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Understanding the Impact of Integration Strategy of Ride-Hailing Platforms on Traveller's Choice Behaviour

Ke LU[1], Yunlin WEI[2], Heng DU[3]

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[1] Corresponding author, k.lu1@outlook.com, Nanjing University of Information Science and Technology, School of Management Science and Engineering
[2] 17372965850@163.com, Nanjing University of Information Science and Technology, School of Management Science and Engineering
[3] quange0216@njit.edu.cn, Nanjing Institute of Technology, School of Economics & Management

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ABSTRACT

With the rapid expansion of ride-hailing services, it has gradually become a new travel choice for urban residents. Various research studies have focused on market relationships and platform strategies from the perspective of platform competition. However, little research has been studying issues related to the platform integration of ride-hailing services from the corporate perspective. Based on an analysis of integration modes and travellers' behavioural factors, we established an evolutionary game model to study travellers' choice behaviour under the integration of ride-hailing platforms. Furthermore, this study employed methods of model deduction and numerical study. The findings indicate the following. (1) When the travel risk associated with platform integration is high, travellers are less likely to choose ride-hailing services, and the integration strategy of ride-hailing platforms will not be pursued. (2) Ride-hailing platforms tend to interconnect with larger-scale platforms. (3) As the negative effect of perceived sacrifice decreases, ride-hailing platforms are more likely to interconnect with other platforms, and travellers are more inclined to choose ride-hailing services. (4) A higher cost of platform integration will decrease the probability of ride-hailing platforms adopting an integration strategy, but it will not significantly impact travellers' behaviour.

KEYWORDS

ride-hailing service; integration; traveller behaviour; choice behaviour; evolutionary game.

1. INTRODUCTION

Ride-hailing services have gradually gained prominence in recent years, emerging as a crucial component of the urban transportation system [1–3]. However, their origins can be traced back to the early 20th century, when the first taxi services emerged. Nevertheless, it was not until the advent of smartphones and GPS technology that the contemporary model of ride-hailing services began to emerge. In 2009, Garrett Camp and Travis Kalanick founded Uber, which is widely considered to be the first ride-hailing service, and it quickly expanded worldwide [4, 5]. Further, the success of Uber led to the establishment of numerous similar enterprises, including Lyft, Didi and Grab, etc.

With the rapid expansion of ride-hailing services, it has effectively transformed transportation systems in various aspects across the world. For example, Uber has promoted ride-hailing services in more than 10,000 cities around the world [6]. In China, as of 31 May 2024, a total of 351 ride-hailing companies have been granted licences to operate ride-hailing services [7]. A growing body of literature indicates that the adoption of ride-hailing services has resulted in a decline in the number of private vehicle usage, particularly in urban areas [8, 9]. What is more, the impact of ride-hailing services on public transportation is a multifaceted phenomenon that exhibits considerable variation. Some studies indicate that ride-hailing services may compete with public transportation, but also complement public transportation [10–12].

Furthermore, compared to other network platforms, the decision-making challenges of ride-hailing platforms exhibit distinctive characteristics, including higher timeliness and dynamics. In addition, these challenges are closely linked to urban geospatial and road networks [1, 13–15]. The real-time nature of ride-hailing platforms necessitates the ability to make prompt decisions in order to accommodate user requests [1, 14]. In addition, the effectiveness of ride-hailing platforms is significantly influenced by the characteristics of urban geospatial and road networks [15]. For example, dense urban cores may arouse heightened demand, yet simultaneously contend with more congestion. It is therefore imperative that platforms take these constraints into account in order to optimise routes and accurately estimate arrival times. Simultaneously, the ride-hailing industry is influenced by unique factors, including the matching efficiency of different platforms, the percentage of drivers' commission and the waiting time of bilateral users. Previous studies have demonstrated that the rise of ride-hailing services has gradually altered the travel behaviour of urban residents, giving rise to new research issues [2, 12, 16, 17]. Noteworthily, the integration of ride-hailing platforms has become a focal point of attention. Unlike the market competition among platform enterprises, platform integration places more emphasis on the cooperation and commonality between different platforms. This involves various mechanisms such as resource sharing, cost allocation and revenue sharing [18, 19].

The integration structure of the ride-hailing platform can be analysed as follows. Incentives are established between platforms to facilitate the interaction of information, funds, user resources, matching technology, etc. [20–22]. This ultimately enables travellers and drivers to engage in cross-platform transactions. In comparison to traditional transportation modes, the choice behaviour of travellers encountering ride-hailing platforms becomes more intricate due to the irrational factors influencing travellers and the multitude of subjects involved in ride-hailing services [3, 19]. Platform integration, as one of the future development directions for ride-hailing platform enterprises, has already yielded practical cases in the realm of the platform economy [23–25]. The choice behaviour of travellers amid the integration of ride-hailing platforms becomes more intricate. Therefore, given the complexity of travellers' choice behaviour and the significance of platform integration, studying the evolution of travellers' choice behaviour under the integration of ride-hailing platforms becomes imperative.

Building on existing research, this paper constructs a theoretical model by introducing the network externality of the ride-hailing platform and considering the perceived loss of travellers from a dynamic perspective. The purpose is to study the evolution of travellers' choice behaviour under the integration of ride-hailing platforms. On one hand, this study aims to provide a more objective analysis of travellers' choice behaviour regarding ride-hailing services. It seeks to enrich existing research results and unveil the general principles governing shared travel in urban transportation. On the other hand, the study is closely integrated with the practice of urban transportation development. The results of the study can, to a certain extent, offer policy references for the implementation of transportation management.

The rest of this paper is organised as follows. The relevant works of literature are reviewed in Section 2. Section 3 presents a brief description of the research problem and modelling. The evolutionary analysis of travellers' behaviour under the integration of ride-hailing platforms is proposed in the fourth section. Section 5 provides a numerical study. In Section 6, the last section presents conclusions, implications and limitations.

2. LITERATURE REVIEW

The choice behaviour of travellers regarding the emerging travel service of ride-hailing service mode has garnered the attention of current research. Concerning the socio-economic characteristics of ride-hailing users, this group exhibits notable traits, including youthfulness, high education levels, high-income levels and a lack of private car ownership [2, 16]. Regarding travel attributes, factors such as travel cost, waiting time, in-transit time, parking space problems and car ownership collectively influence travellers' willingness to use ride-hailing services. Additionally, psychosocial variables have progressively been incorporated into the study of the willingness to use ride-hailing services. Currently, widely considered variables include perceived ease of use, perceived usefulness, subjective norms, perceived value, etc. [19, 26, 27]. Some studies have explored travellers' choice behaviour in different scenarios. For instance, [2] identified attending social and leisure activities and avoiding drunk driving as the primary reasons why travellers opt for ride-hailing services.

Competition and cooperation arise from firms' operations, and achieving integration or mutual compatibility of products is a key consideration in firms' decision-making [24, 28]. Platform firms can merge with other platforms or establish integration between platforms through various forms such as protocols. [18] were the pioneers in studying integration between firms, considering network externalities. Building on this,

[29] examined platform integration from a bilateral market perspective, establishing the basic paradigm of integration research. As a new and emerging business model in the shared mobility sector, ride-hailing services have increasingly attracted researchers' attention. However, research on integrated ride-hailing services remains limited. Currently, existing studies focusing on integrated ride-hailing services primarily approach the topic from the perspective of platform operation. The profitability and social welfare impact of integrated ride-hailing platforms have been discussed in several studies [30–32]. Moreover, the impact of the integrated model of ride-hailing services on travellers has also been examined [20, 22].

The concept corresponding to platform integration is user multihoming, where users can choose to join multiple platforms to access services [33–35]. From the user's perspective, both platform integration and user multihoming provide similar effects, allowing users to enjoy services from multiple platforms. However, there are fundamental differences between the two in terms of platform operation, pricing structure and cost structure. Existing research indicates that user multihoming weakens market competition and generates additional costs. It cannot completely replace platform integration, emphasising that enterprise strategy development should prioritise platform integration [29]. Overall, current research concentrates on the changes in enterprise benefits and overall social welfare resulting from integration strategies. Platform service efficiency, service content and specific enterprise strategies all impact platform integration strategies [23, 36–38]. To a certain extent, integration will enhance the platform's benefits, but the implementation of integration strategies may also have negative effects [29, 36–38]. For example, the implementation of integration strategies for platforms with large market shares may reduce platform benefits. However, the implementation of integration strategies for firms with small horizontal differences may contribute to overall welfare [23].

As for travellers' behaviour related to ride-hailing services, current research has concentrated on examining the influence of users' socioeconomic characteristics, travel attributes, psychosocial factors and travel situational factors on travellers' choice behaviour. Simultaneously, existing research on platform integration has generated numerous results, primarily concentrating on the impact of platform integration strategies on corporate benefits and social welfare. Combined with literature research, it can be observed that existing studies still have the following shortcomings. (1) Current research on the behaviour of ride-hailing service travellers primarily adopts the perspective of platform competition and lacks the analysis of traveller behaviour under the cooperative perspective, such as platform integration. (2) Existing research on traveller behaviour predominantly utilises the method of collecting data from questionnaires for statistical analysis, emphasising static analysis. It lacks the exploration of the dynamic evolution of traveller behaviour in a long-term environment. (3) Existing studies still inadequately consider platform network externalities and the factors influencing travellers' behavioural decision-making.

3. PROBLEM DESCRIPTION AND MODELLING

The integration of ride-hailing platforms encompasses essential elements, including network externalities and cross-platform transactions. Travellers' choice behaviour is also influenced by behavioural decision-making factors, such as perceived loss, in addition to the objective factors of ride-hailing services. A theoretical model of the evolutionary game can be constructed through a systematic analysis of travellers' choice behaviour under the integration of ride-hailing platforms.

3.1 Problem description and assumptions

Ride-hailing enterprises facilitate connections between bilateral travellers and drivers through platforms, providing matching services. This constitutes a typical bilateral market with network externalities. By interconnecting online platforms, the sharing of resources, such as drivers and travellers, can enhance the utilisation rate of online vehicles and reduce travellers' waiting times. Simultaneously, the integration of ride-hailing platforms introduces new features. Integrating ride-hailing platforms facilitates cross-platform transactions, leading to factors such as cross-platform transaction costs and probabilities.

Furthermore, the scope of network externalities is expanded, allowing travellers on a single platform to simultaneously benefit from the externality effects brought by the resources of other platforms. What is more, by analysing traveller behaviour, the integration of ride-hailing platforms also exposes travellers to increased travel risks, including hazards from illegal drivers and vehicle operations. The increased decision-making uncertainty resulting from the integration of ride-hailing platforms may lead travellers to experience perceived losses.

In summary, the study of travellers' choice behaviour under the integration of ride-hailing platforms encompasses multiple subjects. The core subjects of the study are the ride-hailing platform and the traveller, capturing the primary focus of research attention. Furthermore, the relationship between the integration strategy of the ride-hailing platform and the traveller's choice behaviour is characterised by stochasticity. Additionally, it involves the factor of finite rationality, and the behaviour of the two constitutes a dynamic game process. Evolutionary game theory has gradually emerged as the mainstream research method for addressing similar problems [39–41].

We assume that ride-hailing platforms can adopt two strategies, "with integration" and "without integration". The benefits of integration for ride-hailing platforms, arising from cross-platform transactions, are influenced by a combination of factors, including transaction probability, user size, network externalities and others. Travellers are assumed to have two strategies, "choosing ride-hailing" and "not choosing ride-hailing". By combining the problem description, existing literature and the core characteristics of the ride-hailing industry, this research can establish the following assumptions.

Assumption 1: The revenue of ride-hailing platforms is positively correlated with the size of travellers and drivers while being negatively associated with the strength of network externalities.

Assumption 2: The cross-platform transaction issue emerges with the integration of ride-hailing platforms. Travellers will decide whether to opt for ride-hailing services as a mode of travel based on a certain probability.

Assumption 3: The utility derived by travellers choosing ride-hailing services is positively associated with network externalities. Additionally, they will bear the risks associated with ride-hailing services.

3.2 Model construction

Based on the above description and the basic assumptions regarding the problem of travellers' choice behaviour under the integration of ride-hailing platforms, the theoretical model presented in this paper can be constructed. The matrix is shown in *Table 1*.

Table 1 – Payoff matrix of ride-hailing platforms and travellers

Ride-hailing platform	**Traveller**	
	Choosing ride-hailing	Not choosing ride-hailing
With integration	$\begin{pmatrix}(1-\alpha)(p_c-ka)N_c^1N_d^1+\alpha(p_c-ka)N_c^2N_d^1-C_0-C_1,\\ a\left(N_d^1+N_d^2\right)+T-\beta R_1-\gamma\ln[1+\exp(E)]\end{pmatrix}$	$\begin{pmatrix}-C_1-C_2-C_0,\\ T\end{pmatrix}$
Without integration	$\begin{pmatrix}(p_c-ka)N_c^1N_d^1-C_0,\\ aN_d^1+T-\beta R_1\end{pmatrix}$	$\begin{pmatrix}-C_0,\\ T\end{pmatrix}$

The notations are explained as follows. p_c is the average price of a ride-hailing service, influenced by factors such as the level of the economy and the state of ride-hailing service. a is the unit effect of network externality. k is the moderating coefficient of the transaction cost of the traveller's use of the ride-hailing and the network externality. N_i^j is the size of the travellers or drivers on platform j, $i\in\{c,d\}, j\in\{1,2\}$; c denotes travellers and d denotes drivers. α is the probability that a traveller chooses to transact across platforms, and b is the moderating coefficient. C_0 is the fixed cost of the operation of the ride-hailing platform; C_1 is the cost of integrating the ride-hailing platforms, γ is the adjustment factor; C_2 is the additional cost of idling if the ride-hailing platforms are without integration and the traveller does not choose the ride-hailing service. R_1 is the travel risk of a traveller choosing ride-hailing services; R_2 is the additional travel risk of a traveller choosing ride-hailing services under the integration of ride-hailing platforms; β is the moderating factor. E is the perceived loss of the traveller. T is the fixed utility of the traveller. These variables are essential components of the theoretical model constructed to address the problem of travellers' choice behaviour under the integration of ride-hailing platforms, as described in *Table 1*. The notation clarifications aim to enhance precision and facilitate a comprehensive understanding of the model.

4. EVOLUTIONARY GAME ANALYSIS

Assuming that the probability of ride-hailing platforms with integration is $x(0 \leq x \leq 1)$, and the probability without integration is $1-x$; the probability that the traveller chooses ride-hailing service as a mode of travel is $y(0 \leq y \leq 1)$ and the probability that he/she does not choose ride-hailing service is $1-y$. As a result, the dynamic replication equations of the ride-hailing platform and the traveller in the analysis of the traveller's choice behaviour under the integration of ride-hailing platforms are obtained. On the basis of this, the evolution path and stabilisation strategy of the ride-hailing platforms and travellers can be analysed.

4.1 Dynamic replication equations for ride-hailing platforms and travellers

The expected return of the ride-hailing platform with integration is f_{p1}, and the expected return without integration is f_{p2}. Therefore, the expressions are shown in *Equations 1 and 2*, respectively.

$$f_{p1} = y[(1-\alpha)(p_c - ka)N_c^1 N_d^1 + \alpha(p_c - ka)N_c^2 N_d^1 - C_0 - C_1] + (1-y)(-C_1 - C_2 - C_0) \tag{1}$$

$$f_{p2} = y[(p_c - ka)N_c^1 N_d^1 - C_0] + (1-y)(-C_0) \tag{2}$$

Based on *Equations 1 and 2*, the average revenue of the ride-hailing platform $\overline{f_p}$ can be obtained, as shown in *Equation 3*.

$$\overline{f_p} = x f_{P1} + (1-x) f_{P2} \tag{3}$$

According to the Malthusian equation, the dynamic replication equation of the ride-hailing platform in this problem can be obtained as shown in *Equation 4*.

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x\left(f_{p1} - \overline{f_p}\right) = x(1-x)\left(f_{p1} - f_{p2}\right) \\ &= x(1-x)\{y[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) + C_2] - C_1 - C_2\} \end{aligned} \tag{4}$$

The traveller's expected return for choosing ride-hailing is f_{t1}, the expected return for not choosing ride-hailing is f_{t2}. Thus, the expressions are shown in *Equations 5 and 6,* respectively.

$$f_{t1} = x\left[a\left(N_d^1 + N_d^2\right) + T - \beta R_1 - \gamma \ln(1 + e^E)\right] + (1-x)(aN_d^1 + T - \beta R_1) \tag{5}$$

$$f_{t2} = xT + (1-x)T \tag{6}$$

With *Equations 5 and 6*, this gives the average return of the traveller $\overline{f_t}$, as shown in *Equation 7*.

$$\overline{f_t} = y f_{t1} + (1-y) f_{t2} \tag{7}$$

Similarly, the dynamic replication equation for the traveller can be obtained as shown in *Equation 8*.

$$\begin{aligned} F(y) = \frac{dy}{dt} &= y\left(f_{t1} - \overline{f_t}\right) = y(1-y)(f_{t1} - f_{t2}) \\ &= y(1-y)\left[x\left(aN_d^2 - \gamma \ln(1 + e^E)\right) + aN_d^1 - \beta R_1\right] \end{aligned} \tag{8}$$

4.2 Evolutionary path and stability analysis

From the stability theorem of differential equations and the dynamic replication equations of the ride-hailing platform and the traveller, this paper can derive the conditions that need to be satisfied when a certain strategy combination of the ride-hailing platform and the traveller is a stable state, as shown in *Equation 9*.

$$\begin{gathered} F(x) = 0, \frac{\partial F(x)}{\partial x} < 0 \\ F(y) = 0, \frac{\partial F(y)}{\partial y} < 0 \end{gathered} \tag{9}$$

Further, $\frac{\partial F(x)}{\partial x} = (1-2x)\left\{y\left[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) + C_2\right] - C_1 - C_2\right\}$, $\frac{\partial F(y)}{\partial y} = (1-2y)\left[x\left(aN_d^2 - \gamma \ln(1 + e^E)\right) + aN_d^1 - \beta R_1\right]$.

From *Equation 9*, it can be seen that the strategies of the ride-hailing platform and the traveller in this problem have five equilibrium points, which are points $A(0,0)$,$B(0,1)$,$C(1,0)$,$D(1,1)$ and $E(x^*, y^*)$.

where, $x^* = \frac{\beta R_1 - aN_d^1}{aN_d^2 - \gamma\, ln(1+e^E)}$ and $y^* = \frac{C_1+C_2}{\alpha(p_c-ka)N_d^1(N_c^2-N_c^1)+C_2}$.

According to the findings of [42], the Jacobi matrix can be employed in the stability analysis of differential equations. In the field of evolutionary game theory, the Jacobian matrix represents a pivotal analytical instrument for the examination of the stability of strategic dynamics [43–45]. The primary objective of evolutionary game stability is to ascertain the evolutionary stable strategies (ESS) and to determine the dynamic behaviour of strategies within the strategy space. Once the Jacobian matrix has been calculated, the next step is to identify its eigenvalues. The assessment of evolutionary game stability is largely contingent upon the characteristics of these eigenvalues. In particular, if all the eigenvalues of the Jacobian matrix have negative real parts, then the strategy profile is a locally asymptotically stable point. Conversely, if there exists at least one eigenvalue with a positive real part, then the strategy profile is not stable. From the dynamic replication equations of the ride-hailing platform and the traveller, the Jacobi matrix can be obtained as shown in equation (10). Among them, the equilibrium point is the characteristic root, and the trace of the stabilisation point needs to satisfy the conditions $det\,J > 0, tr\,J < 0$, where $det\,J$ equals the product of its eigenvalues and tr$J$ equals the sum of its eigenvalues. In an evolutionary game with two participants, when $det\,J > 0$ and tr$J >$ 0 indicates that all the eigenvalues of Jacobian matrix are negative. Hence, the stability of evolutionary game can be judged through this condition;

$$J = \begin{vmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{vmatrix} \tag{10}$$

where, $J_{11} = \frac{\partial f_p}{\partial x} = (1-2x)\{y[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) + C_2] - C_1 - C_2\}$, $J_{12} = \frac{\partial f_p}{\partial y} = x(1-x)[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) + C_2]$, $J_{21} = \frac{\partial f_t}{\partial x} = y(1-y)(aN_d^2 - \gamma\, ln(1+e^E))$, $J_{22} = \frac{\partial f_t}{\partial y} = (1-2y)[x(aN_d^2 - \gamma\, ln(1+e^E)) + aN_d^1 - \beta R_1]$.

Further, the $det\,J$ and tr$J$ of each equilibrium point can be obtained and analysed. The results of the stability analysis are presented in *Table 2*.

Table 2 – Stability analysis

Points	detJ	trJ
$A(0,0)$	$(-C_1 - C_2)(aN_d^1 - \beta R_1)$	$-C_1 - C_2 + aN_d^1 - \beta R_1$
$B(1,0)$	$(C_1 + C_2)(aN_d^2 - \gamma\, ln(1+e^E) + aN_d^1 - \beta R_1)$	$C_1 + C_2 + aN_d^2 - \gamma\, ln(1+e^E) + aN_d^1 - \beta R_1$
$C(0,1)$	$[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - C_1](-aN_d^1 + \beta R_1)$	$\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - C_1 - aN_d^1 + \beta R_1$
$D(1,1)$	$[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - C_1](aN_d^2 - \gamma\, ln(1+e^E) + aN_d^1 - \beta R_1)$	$-[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - C_1 + aN_d^2 - \gamma\, ln(1 + e^E) + aN_d^1 - \beta R_1]$
$E(x^*, y^*)$	$-(\beta R_1 - aN_d^1)(aN_d^2 - \gamma\, ln(1+e^E) + aN_d^1 - \beta R_1)\frac{(C_1 + C_2)[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - \gamma C_1]}{(aN_d^2 - \gamma\, ln(1+e^E))[\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) + C_2]}$	0

Based on *Table 2*, the conditions of stability of evolutionary game can be further analysed, as it is shown in *Table 3*. In addition, the results of the three cases are summarised in the following propositions, respectively.

Proposition 1: There exists a unique stable evolution strategy (0,0) when the condition $aN_d^1 - \beta R_1 < 0$ is satisfied.

Under this condition, the stabilisation strategy of the ride-hailing platform is not to implement integration, and the stabilisation strategy of the traveller is not to choose the ride-hailing service. In this case, the risk of the traveller choosing the ride-hailing is greater than the network externality effect resulting from this decision. Existing studies have shown that travel risks arising from ride-hailing services, encompassing property and personal safety risks, have become pivotal factors influencing travellers' choices. Simultaneously, addressing ride-hailing services risks is crucial for the operation of ride-hailing platforms. For instance, following incidents of hitchhiking passengers being infringed upon, the Didi platform chose to temporarily shut down and rectify relevant services. Joining a ride-hailing platform and choosing ride-hailing service will also bring additional network externality effects for travellers. In other words, traveller's utility will be correlated with the driver side of the platform, where an increase in the number of drivers and service quality results in a shorter waiting time for a match and a better travel experience for the traveller.

Overall, ride-hailing services offer convenience to travellers but also raise concerns about associated risks. If the risks perceived by travellers outweigh the network externalities generated by choosing a ride-hailing, travellers are less likely to choose a ride-hailing. Additionally, ride-hailing platforms are inclined to consolidate their business and are less likely to interconnect.

Proposition 2: When the conditions (1) $aN_d^1 - \beta R_1 > 0$*, (2)*$N_c^2 - N_c^1 < 0$ *are satisfied, there exists a unique stable evolution strategy (0,1).*

Under this condition, the stabilising strategy of the ride-hailing platform is not to implement integration, and the stabilising strategy of the traveller is to choose the ride-hailing service, both parties continue with the established service model. At this time, the network effect obtained by the traveller choosing ride-hailing outweighs the associated risks. Analysis of *Proposition 1* reveals that the utility of the traveller is ensured, and under these circumstances, the traveller is more inclined to choose the ride-hailing service as a travel mode. Simultaneously, condition (2) signifies that the scale of the ride-hailing platform itself is larger than that of the platform to be integrated. Consequently, the ride-hailing platform is inclined to maintain the status quo, refraining from implementing integration. Therefore, the ride-hailing chosen by travellers under this condition does not involve platform integration.

Existing literature has also produced research results on the relationship between platform integration and platform size. Synthesising various findings indicates that integration can, to a certain extent, promote the increase in platform revenue, but the implementation of an integration strategy may also have negative effects [36–38]. For instance, implementing integration strategies for platforms with large market shares may instead reduce platform benefits, while implementing integration strategies for firms with small horizontal differences contributes to overall welfare [37]. Additionally, integration in cases of asymmetric scale can weaken stronger platforms.

Proposition 3: When the conditions (1) $aN_d^1 - \beta R_1 > 0$ *, (2)* $aN_d^2 - \beta R_2 + E > 0$ *, (3)* $\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - C_1 > 0$ *are satisfied, there exists a unique stable evolution strategy (1,1).*

In this condition, the stabilisation strategy of the ride-hailing platform is to implement the integration, and the stabilisation strategy of the traveller is to choose the ride-hailing service. Unlike the stabilisation strategies (0,0) and (0,1) mentioned above, the traveller's choice of ride-hailing, in this case, involves the scenario of integration among ride-hailing platforms. In other words, while enjoying the service of this platform, there is also the possibility of receiving travel services provided by drivers on other platforms that are integrated with this platform.

From *Proposition 3*, it can be observed that both the integration of the ride-hailing rental platform and the resulting traveller behaviour are grounded in the operation of the basic service of ride-hailing services. On the one hand, the stable evolution strategy (1,1) is premised on the assumption that the network externality generated by the ride-hailing service is greater than the risk of the platform service. On the other hand, platform integration introduces additional risks while providing the traveller with access to resources from other platforms, and the traveller also incurs a perceived loss from such services. In this case, the network effects that travellers obtain from the integrated platforms under the interoperability model outweigh the associated risks and perceived losses caused by the integration.

Based on the analysis of the conclusion of *Proposition 3* from the perspective of the ride-hailing platform, it can be seen that ride-hailing platforms need to consider factors such as network externalities, platform size, and integration costs when deciding to implement the integration strategy. In this scenario, the additional benefits obtained by the platform through integration must outweigh the integration cost of the ride-hailing platform for a stable evolution strategy (1,1) to exist. At this point, there are two possibilities for the price factor and scale factor of the ride-hailing platform, which are (1) $p_c - ka > 0, N_c^2 - N_c^1 > 0$ and $\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) > C_1$, (2)$p_c - ka < 0, N_c^2 - N_c^1 < 0$ and $\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) > C_1$. In the first case, the ride-hailing platform is smaller than the other platforms, and the network externalities generated are weaker, but there is some profitability. In the second case, the ride-hailing platform is larger than the other platforms, and the network externalities are larger, with more traveller resources that can be aggregated on the platform. When the additional benefits generated by integration in both cases outweigh the cost of integration, ride-hailing platforms tend to implement the integration strategy.

Table 3 – Evolutionary stability analysis

	Case 1			**Case 2**			**Case 3**		
	detJ	**trJ**	**Stability**	**detJ**	**trJ**	**Stability**	**detJ**	**trJ**	**Stability**
A(0,0)	+	-	ESS	-	±	Unstable	-	±	Unstable
B(1,0)	±	±	Unstable	+	+	Unstable	+	+	Unstable
C(0,1)	±	±	Unstable	+	-	ESS	-	±	Unstable
D(1,1)	±	±	Unstable	-	±	Unstable	+	-	ESS
E(x*,y*)	±	0	Saddle	±	0	Saddle	+	0	Saddle

5. NUMERICAL STUDY

To present the research results in a more specific and visual manner, this paper analyses the findings based on theoretical research. The overall approach of the example analysis is to generate various strategy combinations (x,y) for the integration of ride-hailing platforms and travellers' choice behaviour under the initial scenario, aiming to analyse the evolutionary pattern under different scenarios. This analysis primarily focuses on the stable evolution strategies of the integration of the ride-hailing platform and travellers' choice behaviour, making comparisons through different parameter settings to study the coexistence of the two agents. The numerical analysis is primarily implemented using MATLAB R2016b programming in the macOS 10.15.4 environment.

1) Scenario 1: $aN_d^1 - \beta R_1 < 0$
   Combined with the assumptions in the theoretical study section, the relevant parameters are set as, $\alpha = 0.3, P_c = 2, k = 0.8, a = 1,$ $N_d^1 = 10, N_d^2 = 10, N_c^1 = 10, N_c^2 = 10,$ $C_1 = 1, C_2 = 0.5, \beta = 1, R_1 = 0.5, R_2 = 0.3, E = 1$. In this scenario, the obtained evolution trend of the strategies of the ride-hailing platform and the traveller is shown in *Figure 1*. When the condition $aN_d^1 - \beta R_1 < 0$ of *Proposition 1* is satisfied, the strategies of both the ride-hailing platform and the traveller converge at the point (0,0). At this time, the ride-hailing platform does not implement the integration, the traveller does not choose ride-hailing, and the stable evolution strategy of the two subjects is (0,0).

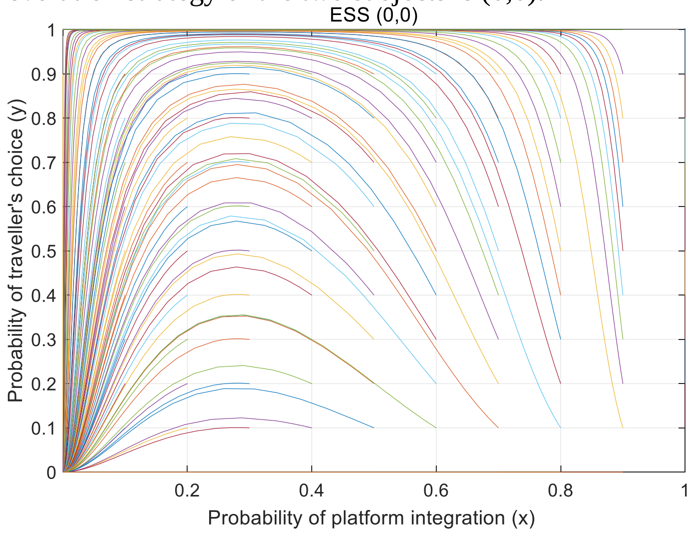


Figure 1 – Stable evolutionary strategy (0,0)

2) Scenario 2: $aN_d^1 - \beta R_1 > 0$, and $N_c^2 - N_c^1 < 0$
   Based on the assumptions of *Proposition 2*, the relevant parameters are set as follows: $\alpha = 0.3, P_c = 2, k = 0.8, a = 1, N_d^1 = 10, N_d^2 = 10, N_c^1 = 10, N_c^2 = 9, C_1 = 1, C_2 = 0.5, \beta = 1, R_1 = 0.5, R_2 = 0.3, E = 1$. On this basis, the evolution path of the ride-hailing platform and the traveller is obtained as shown in *Figure 2*. From the evolutionary trend of both parties in *Figure 2*, it can be seen that the strategies of the ride-hailing platform and the traveller converge to (0,1) when the conditions of *Proposition 2* $aN_d^1 - \beta R_1 > 0$ and $N_c^2 -$

$N_c^1 < 0$ are satisfied. The stabilising strategy in this scenario is that the ride-hailing platform does not implement integration and still maintains the original service, and the traveller chooses to use the ride-hailing service.

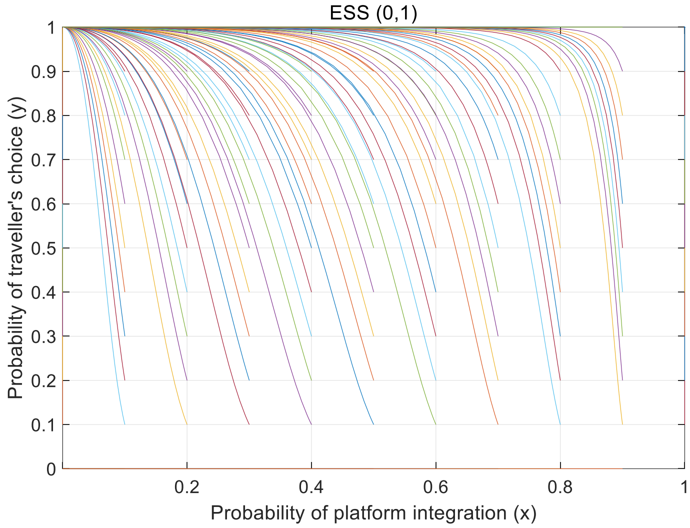


Figure 2 – Stable evolutionary strategy (0,1)

3) Scenario 3:$aN_d^1 - \beta R_1 > 0$,$aN_d^2 - \beta R_2 + E > 0$, and$\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - C_1 > 0$
According to the research assumptions and the setting of scenario 3, the initial benchmark parameters are shown as follows. $\alpha = 0.3, P_c = 2, k = 0.8$, $a = 1, N_d^1 = 10, N_d^2 = 10, N_c^1 = 10, N_c^2 = 15$, $C_1 = 1, C_2 = 0.5, \beta = 1, R_1 = 0.5, R_2 = 0.3, E = 1$. The evolution pattern of the ride-hailing platform and the traveller in this scenario is shown in *Figure 3*, and the strategies of both parties converge at the point of (1,1), and the stable strategy is (1,1). It can be seen that under the conditions $aN_d^1 - \beta R_1 > 0$, $aN_d^2 - \beta R_2 + E > 0$, and $\alpha(p_c - ka)N_d^1(N_c^2 - N_c^1) - C_1 > 0$, the stabilising strategy of the ride-hailing platform is to implement integration, and the stabilising strategy of the traveller is to choose the ride-hailing service.

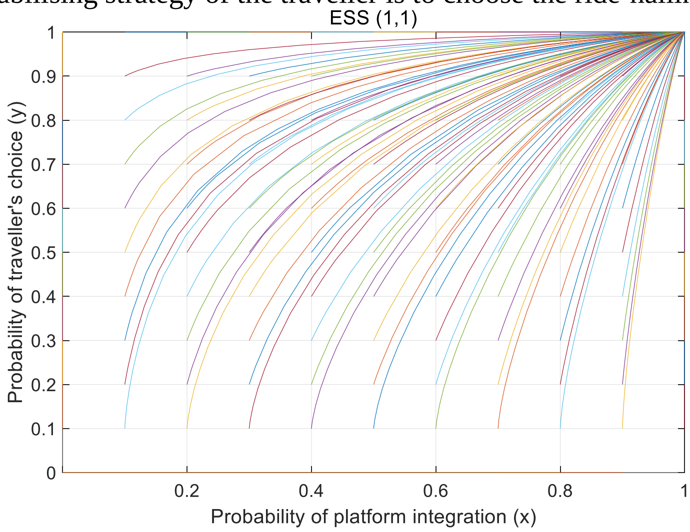
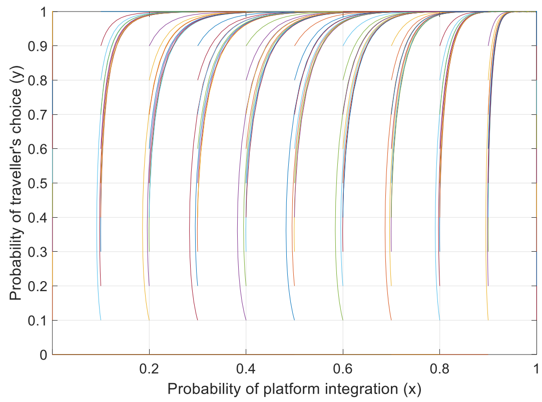
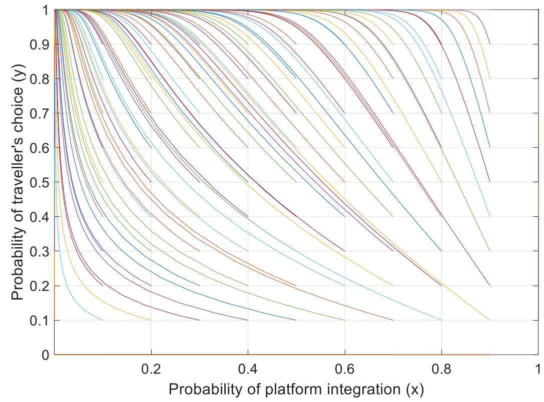


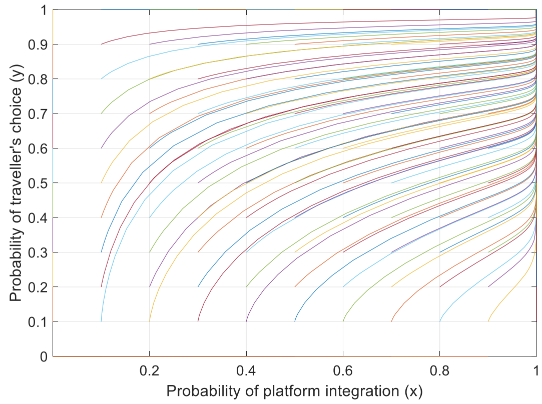
Figure 3 – Stable evolutionary strategy (1,1)

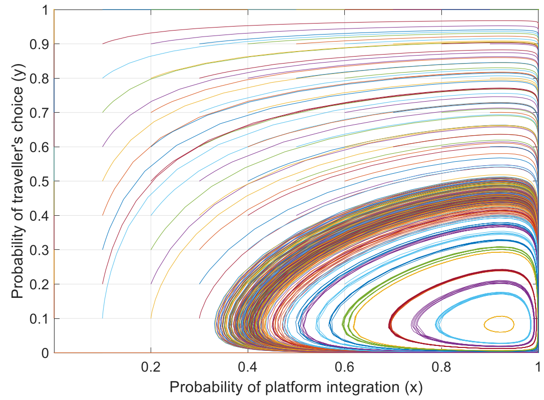
In this paper, key factors such as the size of the traveller group, the cost of connectivity, the change in risk and the perceived loss are further analysed, and the results are presented in *Figure 4*. These results are then compared with the reference group obtained from *Figure 3*. Specifically, for traveller scale, the parameters are set as $N_c^2 = 11$. Consequently, the gap between the sizes of travellers on the two platforms decreases, and the convergence speed of the integration strategy of the ride-hailing platform decreases relative to the travellers. If the parameter setting for traveller size continues to decrease, the stabilisation strategy (1,1) will shift to the (0,1) strategy when the condition $N_c^2 < N_c^1$ is satisfied. At this point, the ride-hailing platform will not be integrated, and the travellers will still choose the ride-hailing service.





(a) $N_c^2 = 11$ *(b)* $c_1 = 20$





(c) $R_2 = 20$ *(d)* $E = -20$

Figure 4 – Evolutionary strategy comparison

Concerning integration costs, this research considers the setup $C_1 = 20$. In this scenario, the cost of implementing integration by the ride-hailing platform is significantly higher than the combined effect of the size difference of the travellers, the price factor and the network externality factor. Consequently, the stabilisation strategy (1,1) is disrupted, and a new convergence point (0,1) gradually forms. At this point, due to the excessive integration cost, the ride-hailing platform will abandon the practice of the integration strategy, and the choice behaviour of the traveller remains unaffected.

In terms of the change in integration risk, the setting $R_2 = 20$. At this point, the travel risk for the traveller resulting from the ride-hailing integration is heightened, and the convergence path of the traveller's stabilisation strategy slows down and does not fully converge to the point (1,1). Due to the increased travel risk, the traveller does not necessarily choose the ride-hailing service. Further increasing the value of the parameter R_2 reveals that the integration stabilisation strategy of the ride-hailing platform will also be disrupted.

Concerning perceived loss, the setting is $E = -20$. In this scenario, the experience that the traveller gains through the ride-hailing under integration is negative. It can be observed that the stabilising strategy (1,1) no longer exists under this condition, and the two-party strategy enters a disordered state.

Further conclusions related to the stable evolution strategy (1,1) can be obtained as follows. Ride-hailing platforms tend to choose platforms with relatively large scales as integration objects. The integration strategy of the ride-hailing platform is closely related to factors such as integration cost and risk. When the integration cost and integration risk increase, the probability that a ride-hailing platform chooses to implement an integration strategy decreases. However, there is a significant difference in the impact of the two factors on travellers' behaviour. The increase in integration cost does not affect travellers' choice of ride-hailing; at this time, travellers can still enjoy ride-hailing under non-integration. However, when the risk of connectivity for the traveller increases, the traveller will choose to abandon the use of ride-hailing service. Additionally, when the negatively perceived loss of the traveller from using the ride-hailing becomes stronger, the stability of both the ride-hailing platform and the traveller is disrupted.

6. CONCLUSION

6.1 Main results

With the deep integration of mobile Internet technology and transportation, ride-hailing services have become an indispensable part of urban transportation. While various ride-hailing platforms compete in the market, there is also the potential for synergistic cooperation, and integration is considered a future development direction. In this paper, after analysing the integration mode of the ride-hailing platform, we construct an evolutionary game model of the traveller's choice behaviour under the integration of the ride-hailing platform and analyse the stabilisation strategy of the evolution of both sides. Furthermore, we validate and analyse the relevant conclusions based on the numerical simulation method.

In summary, the following conclusions can be drawn. (1) When the travel risk borne by the traveller choosing the ride-hailing and the additional travel risk brought by the integration is high, the traveller does not choose the ride-hailing, and the ride-hailing platform is unable to implement the integration. (2) Ride-hailing platforms tend to choose larger platforms as the integration object to obtain greater benefits. (3) As the negative impact of perceived loss decreases, the platforms will interconnect, and travellers will choose ride-hailing. Conversely, when the negative effect of perceived loss is intensified, the integration strategy of ride-hailing platforms and the choice behaviour of travellers become unstable. (4) The increase in integration cost affects the integration strategy of ride-hailing platforms, and although cross-platform transactions under integration may not be feasible, travellers will still choose to use ride-hailing services.

6.2 Implications

The paper thoroughly examines the integration impact of ride-hailing platforms on traveller's choice behaviour, providing profound insights into platform competition and traveller decision-making. By establishing an evolutionary game model, the paper attempts to reveal the evolving patterns of traveller choice behaviour in different scenarios, laying the foundation for future research. On one hand, by constructing an evolutionary game model, the paper provides a theoretical framework for studying the integration of ride-hailing platforms. On the other hand, this study delves into the evolving patterns of traveller choice behaviour in different scenarios, particularly under the influence of platform interconnection. This is significant for comprehending the dynamic changes in traveller decision-making and the impact on platforms. Overall, this research contributes to understanding the complex relationship between platform competition and travellers' decision-making.

Furthermore, several practical implications can be provided as well by referring to the results of this research. Firstly, given the research finding that integration costs influence the decision-making of online vehicle rental platforms, policymakers could consider implementing measures to decrease the costs associated with integration, fostering closer collaboration between platforms. Secondly, since perceived loss impacts integration decisions, policies should focus on enhancing the traveller experience, including safety and convenience, to increase their willingness to choose ride-hailing services. Thirdly, recognising that larger platforms are more likely to become integration partners, policymakers can encourage collaboration between platforms through initiatives such as resource sharing and promoting the healthy development of the industry.

6.3 Limitations

There are still some limitations related to this study. Firstly, while the paper presents theoretical conclusions, there is a lack of sufficient empirical validation. Future research could employ empirical methods to validate the effectiveness of the theoretical model and enhance the practical significance of the study. Secondly, the evolutionary game model may involve simplifying assumptions that might not fully capture the complexity of the real world. Future research could consider incorporating more real-world factors to enhance model realism. Thirdly, this research primarily focuses on the evolution of choice behaviour at specific moments, lacking an in-depth exploration of how these evolutions trend over an extended period. Future work could consider conducting more extensive and dynamic studies over a longer timeframe. By addressing these aspects of limitations, future research can comprehensively understand the impact of integration between ride-hailing platforms on traveller choice behaviour, providing stronger support for policy formulation and industry development.

ACKNOWLEDGEMENTS

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卢珂, 魏韵琳, 杜恒

网约车平台互联互通下出行者选择行为研究

摘要

网约车服务迅速扩展，逐渐成为城市居民的新型出行选择。现有研究基于竞争视角研究了网约车平台之间的市场关系以及平台策略等问题，但仍缺少对协同合作视角下网约车平台互联互通问题的研究。本文在对网约车平台互联互通模式及出行者行为因素分析基础上，构建了网约车平台互联互通下出行者行为的演化博弈理论模型。基于此，分别通过模型推演和数值分析的方法对该问题进行了研究。研究表明：（1）网约车平台互联互通带来的出行风险较高时，出行者倾向于不选择网约车服务，网约车平台也无法实行互联互通。（2）网约车平台倾向于选择规模较大的平台作为互联互通对象。（3）当感知损失降低时，网约车平台会实行互联互通，出行者也会选择网约车服务。（4）互联互通成本的提高会降低网约车平台实行互联互通策略的概率，但出行者依然会选择使用网约车服务。

关键词

网约车；互联互通；出行者行为；选择行为；演化博弈