^*_{Bb1} *and* SU^*_{Bb2} and found that:

$SU^*_{Bb1}-SU^*_{Bb2}=\frac{i(a-a_{2P7})(a-a_{1P7})}{8}$. Where, $a_{2P7}-a_{1P7}=f(i,\delta)$. This suggest that if $f(i,\delta)>0$ then $\forall a\in\left(a_{1P7},a_{2P7}\right)$, $SU^*_{Bb2}>SU^*_{Bb1}$ and if $f(i,\delta)<0$ then $\forall a\in\left(a_{2P7},a_{1P7}\right)$, $SU^*_{Bb2}>SU^*_{Bb1}$. Table D.2 tabulates the expressions for thresholds. Table A.4 shows the calculation of exclusivity of luxury product. Table B.2 tabulates the exclusivity expression of a luxury product at equilibrium.

Proof of Corollary 6:

In this proof we are comparing luxury brand exclusivity of case b1 and b2. We compared SU^*_{Bb1} *and* SU^*_{Bb2} and found that: $\frac{d\left(SU^*_{Bb2}-SU^*_{Bb1}\right)^2}{da^2}=-\frac{i}{4}<0$.

$\frac{d\left(SU^*_{Bb2}-SU^*_{Bb1}\right)}{da}=-\frac{i}{4}\left(a-a_{3P7}\right)$, where $a_{3P7}=\frac{(-2+i)}{2}$. Furthermore, If $f(i,\delta)>0$, then $a_{1P7}<a_{3P7}<a_{2P7}$ and if $f(i,\delta)<0$, then $a_{1P7}>a_{3P7}>a_{2P7}$. Similarly checking price, we found $\frac{d\,p^*_{Bb2}}{da}=\frac{1}{2}>0$.

Proof of Proposition 8:

In this proof, our aim to check when luxury consumer welfare is higher. We compare CW_{b2} and CW_{b1} and found that: $CW_{b2}-CW_{b1}=A\left(a-a_{1P8}\right)\left(a-a_{2P8}\right)$, *where* $0<A=\frac{1-i}{8}$ *and* $a_{2P8}>1$, $a_{2P8}>a_{1P8}$ (Checked via graph). This implies that for $a<a_{1P8}$, $CW_{b2}>CW_{b1}$.

Proof of Corollary 7

In this proof, we check the price of luxury brand in case b2. We found that $\frac{d\, p^{*}_{Bb2}}{da} = \frac{1}{2} > 0$.

Proof of Corollary 8

In this proof, we compared a_{2P1} and a_{1P8} and found that: $\forall \mathbb{R},\ a_{2P1} > a_{1P8}$ checked via graph

5.2 List of Appendix for chapter 3

Appendix F: Summary of Notations

Table F.1: Parametric notations

Notations	**Definitions**	**Parametric Ranges**
$p_{\alpha j}$	Price of player α in case j. Where $\alpha \in \{S, F\}$ and $j \in \{C0, C1, C2, C3\}$	$[0, \infty)$
μ	Luxury brand experience during purchase	$[0,1)$
δ	Platform emphasis on luxury brand experience	$(0,1)$
s	Service quality performance of Brand Run mono brand second-hand market	$(0,1)$
λ	Consumers inclination towards price comparison	$(0,1)$
ε	Style closeness index of follower product	$(0,1)$
d	Blockchain-based product provenance benefit	$(0,1)$
F	Blockchain network participation fixed cost (with read only access)	$[0, \infty)$
a	Blockchain-based product provenance records maintenance per unit cost	$[0,1]$
c	Follower product cost	$[0,1]$
q_{CC0}	Counterfeit product quality	$[0,1]$
$q_{F j}$	Follower product quality, $where\ j \in \{C0, C1, C2, C3\}$	$[0,1]$
$T_{\alpha j}$	Consumer valuation threshold for player α for case j, where $\alpha \in \{S, F, C\}$ and $j \in \{C0, C1, C2, C3\}$	$[0,1]$
$\pi_{\alpha j}$	Profit for player α for case j. Where $\alpha \in \{S, F, C\}$ and $j \in \{C0, C1, C2, C3\}$	$(-\infty, \infty)$
E_j	Exclusivity of a luxury brand for case j, $where\ j \in \{C0, C1, C2, C3\}$	$(-\infty, \infty)$
CS_j	Second-hand product consumer surplus for case j, where $j \in \{C0, C1, C2, C3\}$	$(-\infty, \infty)$

Appendix G: Equilibrium expressions

Table G.1: Equilibrium Outcomes

Case	Notation	Expression
C0	p^*_{SC0}	$\frac{q_F\left(-8-\epsilon-8\lambda-4c_F+2c_c(-1+q_F)+8q_F+\epsilon q_F+4\lambda q_F\right)+q_c\left(4+\epsilon+4\lambda-\epsilon q_F-4q_F^2+2c_F(1+q_F)\right)}{4\left((-4+q_F)q_F+q_c(2+q_F)\right)}.$
	p^*_{FC0}	$\frac{q_F\left(-\epsilon-4c_F+2c_c(-1+q_F)-2q_F+\epsilon q_F+2\lambda q_F+2q_F^2\right)+q_c\left(\epsilon-(-2+\epsilon+2\lambda)q_F-2q_F^2+2c_F(1+q_F)\right)}{2\left((-4+q_F)q_F+q_c(2+q_F)\right)}$
	p^*_{CC0}	$\frac{1}{4}\left(\epsilon+2c_c-\frac{q_c\left(q_F\left(-3\epsilon+4c_F-2c_c(-1+q_F)+2q_F-2\lambda q_F-2q_F^2\right)+q_c\left(\epsilon+2(-1+\epsilon+\lambda)q_F+2q_F^2-2c_F(1+q_F)\right)\right)}{q_F\left((-4+q_F)q_F+q_c(2+q_F)\right)}\right)$

C1	p^{*}_{SC1}	$\frac{\epsilon^2(4+\epsilon+2\lambda)-4c_F(\epsilon-2q_F)+8(2+\epsilon+2\lambda)q_F-4(4+\epsilon+2\lambda)q_F^2}{2\left(\epsilon^2+16q_F-4q_F^2\right)}$
	p^{*}_{FC1}	$\frac{\epsilon^3+4(\epsilon-\epsilon\lambda+4c_F)q_F-8(-1+\epsilon+\lambda)q_F^2-8q_F^3}{2\left(\epsilon^2+16q_F-4q_F^2\right)}$
C2	p^{*}_{SC2}	$\frac{\epsilon^2(2d+4s+\epsilon+2\mu)-4sc_F(\epsilon-2q_F)+8s(2a+2d+2s+\epsilon+2\mu)q_F-4(2d+4s+\epsilon+2\mu)q_F^2}{2\left(\epsilon^2+16sq_F-4q_F^2\right)}$
	p^{*}_{FC2}	$\frac{\epsilon^3+4\left(\epsilon(a-d+s-\mu)+4sc_F\right)q_F+8(a-d+s-\epsilon-\mu)q_F^2-8q_F^3}{2\left(\epsilon^2+16sq_F-4q_F^2\right)}$
C3	p^{*}_{SC3}	$\frac{\epsilon^2(4+2d+\epsilon+2\lambda+2\delta\mu)-4c_F(\epsilon-2q_F)+8(2+2a+2d+2\delta+\epsilon+2\lambda+2\delta\mu)q_F-4(4+2d+\epsilon+2\lambda+2\delta\mu)q_F^2}{2\left(\epsilon^2+16q_F-4q_F^2\right)}$
	p^{*}_{FC3}	$\frac{\epsilon^3+4\left(\epsilon(1+a-d+\delta-\lambda-\delta\mu)+4c_F\right)q_F+8(1+a-d+\delta-\epsilon-\lambda-\delta\mu)q_F^2-8q_F^3}{2\left(\epsilon^2+16q_F-4q_F^2\right)}$

Table G.2: Exclusivity $\left(E_j\right)$ expression of a luxury product at equilibrium. Where *j*= C0, C1, C2 & C3

Cases	Exclusivity of a luxury product
C0	$\frac{-\left(\epsilon\left(q_F\left(8+\epsilon+8\lambda+2c_c+4c_F-(8+\epsilon+4\lambda+2c_c)q_F\right)+q_c\left(-4-\epsilon-4\lambda-2c_F(1+q_F)+q_F(\epsilon+4q_F)\right)\right)\left((\epsilon-2c_c)(-4+q_F)q_F^2+q_c^2\left(\epsilon+2(-5+\epsilon+\lambda-q_F)q_F-2c_F(1+q_F)\right)-q_cq_F\left(\epsilon-4c_F+c_c(2+4q_F)+q_F(-18-\epsilon+2\lambda+6q_F)\right)\right)\right)}{\left(32q_c(-1+q_F)q_F\left((-4+q_F)q_F+q_c(2+q_F)\right)^2\right)}$
C1	$-\frac{1}{2}\epsilon\left(-1+\frac{\left(\epsilon^4+2q_F\left(-\epsilon^2(-6+\epsilon+2\lambda)+4c_F(\epsilon-2q_F)+4q_F\left(4-\epsilon(2+\epsilon)-4\lambda+q_F(-6+\epsilon+2\lambda+2q_F)\right)\right)\right)^2}{\left(\epsilon^2-4(-4+q_F)q_F\right)^2\left(\epsilon^2-4(-1+q_F)q_F\right)^2}\right)$
C2	$\left(\frac{2q_F\left(\epsilon\left(\epsilon(-2a+2d+4s+\epsilon+2\mu)-4sc_F\right)+8s(-2a+2d+2s+\epsilon+2\mu+c_F)q_F-4(-2a+2d+4s+\epsilon+2\mu)q_F^2\right)}{\left(\epsilon^2+4(s-q_F)q_F\right)^2}\right)$ $\left(\frac{\left(\epsilon^4(\epsilon+\mu)+\epsilon^2\left(2a\epsilon-\epsilon(2d-16s+\epsilon)-2(-10s+\epsilon)\mu+4sc_F\right)q_F-8\left(-2as\epsilon+2ds\epsilon-(2s-\epsilon)\left(\epsilon(\epsilon+\mu)+s(3\epsilon+4\mu)\right)+s\epsilon c_F\right)q_F^2+4\left(-2a\epsilon+\epsilon(2d-16s+\epsilon)+2(-10s+\epsilon)\mu\right)q_F^3+16(\epsilon+\mu)q_F^4\right)}{\left(\epsilon^2+16sq_F-4q_F^2\right)^2}\right)$
C3	$\left(-\left(\frac{2q_F\left(\epsilon\left(-\epsilon\left(4-2a+2d+\epsilon+2\lambda+2\delta(-1+\mu)\right)+4c_F\right)-8\left(2-2a+2d+\epsilon+2\lambda+2\delta(-1+\mu)+c_F\right)q_F+4\left(4-2a+2d+\epsilon+2\lambda+2\delta(-1+\mu)\right)q_F^2\right)}{\left(\epsilon^2-4(-4+q_F)q_F\right)^2}\right)\right)$ $\left(\frac{\left(\epsilon^4(\epsilon+\delta\mu)+\epsilon^2\left(-\epsilon^2+20\delta\mu+2\epsilon(8+a-d+\delta-\lambda-\delta\mu)+4c_F\right)q_F-8\left(\epsilon\left(-6-2a+2d-2\delta+\epsilon+\epsilon^2+2\lambda\right)+\delta(-2+\epsilon)(4+\epsilon)\mu+\epsilon c_F\right)q_F^2+4\left(\epsilon^2+2\epsilon\left(-8-a+d+\lambda+\delta(-1+\mu)\right)-20\delta\mu\right)q_F^3+16(\epsilon+\delta\mu)q_F^4\right)}{\left(\epsilon^2-4(-1+q_F)q_F\right)^2}\right)$

Table G.3 Expression of second-hand luxury product consumer surplus $\left(CS_j\right)$ Where *j*= C0, C1, C2 and C3

Cases	Consumer surplus
C0	$\frac{1}{2}\left(1+\frac{\lambda+p_{FC0}^{*}-p_{SC0}^{*}}{1-q_F}\right)\left(1+\epsilon+2\lambda-2p_{SC0}^{*}-\frac{\epsilon\left(\epsilon-2p_{CC0}^{*}\right)}{2q_c}+\frac{\lambda+p_{FC0}^{*}-p_{SC0}^{*}}{-1+q_F}\right)$
C1	$\frac{1}{2}\left(1-\frac{2p_{FC1}^{*}(\epsilon-2q_F)-2\left(\epsilon+2\lambda-2p_{SC1}^{*}\right)q_F}{\epsilon^2+4q_F-4q_F^2}\right)\left(1+\epsilon+2\lambda-2p_{SC1}^{*}+\frac{(1+\epsilon)\left(2p_{FC1}^{*}(\epsilon-2q_F)-2\left(\epsilon+2\lambda-2p_{SC1}^{*}\right)q_F\right)}{\epsilon^2+4q_F-4q_F^2}\right)$
C2	$\frac{1}{2}\left(1-\frac{2p_{FC2}^{*}(\epsilon-2q_F)-2\left(2d+\epsilon+2\mu-2p_{SC2}^{*}\right)q_F}{\epsilon^2+4sq_F-4q_F^2}\right)\left(2d+s+\epsilon+2\mu-2p_{SC2}^{*}+\frac{(s+\epsilon)\left(2p_{FC2}^{*}(\epsilon-2q_F)-2\left(2d+\epsilon+2\mu-2p_{SC2}^{*}\right)q_F\right)}{\epsilon^2+4sq_F-4q_F^2}\right)$
C3	$\frac{1}{2}\left(1-\frac{2p_{FC3}^{*}(\epsilon-2q_F)-2\left(2d+\epsilon+2\lambda+2\delta\mu-2p_{SC3}^{*}\right)q_F}{\epsilon^2+4q_F-4q_F^2}\right)\left(1+2d+\epsilon+2\lambda+2\delta\mu-2p_{SC3}^{*}+\frac{(1+\epsilon)\left(2p_{FC3}^{*}(\epsilon-2q_F)-2\left(2d+\epsilon+2\lambda+2\delta\mu-2p_{SC3}^{*}\right)q_F\right)}{\epsilon^2+4q_F-4q_F^2}\right)$

Appendix H: Notations of expressions used in intermediary calculations

Table H.1: Consumer valuation threshold $\left(T_{\alpha j}\right)$ for player α for case j. Where *j*= C0, C1, C2 & C3 and α= S, F & C

Cases	Notation	Expression
C0	T_{SC0}	$\frac{\lambda+p_{FC0}-p_{SC0}}{-1+q_F}$
	T_{FC0}	$\frac{p_{CC0}-p_{FC0}}{q_c-q_F}$
	T_{CC0}	$-\frac{\epsilon-2p_{CC0}}{2q_c}$
C1	T_{SC1}	$\frac{\epsilon\left(\epsilon+2\lambda-2p_{SC1}\right)+2p_{FC1}\left(2+\epsilon-2q_F\right)}{\epsilon^2+4q_F-4q_F^2}$
	T_{FC1}	$\frac{2p_{FC1}\left(\epsilon-2q_F\right)-2\left(\epsilon+2\lambda-2p_{SC1}\right)q_F}{\epsilon^2+4q_F-4q_F^2}$
C2	T_{SC2}	$\frac{2p_{FC2}\left(\epsilon-2q_F\right)-2\left(2d+\epsilon+2\mu-2p_{SC2}\right)q_F}{\epsilon^2+4sq_F-4q_F^2}$
	T_{FC2}	$\frac{\epsilon\left(2d+\epsilon+2\mu-2p_{SC2}\right)+2p_{FC2}\left(2s+\epsilon-2q_F\right)}{\epsilon^2+4sq_F-4q_F^2}$
C3	T_{SC3}	$\frac{\left(\epsilon\left(2d+\epsilon+2\lambda+2\delta\mu-2p_{SC3}\right)+2p_{FC3}\left(2+\epsilon-2q_F\right)\right)}{\left(\epsilon^2+4q_F-4q_F^2\right)}$

	T_{FC3}	$\frac{\left(2p_{FC3}\left(\epsilon-2q_F\right)-2\left(2d+\epsilon+2\lambda+2\delta\mu-2p_{SC3}\right)q_F\right)}{\left(\epsilon^2+4q_F-4q_F^2\right)}$

Table H.2 Exclusivity $\left(E_j\right)$ expression of a luxury brand. Where *j*= C0, C1, C2 and C3

Cases	Exclusivity of a luxury brand
C0	$\frac{1}{2}\epsilon\left(1-\frac{\epsilon-2p_{CC0}}{2q_c}\right)\left(1+\frac{\lambda+p_{FC0}-p_{SC0}}{1-q_F}\right)$
C1	$\frac{1}{2}\epsilon\left(1-\frac{\left(2p_{FC1}\left(\epsilon-2q_F\right)-2\left(\epsilon+2\lambda-2p_{SC1}\right)q_F\right)^2}{\left(\epsilon^2+4q_F-4q_F^2\right)^2}\right)$
C2	$\frac{1}{2}\left(1-\frac{2p_{FC2}(\epsilon-2q_F)-2(2d+\epsilon+2\mu-2p_{SC2})q_F}{\epsilon^2+4sq_F-4q_F^2}\right)\left(\epsilon+2\mu+\frac{\epsilon\left(2p_{FC2}(\epsilon-2q_F)-2(2d+\epsilon+2\mu-2p_{SC2})q_F\right)}{\epsilon^2+4sq_F-4q_F^2}\right)$
C3	$\frac{1}{2}\left(1-\frac{2p_{FC3}(\epsilon-2q_F)-2(2d+\epsilon+2\lambda+2\delta\mu-2p_{SC3})q_F}{\epsilon^2+4q_F-4q_F^2}\right)\left(\epsilon+2\delta\mu+\frac{\epsilon\left(2p_{FC3}(\epsilon-2q_F)-2(2d+\epsilon+2\lambda+2\delta\mu-2p_{SC3})q_F\right)}{\epsilon^2+4q_F-4q_F^2}\right)$

Appendix I: Summary of results threshold

Table I.1: Threshold values for section 4.1

Notations	Expressions
μ_{1P1}	$\frac{4q_F\left(\epsilon^2+8sq_F-4q_F^2\right)\left(\epsilon^2(-2a+2d+4s+\epsilon)-4sc_F(\epsilon-2q_F)+8s(-2a+2d+2s+\epsilon)q_F+4(2a-2d-4s-\epsilon)q_F^2\right)}{-8q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2}-\frac{\left(\epsilon^2+4sq_F-4q_F^2\right)\left(\epsilon^2+16sq_F-4q_F^2\right)^2}{8q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2}\left(\frac{\left(q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2\left(q_F(-8-\epsilon-8\lambda-4c_F+2c_c(-1+q_F)+8q_F+\epsilon q_F+4\lambda q_F)+q_c\left(4+\epsilon+4\lambda-\epsilon q_F-4q_F^2+2c_F(1+q_F)\right)\right)^2\right)}{\left((-1+q_F)\left(\epsilon^2+16sq_F-4q_F^2\right)^2\left(-\epsilon^2-4sq_F+4q_F^2\right)\left((-4+q_F)q_F+q_c(2+q_F)\right)^2\right)}\right)^{1/2}$
μ_{2P1}	$\frac{-4q_F\left(\epsilon^2+8sq_F-4q_F^2\right)\left(\epsilon\left(\epsilon(-2a+2d+4s+\epsilon)-4sc_F\right)+8s\left(-2a+2(d+s)+\epsilon+c_F\right)q_F-4(-2a+2d+4s+\epsilon)q_F^2\right)}{8q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2}+\frac{\left(\epsilon^2+4sq_F-4q_F^2\right)\left(\epsilon^2+16sq_F-4q_F^2\right)^2}{8q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2}\left(\frac{\left(q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2\left(q_F(-8-\epsilon-8\lambda-4c_F+2c_c(-1+q_F)+8q_F+\epsilon q_F+4\lambda q_F)+q_c\left(4+\epsilon+4\lambda-\epsilon q_F-4q_F^2+2c_F(1+q_F)\right)\right)^2\right)}{\left((-1+q_F)\left(\epsilon^2+16sq_F-4q_F^2\right)^2\left(-\epsilon^2-4sq_F+4q_F^2\right)\left((-4+q_F)q_F+q_c(2+q_F)\right)^2\right)}\right)^{1/2}$
$\bar{\mu}_{1P1}$	$\frac{4\delta q_F\left(\epsilon^2+8q_F-4q_F^2\right)\left(\epsilon^2(4-2a+2d-2\delta+\epsilon+2\lambda)-4c_F(\epsilon-2q_F)-8(-2+2a-2d+2\delta-\epsilon-2\lambda)q_F+4(-4+2a-2d+2\delta-\epsilon-2\lambda)q_F^2\right)}{-8\delta^2q_F\left(\epsilon^2+8q_F-4q_F^2\right)^2}-\frac{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)^2}{8\delta^2q_F\left(\epsilon^2+8q_F-4q_F^2\right)^2}\left(\frac{\left(\delta^2q_F\left(\epsilon^2+8q_F-4q_F^2\right)^2\left(q_F(-8-\epsilon-8\lambda-4c_F+2c_c(-1+q_F)+8q_F+\epsilon q_F+4\lambda q_F)+q_c\left(4+\epsilon+4\lambda-\epsilon q_F-4q_F^2+2c_F(1+q_F)\right)\right)^2\right)}{\left((-1+q_F)\left(\epsilon^2+16q_F-4q_F^2\right)^2\left(-\epsilon^2-4q_F+4q_F^2\right)\left((-4+q_F)q_F+q_c(2+q_F)\right)^2\right)}\right)^{1/2}$
$\bar{\mu}_{2P1}$	$\frac{-4\delta q_F\left(\epsilon^2+8q_F-4q_F^2\right)\left(\epsilon^2(4-2a+2d-2\delta+\epsilon+2\lambda)-4c_F(\epsilon-2q_F)-8(-2+2a-2d+2\delta-\epsilon-2\lambda)q_F+4(-4+2a-2d+2\delta-\epsilon-2\lambda)q_F^2\right)}{8\delta^2q_F\left(\epsilon^2+8q_F-4q_F^2\right)^2}+\frac{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)^2}{8\delta^2q_F\left(\epsilon^2+8q_F-4q_F^2\right)^2}\left(\frac{\left(\delta^2q_F\left(\epsilon^2+8q_F-4q_F^2\right)^2\left(q_F(-8-\epsilon-8\lambda-4c_F+2c_c(-1+q_F)+8q_F+\epsilon q_F+4\lambda q_F)+q_c\left(4+\epsilon+4\lambda-\epsilon q_F-4q_F^2+2c_F(1+q_F)\right)\right)^2\right)}{\left((-1+q_F)\left(\epsilon^2+16q_F-4q_F^2\right)^2\left(-\epsilon^2-4q_F+4q_F^2\right)\left((-4+q_F)q_F+q_c(2+q_F)\right)^2\right)}\right)^{1/2}$
d_{1P2}	$\frac{-q_F\left(\epsilon^2+8sq_F-4q_F^2\right)\left(\epsilon^2(-2a+4s+\epsilon+2\mu)-4sc_F(\epsilon-2q_F)+8s(-2a+2s+\epsilon+2\mu)q_F+4(2a-4s-\epsilon-2\mu)q_F^2\right)}{2q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2}-\frac{\left(\epsilon^6+4q_F\left(-9s\epsilon^4+q_F\left(-96s^2\epsilon^2+3\epsilon^4+4q_F\left(-64s^3+18s\epsilon^2+q_F\left(96s^2-3\epsilon^2+4q_F(-9s+q_F)\right)\right)\right)\right)\right)}{2q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2}$

	$\left(\frac{(q_F(\epsilon^2+8sq_F-4q_F^2)^2(-F\epsilon^6+q_F(\epsilon^4(-36F+(4+\epsilon+2\lambda)^2)+16c_F^2(\epsilon-2q_F)^2-8c_F(\epsilon-2q_F)(\epsilon^2(4+\epsilon+2\lambda)+8(2+\epsilon+2\lambda)q_F-4(4+\epsilon+2\lambda)q_F^2)+4q_F(\epsilon^2(3F(-32+\epsilon^2)+4(2+\epsilon+2\lambda)(4+\epsilon+2\lambda))+2q_F(-\epsilon^4+4F(-32+9\epsilon^2)+32\epsilon(1+\lambda)+32(1+\lambda)^2-4\epsilon^3(2+\lambda)-4\epsilon^2(2+\lambda(4+\lambda))+2q_F(-3F(-32+\epsilon^2)-4(2+\epsilon+2\lambda)(4+\epsilon+2\lambda)+q_F(-36F+(4+\epsilon+2\lambda)^2+4Fq_F))))))))}{((\epsilon^2+4(s-q_F)q_F)(\epsilon^2-4(-4+q_F)q_F)^2(\epsilon^2-4(-1+q_F)q_F)(\epsilon^2+16sq_F-4q_F^2)^2)}\right)^{1/2}$
d_{2P2}	$\frac{-q_F(\epsilon^2+8sq_F-4q_F^2)(\epsilon^2(-2a+4s+\epsilon+2\mu)-4sc_F(\epsilon-2q_F)+8s(-2a+2s+\epsilon+2\mu)q_F+4(2a-4s-\epsilon-2\mu)q_F^2)}{2q_F(\epsilon^2+8sq_F-4q_F^2)^2}+\frac{(\epsilon^2+4sq_F-4q_F^2)(\epsilon^2+16sq_F-4q_F^2)^2}{2q_F(\epsilon^2+8sq_F-4q_F^2)^2}\;(-\epsilon^2-8sq_F+4q_F^2)$ $\Bigg(\frac{q_F(-F\epsilon^6+\epsilon^2(\epsilon^2(-36F+(4+\epsilon+2\lambda)^2)-8\epsilon(4+\epsilon+2\lambda)c_F+16c_F^2)q_F+4\epsilon(\epsilon(3F(-32+\epsilon^2)+4(8+6\epsilon+\epsilon^2+12\lambda+4\epsilon\lambda+4\lambda^2))+4(\epsilon^2+2\epsilon\lambda-8(1+\lambda))c_F-16c_F^2)q_F^2-8(8\epsilon^3+\epsilon^4-4F(-32+9\epsilon^2)-32\epsilon(1+\lambda)-32(1+2\lambda)+8\epsilon^2(1+2\lambda))q_F^3)}{(\epsilon^2+4q_F-4q_F^2)(\epsilon^2+16q_F-4q_F^2)^2(\epsilon^2+4sq_F-4q_F^2)(\epsilon^2+16sq_F-4q_F^2)^2}+$ $\frac{16q_F^4(2\lambda(\epsilon^3+8\lambda-\epsilon^2\lambda)+4c_F^2-(3F(-32+\epsilon^2)+4(8+6\epsilon+\epsilon^2+12\lambda+4\epsilon\lambda+4\lambda^2))q_F+(-36F+(4+\epsilon+2\lambda)^2)q_F^2+4Fq_F^3+2c_F(8+8\epsilon+\epsilon^2+8\lambda+2\epsilon\lambda-2(4+\epsilon+2\lambda)q_F))}{(\epsilon^2+4q_F-4q_F^2)(\epsilon^2+16q_F-4q_F^2)^2(\epsilon^2+4sq_F-4q_F^2)(\epsilon^2+16sq_F-4q_F^2)^2}\Bigg)^{1/2}$
$\bar{d}_{1P2}$	$\frac{q_F(\epsilon^2+8q_F-4q_F^2)(\epsilon^2(4-2a+\epsilon+2\lambda+2\delta(-1+\mu))-4c_F(\epsilon-2q_F)-8(-2+2a-\epsilon-2\lambda-2\delta(-1+\mu))q_F+4(-4+2a-\epsilon-2\lambda-2\delta(-1+\mu))q_F^2)}{-2q_F(\epsilon^2+8q_F-4q_F^2)^2}-\frac{(\epsilon^2+4q_F-4q_F^2)(\epsilon^2+16q_F-4q_F^2)^2}{2q_F(\epsilon^2+8q_F-4q_F^2)^2}\;(-\epsilon^2-8q_F+4q_F^2)$ $\Bigg(\frac{q_F(-F\epsilon^6+\epsilon^2(\epsilon^2(-36F+(4+\epsilon+2\lambda)^2)-8\epsilon(4+\epsilon+2\lambda)c_F+16c_F^2)q_F+4\epsilon(\epsilon(3F(-32+\epsilon^2)+4(8+6\epsilon+\epsilon^2+12\lambda+4\epsilon\lambda+4\lambda^2))+4(\epsilon^2+2\epsilon\lambda-8(1+\lambda))c_F-16c_F^2)q_F^2-8(8\epsilon^3+\epsilon^4-4F(-32+9\epsilon^2)-32\epsilon(1+\lambda)-32(1+2\lambda)+8\epsilon^2(1+2\lambda))q_F^3)}{(\epsilon^2+4q_F-4q_F^2)^2(\epsilon^2+16q_F-4q_F^2)^4}$ $+\frac{16q_F^4(2\lambda(\epsilon^3+8\lambda-\epsilon^2\lambda)+4c_F^2-(3F(-32+\epsilon^2)+4(8+6\epsilon+\epsilon^2+12\lambda+4\epsilon\lambda+4\lambda^2))q_F+(-36F+(4+\epsilon+2\lambda)^2)q_F^2+4Fq_F^3+2c_F(8+8\epsilon+\epsilon^2+8\lambda+2\epsilon\lambda-2(4+\epsilon+2\lambda)q_F))}{(\epsilon^2+4q_F-4q_F^2)^2(\epsilon^2+16q_F-4q_F^2)^4}\Bigg)^{1/2}$
$\bar{d}_{2P2}$	$\frac{-q_F(\epsilon^2+8q_F-4q_F^2)(\epsilon^2(4-2a+\epsilon+2\lambda+2\delta(-1+\mu))-4c_F(\epsilon-2q_F)-8(-2+2a-\epsilon-2\lambda-2\delta(-1+\mu))q_F}{2q_F(\epsilon^2+8q_F-4q_F^2)^2}+\frac{(\epsilon^2+4q_F-4q_F^2)(\epsilon^2+16q_F-4q_F^2)^2}{2q_F(\epsilon^2+8q_F-4q_F^2)^2}\;(-\epsilon^2-8q_F+4q_F^2)$

	$\Bigg(\frac{q_F\left(-F\epsilon^6+\epsilon^2\left(\epsilon^2\left(-36F+(4+\epsilon+2\lambda)^2\right)-8\epsilon(4+\epsilon+2\lambda)c_F+16c_F^2\right)q_F+4\epsilon(\epsilon\left(3F\left(-32+\epsilon^2\right)+4\left(8+6\epsilon+\epsilon^2+12\lambda+4\epsilon\lambda+4\lambda^2\right)\right)+4\left(\epsilon^2+2\epsilon\lambda-8(1+\lambda)\right)c_F-16c_F^2)q_F^2-8\left(8\epsilon^3+\epsilon^4-4F\left(-32+9\epsilon^2\right)-32\epsilon(1+\lambda)-32(1+2\lambda)+8\epsilon^2(1+2\lambda)\right)q_F^3\right)}{\left(\left(\epsilon^2+4q_F-4q_F^2\right)^2\left(\epsilon^2+16q_F-4q_F^2\right)^4\right)}$ $+\frac{q_F\left(16q_F^3\left(-2\lambda\left(\epsilon^3-8\lambda+\epsilon^2\lambda\right)+4c_F^2-\left(3F\left(-32+\epsilon^2\right)+4\left(8+6\epsilon+\epsilon^2+12\lambda+4\epsilon\lambda+4\lambda^2\right)\right)q_F+\left(-36F+(4+\epsilon+2\lambda)^2\right)q_F^2+4Fq_F^3+2c_F\left(8+8\epsilon+\epsilon^2+8\lambda+2\epsilon\lambda-2(4+\epsilon+2\lambda)q_F\right)\right)\right)}{\left(\left(\epsilon^2+4q_F-4q_F^2\right)^2\left(\epsilon^2+16q_F-4q_F^2\right)^4\right)}\Bigg)^{1/2}$
δ_{1P3}	$\frac{(-1+\mu)\left(\epsilon^2+8q_F-4q_F^2\right)\left(\epsilon^2(4-2a+2d+\epsilon+2\lambda)-4c_F(\epsilon-2q_F)+8(2-2a+2d+\epsilon+2\lambda)q_F+4(-4+2a-2d-\epsilon-2\lambda)q_F^2\right)}{-2(1-\mu)^2\left(\epsilon^2+8q_F-4q_F^2\right)^2}-\frac{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)^2}{2(-1+\mu)^2\left(\epsilon^2+8q_F-4q_F^2\right)^2}\left(\frac{\left((-1+\mu)^2\left(\epsilon^2+8q_F-4q_F^2\right)^2\left(\epsilon^2(-2a+2d+4s+\epsilon+2\mu)-4sc_F(\epsilon-2q_F)+8s(-2a+2d+2s+\epsilon+2\mu)q_F+4(2a-2d-4s-\epsilon-2\mu)q_F^2\right)^2\right)}{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)^2\left(\epsilon^2+4sq_F-4q_F^2\right)\left(\epsilon^2+16sq_F-4q_F^2\right)^2}\right)^{1/2}$
δ_{2P3}	$\frac{-(-1+\mu)\left(\epsilon^2+8q_F-4q_F^2\right)\left(\epsilon^2(4-2a+2d+\epsilon+2\lambda)-4c_F(\epsilon-2q_F)+8(2-2a+2d+\epsilon+2\lambda)q_F+4(-4+2a-2d-\epsilon-2\lambda)q_F^2\right)}{2(-1+\mu)^2\left(\epsilon^2+8q_F-4q_F^2\right)^2}+\frac{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)^2}{2(-1+\mu)^2\left(\epsilon^2+8q_F-4q_F^2\right)^2}\left(\frac{\left((-1+\mu)^2\left(\epsilon^2+8q_F-4q_F^2\right)^2\left(\epsilon^2(-2a+2d+4s+\epsilon+2\mu)-4sc_F(\epsilon-2q_F)+8s(-2a+2d+2s+\epsilon+2\mu)q_F+4(2a-2d-4s-\epsilon-2\mu)q_F^2\right)^2\right)}{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)^2\left(\epsilon^2+4sq_F-4q_F^2\right)\left(\epsilon^2+16sq_F-4q_F^2\right)^2)}\right)^{1/2}$

Appendix J: Proofs

Proof of convexity of cases and equilibrium outcomes (As summarised in appendix F and notations in Appendix G): In the case C0, the demand of second-hand platform, follower brand and counterfeit are $1-T_{\mathrm{SC0}}$, $T_{\mathrm{SC0}}-T_{\mathrm{FC0}}$ and $T_{\mathrm{FC0}}-T_{\mathrm{CC0}}$, respectively. The T_{SC0} is calculated by comparing U_{SC0} and U_{FC0}. Similarly, T_{FC0} is calculated by comparing U_{FC0} and U_{FC0}, and T_{CC0} is calculated by comparing U_{FC0} and U_{NC0}. Then these values are substituted in π_{SC0}, π_{FC0} and π_{CC0}. The second-hand platform, follower brand and counterfeit player decide their prices my maximizing profit π_{SC0}, π_{FC0} and π_{CC0}. Where $\dfrac{\partial^2 \pi_{\mathrm{SC0}}}{\partial \left(p_{\mathrm{SC0}}\right)^2}=\dfrac{-2}{1-q_F}<0$, $\dfrac{\partial^2 \pi_{\mathrm{FC0}}}{\partial \left(p_{\mathrm{FC0}}\right)^2}=2\left(\dfrac{-1}{q_F-q_C}-\dfrac{1}{1-q_F}\right)<0$ and $\dfrac{\partial^2 \pi_{\mathrm{CC0}}}{\partial \left(p_{\mathrm{CC0}}\right)^2}=-2\left(\dfrac{1}{q_F-q_c}+\dfrac{1}{q_c}\right)<0$.

In case C1, third party second-hand platform uses luxury brand shared product authentications information to keep the counterfeits out from the market, raising the status utility for its consumers. The demand of second-hand platform and follower brand are $1-T_{\mathrm{SC1}}$ and $T_{\mathrm{SC1}}-T_{\mathrm{FC1}}$. The T_{SC1} is calculated by comparing U_{SC1} and U_{FC1}. Similarly, T_{FC1} is calculated by comparing U_{FC1} and U_{NC1}. The second-hand platform and follower brand simultaneously decide their prices maximizing their profit functions π_{SC1} and π_{FC1}, respectively. Where $\dfrac{\partial^2 \pi_{\mathrm{SC1}}}{\partial \left(p_{\mathrm{SC1}}\right)^2}=\dfrac{-8q_F}{\epsilon^2-4q_F^2+4q_F}<0$ and $\dfrac{\partial^2 \pi_{\mathrm{FC1}}}{\partial \left(p_{\mathrm{FC1}}\right)^2}=\dfrac{-8}{\epsilon^2-4q_F^2+4q_F}<0$ in parametric region.

In case C2, the second-hand platform is a mono-brand second-hand platform which facilitates in providing the luxury experience to the second-hand consumers and records ownership transfer of luxury product on blockchain based database. The platform focuses on maximising the aspirational value luxury brand while deciding its prices. Consequently, follower brand strategically decides its price $\left(p_{FC2}\right)$ after observing the second-hand product process in the market $\left(p_{SC2}\right)$. The demand of second-hand platform and follower brand are $1-T_{\mathrm{SC2}}$ and $T_{\mathrm{SC2}}-T_{\mathrm{FC2}}$. The T_{SC2} is calculated by comparing U_{SC2} and U_{FC2}. Similarly, T_{FC2} is calculated by comparing U_{FC2} and U_{NC2}. The second-hand platform and follower brand then sequentially decide their prices maximizing their profit functions π_{SC2} and π_{FC2}, respectively. Where $\frac{\partial^2 \pi_{\mathrm{SC2}}}{\partial\left(p_{\mathrm{SC2}}\right)^2}=\frac{-8q_F}{4sq_F-4q_F^2+\epsilon^2}$ and $\frac{\partial^2 \pi_{\mathrm{FC2}}}{\partial\left(p_{\mathrm{FC2}}\right)^2}=\frac{-8s}{4sq_F-4q_F^2+\epsilon^2}$ is negative definite if lemma 1 holds true.

Lemma 1 proof:

For $\frac{\partial^2 \pi_{\mathrm{SC2}}}{\partial\left(p_{\mathrm{SC2}}\right)^2}$ and $\frac{\partial^2 \pi_{\mathrm{FC2}}}{\partial\left(p_{\mathrm{FC2}}\right)^2}$ will be always negative if the denominator $4sq_F-4q_F^2+\epsilon^2>0$ .The above quadratic equation in q_F is always positive for $q_F \in \left[0,\frac{\sqrt{s^2+\epsilon^2}+s}{2}\right]$.

In case C3, the second-hand platform is a multi-brand second-hand platform that records ownership transfer of luxury product on blockchain based database. The platform focuses on maximising the aspirational value luxury brand while deciding its prices. Consequently, follower brand strategically decides its price $\left(p_{FC3}\right)$ after observing the second-hand product process in the market $\left(p_{SC3}\right)$. The demand of second-hand platform and follower brand are $1-T_{\mathrm{SC3}}$ and $T_{\mathrm{SC3}}-T_{\mathrm{FC3}}$. The T_{SC3} is calculated by comparing U_{SC3} and U_{FC3}. Similarly, T_{FC3} is calculated by comparing U_{FC3} and U_{NC3}. The second-hand platform and follower brand then sequentially decide their prices maximizing their profit functions π_{SC3} and π_{FC3}, respectively. Where $\frac{\partial^2 \pi_{\mathrm{SC3}}}{\partial\left(p_{\mathrm{SC3}}\right)^2}=\frac{-8q_F}{\epsilon^2-4q_F^2+4q_F}<0$ and $\frac{\partial^2 \pi_{\mathrm{FC3}}}{\partial\left(p_{\mathrm{FC3}}\right)^2}=\frac{-8s}{4sq_F-4q_F^2+\epsilon^2}<0$.

Proof of proposition 1:

In this proof we are comparing case C0 with C1, C2 and C3 to find the conditions when benchmark case is profitable choice for second-hand platform. We compared π_{SC0}^* and π_{SC1}^* and found that: $\pi_{SC1}^*-\pi_{SC0}^*=\left(p_{SC1}^*\left(1-T_{SC1}^*\right)-F\right)-\left(p_{\mathrm{SC0}}^*\left(1-T_{\mathrm{SC0}}^*\right)\right)=F_{P1}-F$. Suggesting that for $F>F_{P1}\Rightarrow \pi_{SC1}^*<\pi_{SC0}^*$.

Furthermore, when we compared π_{SC0}^{*} and π_{SC2}^{*}, we found that: $\pi_{SC2}^{*} - \pi_{SC0}^{*} = A\left(\mu - \mu_{1P1}\right)\left(\mu - \mu_{2P1}\right)$ such that $0 < A = \frac{4q_F\left(\epsilon^2+8sq_F-4q_F^2\right)^2}{\left(\epsilon^2+4(s-q_F)q_F\right)\left(\epsilon^2+16sq_F-4q_F^2\right)^2}$ and $\mu_{2P1} > \mu_{1P1}$ for $q_F \in \left(0, \frac{s+\sqrt{s^2+\epsilon^2}}{2}\right)$. This implies for $\mu \in \left(\mu_{1P1}, \mu_{2P1}\right)$, $\pi_{SC2}^{*} < \pi_{SC0}^{*}$

Similarly, by comparing π_{SC0}^{*} and π_{SC3}^{*}, we found that $\pi_{SC3}^{*} - \pi_{SC0}^{*} = B\left(\mu - \bar{\mu}_{1P1}\right)\left(\mu - \bar{\mu}_{2P1}\right)$ such that $0 < B = \frac{4\delta^2 q_F\left(\epsilon^2-4(-2+q_F)q_F\right)^2}{\left(\epsilon^2-4(-4+q_F)q_F\right)^2\left(\epsilon^2-4(-1+q_F)q_F\right)}$ and $\bar{\mu}_{2P1} > \bar{\mu}_{1P1}$ in the parametric region. This implies for $\mu \in \left(\bar{\mu}_{1P1}, \bar{\mu}_{2P1}\right)$, $\pi_{SC3}^{*} < \pi_{SC0}^{*}$. The above results suggest that for $\mu \in \left(\mu_{\min}, \mu_{\max}\right)$ and $F > F_{P1} \Rightarrow \pi_{SC0}^{*} > \pi_{SC2}^{*}$, $\pi_{SC0}^{*} > \pi_{SC3}^{*}$ and $\pi_{SC0}^{*} > \pi_{SC1}^{*}$. Where, $\mu_{\min} = \max\left\{\mu_{1P1}, \bar{\mu}_{1P1}\right\}$ and $\mu_{\max} = \min\left\{\mu_{2P1}, \bar{\mu}_{2P1}\right\}$ ($\because$ for most of the parametric region μ_{1P1} is lesser than $\bar{\mu}_{2P1}$). Table D.1 tabulates the expressions for thresholds.

Proof of Corollary 1:

In this proof we are comparing second-hand product demand and prices of case C0, C2 and C3. We compared D_{SC0}^{*}, D_{SC2}^{*}, and D_{SC3}^{*} and found that: $\frac{d\left(D_{SC0}^{*} - D_{SC2}^{*}\right)}{d\mu} = \frac{-4q_F\left(\epsilon^2+8sq_F-4q_F^2\right)}{\left(\epsilon^2+4sq_F-4q_F^2\right)\left(\epsilon^2+16sq_F-4q_F^2\right)} < 0$ for $q_F \in \left[0, \frac{\sqrt{s^2+\epsilon^2}+s}{2}\right]$ and $\frac{d\left(D_{SC0}^{*} - D_{SC3}^{*}\right)}{d\mu} = \frac{-4\delta q_F\left(\epsilon^2+8q_F-4q_F^2\right)}{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)} < 0$.

Similarly, comparing p_{SC0}^{*}, p_{SC2}^{*}, and p_{SC3}^{*} and found that: $\frac{d\left(p_{SC0}^{*} - p_{SC2}^{*}\right)}{d\mu} = -\frac{\epsilon^2+8sq_F-4q_F^2}{\epsilon^2+16sq_F-4q_F^2} < 0$ for $q_F \in \left[0, \frac{\sqrt{s^2+\epsilon^2}+s}{2}\right]$ and $\frac{d\left(p_{SC0}^{*} - p_{SC3}^{*}\right)}{d\mu} = -\frac{\delta\left(\epsilon^2+8q_F-4q_F^2\right)}{\epsilon^2+16q_F-4q_F^2} < 0$.

Proof of proposition 2:

This proof compared the case C1 with C0, C2 and C3 to find conditions when platform should collaborate with luxury brand for authentication information sharing. We compared π_{SC1}^{*} and π_{SC2}^{*}, and found that: $\pi_{SC2}^{*} - \pi_{SC1}^{*} = A(d - d_{1P2})(d - d_{2P2})$ such that $0 < A = \frac{4q_F\left(8sq_F-4q_F^2+\epsilon^2\right)^2}{\left(4q_F(s-q_F)+\epsilon^2\right)\left(16sq_F-4q_F^2+\epsilon^2\right)^2}$ and $d_{2P2} > d_{1P2}$ for $q_F \in \left(0, \frac{\sqrt{s^2+\epsilon^2}+s}{2}\right)$. Suggesting that for $d \in \left(d_{1P2}, d_{2P2}\right)$, $\pi_{SC2}^{*} < \pi_{SC1}^{*}$. Similarly, by comparing π_{SC1}^{*} and π_{SC3}^{*} we found that: $\pi_{SC3}^{*} - \pi_{SC1}^{*} = B(d - \bar{d}_{1P2})(d - \bar{d}_{2P2})$. Such that

$0 < B = \frac{4q_F\left(\epsilon^2-4(q_F-2)q_F\right)^2}{\left(\epsilon^2+4(4-q_F)q_F\right)^2\left(\epsilon^2-4(q_F-1)q_F\right)}$ and $\bar{d}_{2P2} > \bar{d}_{1P2}$ in parametric region. Suggesting that for $d \in \left(\bar{d}_{1P2}, \bar{d}_{2P2}\right)$, $\pi^*_{SC1} > \pi^*_{SC3}$. Furthermore, from proof of proposition 2 we know that for $F < F_{P1} \Rightarrow \pi^*_{SC1} > \pi^*_{SC0}$. The above results suggest that for $d \in \left(d_{\min}, d_{\max}\right)$ and $F < F_{P1} \Rightarrow \pi^*_{SC1} > \pi^*_{SC0}$, $\pi^*_{SC1} > \pi^*_{SC2}$ and $\pi^*_{SC1} > \pi^*_{SC3}$. Where, $d_{\min} = \max\left\{d_{1P2}, \bar{d}_{1P2}\right\}$ and $d_{\max} = \min\left\{d_{2P2}, \bar{d}_{2P2}\right\}$ ($\because$ for most of the parametric region d_{1P2} is lesser than $\bar{d}_{2P2}$). Table D.1 tabulates the expressions for thresholds. Table D.1 tabulates the expressions for thresholds.

Proof of Corollary 2:

In this proof we are comparing second-hand product demand and prices of case C1, C2 and C3. We compared D^*_{SC0}, D^*_{SC2}, and D^*_{SC3} and found that: $\frac{d\left(D^*_{SC1} - D^*_{SC2}\right)}{d\,(d)} = -\frac{4q_F\left(8sq_F-4q_F^2+\epsilon^2\right)}{\left(4sq_F-4q_F^2+\epsilon^2\right)\left(16sq_F-4q_F^2+\epsilon^2\right)} < 0$ for $q_F \in \left[0, \frac{\sqrt{s^2+\epsilon^2}+s}{2}\right]$ and $\frac{d\left(D^*_{SC1} - D^*_{SC3}\right)}{d\,(d)} = -\frac{4q_F\left(\epsilon^2+8q_F-4q_F^2\right)}{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)} < 0$. Similarly, comparing p^*_{SC1}, p^*_{SC2}, and p^*_{SC3} and found that: $\frac{d\left(p^*_{SC1} - p^*_{SC2}\right)}{d\,(d)} = -\frac{\epsilon^2+8sq_F-4q_F^2}{\epsilon^2+16sq_F-4q_F^2} < 0$ for $q_F \in \left[0, \frac{\sqrt{s^2+\epsilon^2}+s}{2}\right]$ and $\frac{d\left(p^*_{SC1} - p^*_{SC3}\right)}{d\,(d)} = -\frac{\epsilon^2+8q_F-4q_F^2}{\epsilon^2+16q_F-4q_F^2} < 0$.

Proof of proposition 3:

This proof compares the case C2 and case C3 to find when luxury brand controlled second-hand platform should be mono brand or multi brand. We compared π^*_{SC2} and π^*_{SC3} and found that: $\pi^*_{SC3} - \pi^*_{SC2} = A(\delta - \delta_{1P3})(\delta - \delta_{2P3})$ such that $0 < A = \frac{4(\mu-1)^2 q_F\left(\epsilon^2-4(q_F-2)q_F\right)^2}{\left(\epsilon^2-4(q_F-4)q_F\right)^2\left(\epsilon^2+4(1-q_F)q_F\right)}$ and $\delta_{2P3} > \delta_{1P3}$ in the parametric region. This suggests that for $\delta \in \left(\delta_{1P3}, \delta_{2P3}\right)$, $\pi^*_{SC3} < \pi^*_{SC2}$. Table D.1 tabulates the expressions for thresholds.

Proof of Corollary 3:

In this proof we are comparing second-hand platform profits and prices of case C2 and C3. We compared π^*_{SC2} and π^*_{SC3} and found that:

$\frac{d\left(\pi^*_{SC2}-\pi^*_{SC3}\right)^2}{d\delta^2}=-\frac{2q_F\left(-\epsilon^2(-2+2\mu)+8(2-2\mu)q_F+4(-2+2\mu)q_F^2\right)^2}{\left(\epsilon^2+4q_F-4q_F^2\right)\left(\epsilon^2+16q_F-4q_F^2\right)^2}<0\ \forall\,\delta\in[0,1]$. Similarly, we compared p^*_{SC2}, and p^*_{SC3} and found that: $\frac{d\left(p^*_{SC2}-p^*_{SC3}\right)}{d\delta}=\frac{-\epsilon^2\mu-8(1+\mu)q_F+4\mu q_F^2}{\epsilon^2+16q_F-4q_F^2}<0\ \forall\ \delta\in[0,1]$.

Proof of proposition 4:

In this proof we are checking the variation of brand exclusivity with consumers price sensitivity in case C0, C1 and C3. We checked with E^*_{C0}, E^*_{C1} and E^*_{C3} and found that: $\frac{d\left(E^*_{C0}\right)^2}{d\lambda^2}=\frac{\epsilon(q_c-q_F)(q_c+(-2+q_F)q_F)}{2(-1+q_F)((-4+q_F)q_F+q_c(2+q_F))^2}<0$ for $q_F>q_C$, $\frac{d\left(E^*_{C1}\right)^2}{d\lambda^2}=-\frac{16\epsilon q_F^2\left(\epsilon^2+8q_F-4q_F^2\right)^2}{\left(\epsilon^2-4(-4+q_F)q_F\right)^2\left(\epsilon^2-4(-1+q_F)q_F\right)^2}<0$, and $\frac{d\left(E^*_{C3}\right)^2}{d\lambda^2}=-\frac{16\epsilon q_F^2\left(\epsilon^2+8q_F-4q_F^2\right)^2}{\left(\epsilon^2+4q_F-4q_F^2\right)^2\left(\epsilon^2+16q_F-4q_F^2\right)^2}<0$.

Proof of proposition 5:

In this proof we are checking the variation of brand exclusivity with product ownership transfer desirability in case C2 and C3. We checked with E^*_{C2} and E^*_{C3} and found that:

$\frac{d\left(E^*_{C2}\right)^2}{d(d)^2}=-\frac{16\epsilon q_F^2\left(\epsilon^2+8sq_F-4q_F^2\right)^2}{\left(\epsilon^2+4sq_F-4q_F^2\right)^2\left(\epsilon^2+16sq_F-4q_F^2\right)^2}<0$ and $\frac{d\left(E^*_{C3}\right)^2}{d(d)^2}=-\frac{16\epsilon q_F^2\left(\epsilon^2+8q_F-4q_F^2\right)^2}{\left(\epsilon^2+4q_F-4q_F^2\right)^2\left(\epsilon^2+16q_F-4q_F^2\right)^2}<0$.

Proof of proposition 6:

In this proof we are checking the variation of consumer surplus of case C3. We checked with CS^*_{C3} and found that: $\frac{d\left(CS^*_{C3}\right)^2}{d\delta^2}=-\frac{16(-1+\mu)^2q_F^2\left((-3+\epsilon)\epsilon^2+8(-1+\epsilon)q_F-4(-3+\epsilon)q_F^2\right)}{\left(\epsilon^2-4(-4+q_F)q_F\right)\left(\epsilon^2-4(-1+q_F)q_F\right)^2}>0$ for $q_F<q'_F\ \forall\varepsilon\in[0,1]$. Where $q'_F=\frac{2-2\epsilon+\sqrt{4-8\epsilon+13\epsilon^2-6\epsilon^3+\epsilon^4}}{6-2\epsilon}$.

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