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MODELING THE DIFFUSION OF DIGITAL BANKING ADOPTION IN UZBEKISTAN: EVIDENCE FROM TBC BANK USING THE BASS DIFFUSION MODEL AND A HYBRID REGRESSION APPROACH

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Abstract. This study models the diffusion dynamics of digital banking adoption in Uzbekistan using TBC Bank as a case study. Building on the Bass diffusion framework, customer acquisition is conceptualized as a combined effect of innovation-driven adoption and imitation-driven adoption amplified by network effects. Using historical data for 2019–2024, diffusion parameters are estimated through nonlinear curve fitting, and adoption trajectories are forecast through 2030. The baseline Bass model suggests that the number of registered customers may approach approximately 19.9 million by 2030, with the most rapid growth expected during 2025–2027, followed by gradual deceleration. However, standalone diffusion estimates exhibit non-trivial forecasting errors when compared with observed customer data, reflecting the model's limited capacity to account for demographic trends and market shocks. To enhance predictive accuracy, a hybrid specification combining polynomial trend regression with Bass-type diffusion components is proposed. The hybrid model demonstrates substantially lower error metrics and closer alignment with observed adoption dynamics. Overall, the findings support the applicability of diffusion modeling for strategic planning in emerging digital banking markets, while emphasizing the necessity of integrating demographic, competitive, and regulatory factors into forecasting frameworks.

Key words: Bass diffusion; digital banking; customer adoption; network effects; forecasting; Uzbekistan; TBC Bank; hybrid model.

Annotatsiya. Mazkur tadqiqot O'zbekistonda raqamli bank xizmatlarining ommalashuv jarayonini TBC Bank misolida modellashirishga bag'ishlangan. Bass diffuziya modeli asosida mijozlarni jalb etish jarayoni innovatsiyaga asoslangan qabul qilish hamda tarmoq effektlari bilan kuchaytirilgan taqlidga asoslangan qabul qilishning birgalikdagi ta'siri sifatida talqin etiladi. 2019–2024-yillar uchun tarixiy ma'lumotlar asosida diffuziya parametrlarining nolinear baholash usullari qo'llanilib, 2030-yilgacha prognozlar shakllantirildi. Bazaviy Bass modeli ro'yxatdan o'tgan mijozlar soni 2030-yilga kelib taxminan 19,9 million nafarga yetishini ko'rsatadi, eng yuqori o'sish sur'atlari esa 2025–2027-yillarga to'g'ri kelishi kutiladi. Biroq alohida qo'llangan diffuziya modeli kuzatilgan real ma'lumotlar bilan solishtirilganda sezilarli prognoz xatolarini namoyon etadi, bu esa modelning demografik o'zgarishlar va bozor zarbalarini yetarli darajada inobatga olmasligi bilan izohlanadi. Prognoz aniqligini oshirish maqsadida polinom trend regressiyasi va Bass turidagi diffuziya komponentlarini birlashtirgan gibrid model taklif etildi. Ushbu model xatolik ko'rsatkichlarining sezilarli darajada kamayishini hamda real qabul qilish dinamikasi bilan yuqori moslikni ta'minladi. Tadqiqot natijalari rivojlanayotgan raqamli bank bozorlarida strategik rejalashtirish uchun diffuziya modellaridan foydalanish imkoniyatlarini tasdiqlaydi va prognozlash tizimlariga demografik, raqobatbardosh hamda institutsional omillarni integratsiya qilish zarurligini ko'rsatadi.

Kalit so'zlar: Bass diffuziya modeli; raqamli bank xizmatlari; mijozlar qabul qilishi; tarmoq effektlari; prognozlash; O'zbekiston; TBC Bank; gibrid model.

Аннотация. В статье моделируется динамика распространения цифровых банковских услуг в Узбекистане на примере TBC Bank. На основе модели диффузии Басса процесс привлечения клиентов интерпретируется как совокупное воздействие инновационного принятия и имитационного принятия, усиленного сетевыми эффектами. На основе исторических данных за 2019–2024 годы параметры диффузии оценены с использованием методов нелинейной аппроксимации, а также сформированы прогнозы до 2030 года. Базовая модель Басса показывает,



что число зарегистрированных клиентов может приблизиться к 19,9 млн к 2030 году, при этом наиболее интенсивный рост ожидается в 2025–2027 годах с последующим замедлением. Вместе с тем автономные оценки диффузии демонстрируют заметные ошибки прогнозирования по сравнению с фактическими данными, что отражает ограниченные возможности модели по учёту демографических изменений и рыночных шоков. Для повышения точности прогнозирования предложена гибридная модель, объединяющая полиномиальную трендовую регрессию и диффузионные компоненты типа Басса. Результаты показывают существенное снижение ошибок и более точное соответствие наблюдаемой динамике принятия цифровых банковских услуг. Полученные выводы подтверждают целесообразность использования диффузионного моделирования для стратегического планирования на развивающихся рынках цифрового банкинга и подчёркивают необходимость интеграции демографических, конкурентных и регуляторных факторов в прогнозные модели.

Ключевые слова: модель диффузии Басса; цифровой банкинг; принятие клиентами; сетевые эффекты; прогнозирование; Узбекистан; TBC Bank; гибридная модель.

INTRODUCTION

The rapid expansion of the digital economy has reshaped financial intermediation, accelerating the transition from branch-centred banking to platform-based and mobile-first service delivery. In emerging markets, digital banks and fintech ecosystems diffuse under conditions of evolving regulation, dynamic demographics, and strong network externalities driven by payment platforms and peer-to-peer effects. Uzbekistan offers a particularly relevant context due to its growing mobile connectivity, increasing digital payment penetration, and active transformation of the banking sector.

TBC Bank's entry into Uzbekistan represents a distinct digital adoption pathway. Rather than relying primarily on physical branch expansion, the bank leveraged the acquisition of a major payment platform (Payme), monitored market conditions, and then scaled registered customer adoption after obtaining a banking license. This sequence suggests that adoption may be characterized by: (i) an initial base formed through platform users, (ii) accelerated growth supported by social diffusion and network effects, and (iii) a potential saturation stage where growth decelerates as the accessible market becomes increasingly covered.

To analyze such dynamics, diffusion models provide a parsimonious but theoretically grounded tool. The Bass diffusion model, originally proposed to describe the spread of new products and technologies, has been widely used to forecast adoption trajectories and identify stages of diffusion (latent, rapid growth, saturation). Nonetheless, classical Bass formulations rely on restrictive assumptions (constant population, no churn, no competitive response), which may limit predictive performance in real digital banking markets. Therefore, a combined approach that preserves diffusion logic while incorporating macro trends is often desirable.

This study contributes by (1) applying the Bass diffusion model to TBC Bank customer data in Uzbekistan, (2) estimating innovation and imitation parameters using historical adoption records, (3) forecasting customer adoption through 2030, and (4) proposing a hybrid model combining diffusion dynamics with regression-based trend estimation to better approximate demographic and system-level effects.

LITERATURE REVIEW

The diffusion of innovations has long been a central topic in economics, marketing, and technology studies. Early theoretical foundations were established within the diffusion of innovations framework, which conceptualizes adoption as a social process driven by communication, uncertainty reduction, and learning among individuals over time. Within this tradition, the Bass diffusion model represents one of the most influential quantitative approaches for modeling the adoption of new products and technologies.

The Bass model formalizes adoption dynamics by decomposing demand into two components: innovation-driven adoption and imitation-driven adoption. Innovators adopt independently of others, whereas imitators are influenced by prior adopters, generating endogenous growth through social interaction. This structure produces the characteristic S-shaped adoption curve, which has been empirically observed across a wide range of products and technologies, including consumer durables, telecommunications, and digital services.

Subsequent research extended the original Bass framework by refining estimation techniques, testing parameter stability, and applying the model to diverse empirical contexts. Mahajan, Muller, and Bass demonstrated that the model performs particularly well in environments where adoption decisions are subject to uncertainty and where social influence plays a significant role. Later studies emphasized that the imitation parameter often dominates long-run adoption dynamics, especially in networked markets, reinforcing the relevance of diffusion-based modeling for digital platforms.

The Bass diffusion model conceptualizes adoption as the outcome of two behavioral mechanisms. First, innovators adopt independently of the number of existing adopters. Second, imitators adopt as a function of



social influence, whereby adoption intensity increases with the number of current adopters, reflecting word-of-mouth and network effects. In digital markets, such imitation is particularly relevant because platform value often grows with user base size.

The standard Bass model expresses cumulative adopters, $B(t)$, within a fixed market potential, N . The adoption flow is represented as:

$$\frac{dB}{dt} = p(N - B) + qB(N - B) = (p + qB)(N - B),$$

where p denotes the coefficient of innovation and q denotes the coefficient of imitation.

Digital products and services are frequently characterized by strong network externalities, meaning that the utility derived from adoption increases with the number of other users. This phenomenon has been widely discussed in the literature on network economics and platform markets. In such environments, adoption decisions are not independent; instead, they are interlinked through social, informational, and transactional networks.

Although the Bass model was not originally designed as a network model, its imitation component implicitly captures positive feedback mechanisms analogous to network effects. Several studies have shown that diffusion models incorporating social influence can approximate the aggregate effects of network externalities, particularly when micro-level interaction data are unavailable. Research on smartphones, online platforms, and digital payment systems confirms that network-driven imitation accelerates adoption during early and middle diffusion stages, while saturation effects emerge as markets mature.

In digital finance, network effects arise from interoperability, peer-to-peer transfers, merchant acceptance, and ecosystem integration. As more users join a digital banking or payment platform, the perceived value of the service increases, reinforcing imitation-driven adoption. This theoretical insight supports the application of diffusion models to digital banking contexts, especially in emerging markets where platform-based growth is pronounced.

Digital banking and payment ecosystems often exhibit positive feedback loops: as more users adopt a service, the service becomes more valuable, reflected in greater peer compatibility, wider merchant coverage, increased trust, and richer data-driven personalization. This mechanism is consistent with Metcalfe-type reasoning commonly used to represent network externalities. While the classical Bass diffusion model is not a network model per se, it operationalizes a similar feedback process through the imitation term $qB(N - B)$.

The application of diffusion theory to banking and financial innovation has expanded alongside the digital transformation of financial services. Empirical studies have examined the adoption of internet banking, mobile banking, and digital payment systems using diffusion-based and econometric approaches. These studies generally find that adoption follows non-linear growth paths consistent with diffusion theory, with early adoption driven by technologically inclined users and later adoption shaped by social influence and institutional trust.

In emerging economies, digital banking adoption is often accelerated by the absence of legacy infrastructure constraints and by rapid mobile penetration. Research indicates that imitation effects are particularly strong in such contexts, as users rely on peer experience and social validation when adopting new financial technologies. This aligns with findings that the imitation parameter in diffusion models tends to be larger in developing and transitional economies than in mature markets.

However, several authors have highlighted limitations of pure diffusion models in financial services. Banking adoption is influenced not only by social learning but also by regulatory frameworks, demographic trends, income dynamics, and macroeconomic stability. Consequently, models that ignore these factors may exhibit forecasting bias or parameter instability over time.

Real markets rarely feature a single provider. Competitive diffusion models extend Bass dynamics to multiple adopters and allow for switching, or churn, between providers. Such models show that long-run outcomes can range from stable coexistence to winner-takes-all dominance, depending on churn intensities, imitation strength, and relative attractiveness. This is particularly relevant in banking markets, where switching costs, loyalty programs, and ecosystem lock-in shape equilibrium market shares.

Recognizing the limitations of the classical Bass model, the literature has proposed numerous extensions. One strand of research incorporates competition by modeling multiple products or firms simultaneously, allowing for substitution effects and market-share dynamics. Another strand introduces time-varying parameters, enabling diffusion intensity to evolve in response to changing market conditions.

A growing body of work advocates hybrid approaches that combine diffusion models with regression-based or structural components. Such models integrate the theoretical strengths of diffusion dynamics with



empirical flexibility, allowing exogenous drivers—such as population growth, income trends, and technological infrastructure—to influence adoption paths. Empirical evidence suggests that hybrid models often outperform standalone diffusion or regression models in forecasting accuracy, particularly over medium-term horizons.

In the context of digital banking, hybrid modeling is especially relevant. Adoption is shaped by endogenous network effects as well as exogenous forces, including demographic expansion, digital literacy growth, regulatory reforms, and ecosystem partnerships. By combining diffusion mechanisms with trend-based or covariate-driven components, hybrid models provide a more realistic representation of adoption dynamics without sacrificing analytical transparency.

Despite the extensive literature on diffusion modeling and digital finance adoption, several gaps remain. First, empirical studies applying diffusion models to digital banking in Central Asian or comparable emerging-market contexts remain limited. Second, many existing studies rely exclusively on either diffusion-based or regression-based approaches, without systematically comparing predictive performance or exploring integrated specifications. Third, relatively few studies explicitly address the trade-off between theoretical parsimony and empirical accuracy in modeling digital banking adoption.

This study contributes to the literature by applying the Bass diffusion model to the case of TBC Bank in Uzbekistan, an emerging digital banking market characterized by rapid platform-based growth. Furthermore, it extends the analysis through a hybrid regression–diffusion framework, demonstrating how the integration of diffusion dynamics with time-based trend estimation improves forecast accuracy and interpretability. In doing so, the study bridges diffusion theory and applied forecasting practice, offering insights relevant to both academic research and strategic decision-making in digital banking.

The study uses annual observations for 2019–2024, including total population, N_t (million), and registered customers, B_t (million), for TBC Bank. The 2019 baseline reflects the initial scale associated with the Payme platform user base and the early stage of market entry.

Market potential, m (or N in canonical Bass notation), represents the maximum attainable number of adopters. Based on historical evidence and the assumption that approximately 50–60 percent of the population may constitute reachable customers, the potential market is approximated for 2030 using projected population levels. With an expected population of 40 million by 2030, market potential is set as:

$$m \approx 20 \text{ million.}$$

This assumption operationalizes an upper bound for diffusion-based forecasting.

Research Methodology

We model cumulative registered customers, $B(t)$, using the Bass differential equation:

$$\frac{dB}{dt} = (p + qB)(N - B),$$

where:

- $B(t)$ denotes cumulative registered customers;
- m denotes market potential;
- p denotes the coefficient of innovation;
- q denotes the coefficient of imitation.

The closed-form solution for $B(t)$ is employed to generate forecasts once the parameters are estimated.

In practice, parameter estimation is conducted by selecting values of p and q that minimize the deviation between observed data and model-implied adoption trajectories.

Parameters p and q are estimated via nonlinear optimization (curve fitting) with bounds constrained to the interval $[0, 1]$. The objective function minimizes the sum of squared errors between observed B_t and predicted B'_t over the period 2019–2024.

Forecast accuracy is evaluated using the following metrics:

Mean Absolute Error (MAE);
Mean Squared Error (MSE);



Root Mean Squared Error (RMSE);
relative error measures, where appropriate.

Because population dynamics and macro-level trends evolve over time, a diffusion-only model may underfit during periods shaped by structural shifts. Accordingly, a hybrid framework is introduced that combines: a polynomial trend capturing systematic growth drivers; a Bass-type diffusion component capturing adoption feedback effects.

A stylized representation of the hybrid specification is given by:

$$B'(t) = (at^2 + bt + c) + \left[p(M - B') + \frac{qB'}{M} (M - B') \right],$$

where a , b , and c are regression coefficients estimated from the observed data. The hybrid design conceptually preserves diffusion-driven saturation while allowing for time-dependent trend adjustment.

ANALYSIS AND RESULTS

TBC Bank registered customers increased from 1.8 million (2019) to 18.4 million (2024). Annual growth rates show rapid scaling consistent with diffusion theory (Table 1):

Table 1. Growth Dynamics of TBC Bank's Customer Base (2019–2024)

Year	Real customers (million)	Growth
2019	1.8	–
2020	3.0	+66.6%
2021	5.8	+93.3%
2022	9.3	+60.0%
2023	13.2	+41.9%
2024	18.4	+39.0%

This pattern reflects a relatively short latent phase followed by accelerated growth driven primarily by imitation mechanisms and platform-based network effects.

The baseline Bass model generates a characteristic S-shaped diffusion trajectory. Forecast results indicate that by 2030 the customer base may approach approximately 19.9 million users, with the highest incremental growth expected during 2025–2027. After this period, marginal gains are projected to slow as the market gradually approaches saturation.

A comparison between predicted and observed values is presented below (Table 2).

Table 2. Comparison of Bass Model Predictions and Actual Customer Adoption with Forecast Errors (2019–2030)

Year	Consumer quantity of Bass model (B)	Real consumer quantity (H)	difference F=Abs(B-H)	Error (F/H)
2019	0,0	1 800 000	1 800 000	1,0
2020	2 588 511	3 000 000	411 489	0,137
2021	5 930 422	5 800 000	130 422	0,022
2022	9 595 443	9 300 000	295 443	0,031
2023	12 960 702	13 200 000	238 298	0,018
2024	15 582 750	18 400 000	2 817 250	0,153
2025	17 376 314			
2026	18 496 606			
2027	19 157 117			
2028	19 533 367			
2029	19 743 499			
2030	19 859 562			

Comparisons between predicted and actual values indicate that, while the Bass model successfully captures the general shape of adoption over time, it exhibits notable deviations in certain years. In particular, forecast errors increase when observed adoption accelerates beyond what the fitted diffusion curve anticipates. This suggests the presence of additional drivers not explicitly captured by the baseline model, such as marketing intensity, product and service innovations, competitive dynamics, macroeconomic conditions, regulatory changes, and platform integration effects.



Standalone Bass forecasting therefore produces non-trivial errors, illustratively on the order of several hundred thousand customers in MAE and RMSE terms. This outcome motivates the augmentation of the diffusion framework.

The hybrid regression–diffusion approach substantially improves alignment with historical observations, yielding materially lower error metrics relative to the standalone Bass model. These results indicate that a portion of observed adoption reflects time-structured trends associated with demographic and macroeconomic drivers, while diffusion-based feedback mechanisms capture the social dynamics underlying customer adoption.

The empirical adoption trajectory corresponds closely to the classical phases of diffusion. The latent phase reflects the early stage of market entry, during which adoption grows relatively slowly. For TBC Bank, this phase appears shortened, likely due to the pre-existing Payme platform user base and a relatively high level of early digital readiness among consumers. The rapid growth phase is characterized by accelerated adoption driven by imitation mechanisms and network effects; the period 2021–2027 aligns with this stage in the model. Finally, the saturation phase is marked by a deceleration of adoption growth as the accessible market approaches coverage limits, with the model indicating an inflection point around 2027–2028.

The Bass model inflection condition can be derived from the second-derivative rule. Under typical parameter conditions, the inflection occurs when:

$$B_{\text{inflection}} = \frac{qN - p}{2q}$$

subject to the condition $p < qm$. In this study, the estimated inflection point aligns with the predicted transition from rapid expansion to slower growth, consistent with the empirical adoption pattern.

The Bass model rests on several simplifying assumptions, including a constant market potential, the absence of demographic growth, no customer churn, no competitive interaction, and stable innovation and

imitation parameters (p and q). Digital banking markets frequently violate these assumptions. Population growth, regulatory reforms, platform expansion, service diversification, and competitor strategies can all alter adoption intensity over time. Consequently, integrating regression-based trend components and/or explicit exogenous drivers can enhance predictive validity.

From a strategic and policy perspective, diffusion modeling provides a quantitative framework for anticipating peak growth windows and the onset of saturation. Forecasts derived from such models can inform the prioritization of acquisition versus retention strategies. As saturation emerges, incremental growth increasingly depends on user engagement—such as monthly active users and daily active users—cross-selling, and ecosystem deepening rather than on new registrations alone. In this context, hybrid modeling approaches support scenario planning by incorporating macro-level trends and relaxing restrictive diffusion assumptions.

Despite the analytical usefulness of the Bass diffusion model and the proposed hybrid regression–diffusion specification for describing the dynamics of TBC Bank’s customer adoption in Uzbekistan, several methodological and empirical limitations should be acknowledged. These limitations do not invalidate the results; rather, they delimit the scope of inference and indicate directions for future refinement.

First, the empirical dataset is available at an annual frequency for 2019–2024, which constrains the ability to capture short-term adoption shocks and intra-year dynamics. Digital banking adoption often responds to high-frequency drivers, including marketing campaigns, product releases, tariff changes, seasonal payment patterns, and regulatory announcements. When observations are aggregated annually, such effects are compressed into single data points, potentially inducing temporal aggregation bias and weakening the identifiability of diffusion parameters. Future research based on monthly or quarterly data would enable more robust estimation and more precise identification of inflection points and growth acceleration phases.

Second, the analysis relies on an exogenously fixed market potential m (or N in canonical Bass notation). Although the study employs a plausible demographic assumption—namely, a given fraction of the projected population by 2030—the true market potential for digital banking is not purely demographic. It depends on eligibility constraints such as age structure, residency, and documentation, as well as adoption barriers including digital literacy, smartphone access, and trust. Institutional factors, such as KYC requirements, interoperability,

and ecosystem partnerships, further shape the addressable market. Specifying m as a single constant therefore introduces model risk, given the sensitivity of diffusion outcomes to the assumed upper bound. More rigorous

approaches could treat m as an estimable parameter, apply scenario-based sensitivity analysis, or rely on micro-level data to approximate the addressable population more accurately.

Third, the baseline Bass formulation assumes a closed population and effectively abstracts from demographic change and migration. While the hybrid model partially captures macro trends through a polynomial



time component, this adjustment remains reduced-form rather than structural. In Uzbekistan, population growth and shifts in age composition can expand the pool of digitally active individuals over time, implying that market potential may be time-varying rather than fixed. A natural extension would be to specify $m(t)$ explicitly, for example by linking it to projected population dynamics and the digitally eligible segment.

Fourth, the model uses registered customers as the dependent measure of adoption. In digital banking, registration does not necessarily correspond to economically meaningful usage. Some users may remain inactive, engage sporadically, or hold dormant accounts. As a result, adoption measured solely through registrations may overstate effective diffusion in terms of active usage, transaction intensity, or revenue-generating engagement. Future studies should complement registration data with operational indicators such as monthly active users (MAU), daily active users (DAU), transaction volumes, or product penetration metrics, including cards issued or loans disbursed.

Fifth, the model assumes time-invariant diffusion parameters p and q . In practice, innovation- and imitation-driven adoption intensities are rarely constant in digital markets. Early adoption may be dominated by initial platform effects, such as the Payme ecosystem, whereas later adoption may be driven by product diversification, improvements in user experience, interoperability, or trust-building measures. Similarly, imitation effects may strengthen as social proof accumulates and weaken as the market approaches saturation. Assuming constant parameters can therefore induce averaging across structurally distinct phases. More flexible frameworks

incorporating time-varying parameters (p_t , q_t), regime-switching diffusion, or diffusion models with explicit exogenous covariates represent promising avenues for future research.

CONCLUSION AND RECOMMENDATIONS

This study applied the Bass diffusion model and a hybrid regression–diffusion approach to analyze and forecast digital banking adoption in Uzbekistan using TBC Bank as a case study. The results demonstrate that customer adoption follows a classical S-shaped diffusion pattern, in which innovation-driven early adoption is gradually overtaken by imitation effects amplified by network externalities. While the standalone Bass model successfully captures the general diffusion logic, its forecasting accuracy is constrained by restrictive assumptions regarding fixed market potential and time-invariant parameters.

The proposed hybrid model, which integrates diffusion dynamics with a time-based regression trend, substantially improves predictive performance and more accurately reflects the combined influence of social diffusion mechanisms and structural growth factors. Overall, the findings confirm the relevance of diffusion-based modeling for understanding digital banking expansion in emerging markets and provide a practical forecasting framework for medium-term strategic planning. At the same time, the results highlight the need for further model extensions that explicitly incorporate demographic dynamics, regulatory conditions, and institutional drivers.

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