

EMPIRICAL EVIDENCE ON THE ROLES OF FINANCIAL TECHNOLOGY PRODUCTS ON THE SHADOW ECONOMY: A COMPARATIVE ANALYSIS BETWEEN ADVANCED, EMERGING AND DEVELOPING COUNTRIES

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Abstract

The shadow economy, which can be defined as undeclared economic activities carried out in secret from public authorities,, and that cause negativities such as tax losses outside of official economic activities, has become a part of the economic activities of both developed and developing countries. The shadow economy literature bears witness to very different findings within the framework of national income levels, and this encourages researchers to address the issue from different perspectives with further studies. This study examines the effects of financial technology products, inflation, and the rule of law on the shadow economy in advanced, emerging and developing countries by using the method of the moment-quantile regression model and different robustness control methods. The most interesting finding from the study is that the effect of financial technology products on the shadow economy is asymmetric in both country groups. Accordingly, while automated teller machine use reduces the shadow economy in advanced countries, it increases it in emerging and developing countries. However, inflation has an increasing effect on the shadow economy in both groups, while the rule of law has a decreasing effect. It can be said that these empirical results provide policy implications that will help decision-makers develop strategies in the fight against the shadow economy.

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INTRODUCTION

The shadow or informal economy is an important phenomenon that has found its place in academic literature in the past decade due to its effects on countries. The definition of the shadow economy (SE) has also changed as the literature and perspectives have developed. While Feige (1990) put forward a definition that all legal/illegal activities not included in official economic records are included in this scope, Schneider and Enste (2000) defined it as activities that are kept secret to avoid taxes or official practices. The International Labor Organization (ILO) (2002) defined the subject within the framework of both businesses and employees. As a result, the SE refers to the totality of activities associated with low income and insecurity, which are excluded from official regulations. A similar definition was reflected in the OECD's 2008 employment reports: all kinds of employment, production, etc., outside of official regulations and thus not subject to taxation activities are included in this scope.

In addition to threatening the economic stability of countries, the SE has multifaceted negative effects that can be expressed as tax loss, problems in social security systems, and ineffective implementation of economic policies (Gokmenoglu & Amir, 2023). This multifaceted nature of the issue is one of the reasons why it has been the focus of attention of policymakers and academics. In this context, while searching for answers to the question of what factors may affect the SE, studies have been conducted in dimensions classified as institutional, economic, technological, social and cultural factors (Schneider & Enste, 2000; Medina & Schneider, 2018). Among these factors, issues such as the rule of law and corruption have been intensively studied as determinants of the SE under the institutional dimension (Dreher & Schneider, 2010; Canh et al., 2021; Nguyen & Duong, 2021; Zhanabekov, 2022), issues such as inflation and financial development under the economic dimension (Safuan et al., 2021; Elbahnasawy & Ellis, 2022; Abu Alfoul et al., 2022; Tran et al., 2024), and issues such as education level under the scope of social and cultural factors (Gerxhani & Cichocki, 2023; Hashmi et al., 2024). However, in recent years, developments in financial technologies have directed the subject to a different focus, and the impact of these developments on the SE has become a matter of curiosity.

Financial technology products/services, abbreviated as FinTech, can be expressed as innovative products and services that emerge by adapting the developing technological infrastructure to financial services. Products/services within this scope mainly enable financial transactions to be made faster, and these processes can be carried out securely and are accessible to everyone (Gomber et al., 2017). All banking services on digital platforms, such as ATM banking services, mobile

banking, and digital payment systems with their renewed and changing technological content, are within the scope of financial technological products. The widespread use of financial technology products and the developing technological infrastructure have a two-way effect on the economic system. The first is that it strengthens financial participation by including more people in the banking system and reduces the SE by increasing transactions made through official means (Sahay et al., 2020). In addition, payments that can be made easily and quickly through digital payment systems will increase the registration of records, thus causing a contraction in the cash economy and reducing SE activities (Demirguc-Kunt et al., 2018). Conversely, technological products that cannot be recorded and within which user identities are kept confidential, such as cryptocurrency markets or decentralized finance platforms, can increasingly affect the SE (Foley et al., 2019; Zetzsche et al., 2017). Since technological products in this direction are not connected to official financial systems, they cause the state's tax revenues to decrease and the authorities to be unable to follow these transactions, thus increasing informality. One of the main factors in the differentiation of the impact of financial technology products on the SE is undoubtedly the development level of the countries. Medina and Schneider (2019) provide evidence that the size of the SE is lower in developed countries than in less developed and developing countries. In developed countries, an inevitable systematic process has been established for financial activities, and a strong infrastructure exists. In this direction, while FinTech applications in developed countries contribute more to the acceleration of transactions and the reduction of costs, in developing countries, this situation has the effect of increasing participation in the financial system (Philippon, 2016; Demirguc-Kunt et al., 2018). The increase in the development level of countries encourages people to be included in the financial system by increasing their access to financial products and services in the early stages of development. The increase in financial access paves the way for borrowing from banks, especially in commercial activities, and thus, it becomes possible to register informal businesses (Cama et al., 2024). One of the crucial handicaps for developing countries is that although the participation of individuals in the financial system is increased, the lack of regulation and supervision in the countries may constitute an obstacle to reducing the SE (Beck, 2020). As a result, while financial technology products provide more effective use of the financial system in developed countries, they play a critical role in reducing informal activities in developing countries. However, the existence of weak regulatory mechanisms also carries the risk of increasing the SE. The impact of financial technologies on the SE will differ depending on the economic dynamics of the

countries and the regulatory mechanisms implemented (Frost, 2020).

While evaluating the effects of financial technology products on the SE, inflation and the rule of law were included in the study as control variables, so as to not ignore the impact of external factors. In this context, a high inflationary environment will cause an increase in the cost of goods and services, thus decreasing purchasing power and welfare, increasing economic uncertainty, increasing business establishment costs and tax payments, and expanding the SE (Goel & Nelson, 2016). Nevertheless, it is also thought that the SE is essential in reducing the effects of economic shocks, wages, and inflation (Cama et al., 2024). The increase in inflation in developing economies is associated with increased purchasing power and a faster demand for products/services than supply. Keeping borrowing costs low in these countries can provide a lasting stimulus to the economy by paving the way for businesses to enter the formal sector to access finance (Nsi Ella & Mabiala, 2024). The rule of law is a governance system based on transparent, fair, and consistent implementation of legal regulations, independence of the judiciary, and impartiality of legal processes (World Bank, 2017). In countries where the rule of law is high, it is crucial for promoting both equitable and sustainable growth in the long term, broadening the welfare base of society, increasing trust in government, and better-combating corruption (Dabla-Norris et al., 2008). It also encourages individuals to register their businesses by securing their property rights and increasing the enforceability of contracts (Acemoglu & Robinson, 2012; North, 1990). A strong legal system facilitates the development of individuals' tax morale, the regular payment of more taxes, the more effective implementation of labor market rules, and thus the reduction of informal employment, which in turn facilitates the acquisition of social rights (Schneider, 2019; Togler, 2005; Loayza, 1996).

The fact that the impact of financial technologies on the SE may vary within the framework of the issues mentioned above motivates research on the subject, and it is essential to present comparative results, in particular by separating the scope between developed and developing countries. In this context, the study aims to analyze the effects of financial technology products on the SE. The study will discuss the impact of financial technology products on the SE in a broad framework, including inflation and the rule of law as control variables in the model. Estimations are made using the method of moment-quantile regression (MM-QREG), which is the primary method of the study, and the robustness tests performed also confirm the reliability of the results. It can be said that the study makes the following contributions to the existing literature:

a) the selection of a large sample of 24 advanced and 47 emerging and developing countries allows the generalization of the results obtained, b) it makes comparisons between groups of advanced and developing countries increases the relevance of the findings in the eyes of policymakers, c) it reveals the potential effects of financial technology products on the growth/decline of the SE guides policymakers and regulatory institutions. Considering the countries in two different income groups and making a comparison between them, thus revealing how the SE in these countries is affected, especially in terms of financial technologies, will fill an important gap in the literature.

The following section of the study includes a literature review. The econometric methodology follows this section. The last section consists of the conclusion, which includes evaluations of the findings obtained from the study.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

The role of the SE in economic activities and its adverse effects on financial stability have been the subject of research for many years. Due to its negative impact on per capita income, the SE can cause a decrease in tax revenues, an incorrect determination of the size of the public sector, budget deficits, inaccurate calculations of statistical information such as unemployment and inflation, loss of trust by paving the way for corruption, and a decrease in the level of welfare of the society. However, it also provides various advantages, especially in times of crisis. For example, affordable goods and services can be provided by reducing costs. It contributes to capital growth by animating the economy (Erđinç, 2016). It is also considered as a survival strategy or a strategy to increase low living standards, especially for small businesses (Efendic et al., 2018). This controversial position on the effects of the SE has been discussed in the literature on various economic variables, especially economic growth (Ajide & Dada, 2024b; Wu & Schneider, 2019), tax evasion/tax burden (Schneider et al., 2015; Tanzi, 2002), corruption (Dang et al., 2023; Nemeć et al., 2021; Esaku, 2021a), income inequality (Pham et al., 2024; Esaku, 2021b; Navickas et al., 2019), economic complexity (Ajide & Dada, 2024a; Ketu et al., 2024; Nguyen, 2022), economic/political uncertainty (Cetin, 2024; Nguyen et al., 2023), rule of law and regulations (Jamalmanesh et al., 2014; Enste, 2010), education (Ciucci, 2024; Ivařcu & Ștefoni, 2023; Berrittella, 2015), trade openness/foreign investment (Canh et al., 2021; Huynh et al., 2020), and financial development (Jacolin et al., 2019; Berdiev & Saunoris, 2016) have paved the way for examining the effects of many factors such as different countries/country groups, different periods

and different methods. However, the diversification of economic activities and the introduction of more financial technology products into our lives and technological innovations have made it essential to investigate the relationship between the SE and this technological infrastructure. In the context of the framework of the study, this section will present a summary of the literature and discussion on studies examining the relationship between the SE and financial technologies, the rule of law, and inflation.

SHADOW ECONOMY AND FINANCIAL TECHNOLOGY PRODUCTS

Financial technologies can be defined as using new technologies, products, and innovative business models to provide financial services (Nicoletti, 2017). In the development of financial technologies, the technological advancement of countries, macroeconomic factors, and institutional quality come to the fore (Bobbo et al., 2024). Developments in financial technology (mobile applications, POS, ATMs, etc.) positively affect financial participation and development, allowing individuals/businesses to access loans, make investments more easily, transfer money faster, and be preferred more in payments due to the advantages of the system (Rahman et al., 2023b). Increasing participation in the financial system generally leads to a decrease in the SE. The financing provided and services received from official financial institutions mainly cause the mandatory registration of individuals or businesses. By contrast, due to its systematic risk, it can also increase the SE, especially in developing countries, due to underdeveloped legal regulations (Syed et al., 2021). Less financial access in developing countries can be considered one of the main reasons for the increase in the SE. At a low level of financial development, there is a lack of loanable cash in the system, a lack of competition among financial institutions, high levels of market pressure, and problems in collecting and analyzing data for lending institutions (Rahman et al., 2023a).

There are limited studies in the literature investigating the impact of financial technology products especially ATMs, on the SE. Therefore, studies examining the effect of financial development and financial inclusion on the SE are also reviewed and summarized below. While financial development and financial inclusion are sometimes used interchangeably, financial development focuses on the size and efficiency of financial institutions and markets, while financial inclusion focuses on the accessibility of individuals and institutions to the financial system.

Examining the relationship between financial stability and inclusion and the SE, Syed (2024) focused on the regulatory role of institutional quality, banking regulations, and governance in this relationship and con-

sidered the G5 countries. While financial inclusion effectively reduced the SE in the G5 countries, it was observed that governance and banking regulations contributed to the increase in size by fuelling this effect. One of the main conclusions of the study is that access to financial services should be expanded through financial technologies to reduce the SE, but policymakers must introduce the necessary regulations and take steps to eliminate security threats and potential risks while doing this. Technological innovations and globalization in financial services have caused problems, especially in ensuring financial stability. The effects of these services being available to even the most rural areas at affordable prices on financial stability, especially for developing country economies, are still debatable. One of these discussions is undoubtedly that easily accessible cash can pave the way for tax evasion (Schneider, 2019). In general, the existence of a positive relationship between the share of cash in total payments and the SE is striking. However, cash density can also be seen occasionally in economies such as Germany and Austria, where the SE is relatively small. Nevertheless, in Sweden, where cash payments are very low, the SE is moderate (Schneider, 2019). While financial technologies contribute to reducing the SE by transferring money transfers to digital environments and thus increasing cashless payments, the use of financial technological products such as Automated Teller Machines (ATMs) can negatively affect the SE (Boitan & Ştefoni, 2023). ATMs allow individuals to easily access cash, paving the way for cash circulation in the market through unofficial means (Schneider, 2019). Although this situation is not the main reason for tax evasion, statistics show that this situation is vital for countries. European Central Bank (2021) reports highlight the increase in contactless payments and the decrease in ATMs in the euro area. ATMs, which are considered one of the most important developments in financial technology in the FinTech 2.0 (1967-2008) period, today have question marks about their sustainability due to innovations in digitalization technology (Alfhaili et al., 2025; Ardizzi & Cologgi, 2025). Syed, Ahmed, Kamal and Trinidad Segovia (2021) considered the number of ATMs and mobile money transactions in their research on South Asian countries. The research results revealed that both variables have a reducing effect on the SE in the relevant countries. In addition, the study shows that the lack of technological infrastructure and tools used to access financial technologies such as the Internet increases the SE and constitutes an obstacle to development. Cama et al. (2024) examined the impact of financial inclusion on the SE in different dimensions. In the study, the financial inclusion indicators used (financial inclusion index, number of commercial bank branches, number of ATMs, number of depositors, number of customers using loans) and all analyses con-

ducted show that the impact on the SE is negative. The study conducted on 186 different countries stated that low-middle-income countries lack access to financial services, which can hinder financial inclusion. In these countries, financial inclusion is much more critical in reducing informality than in other countries. Rahman et al. (2023a), who examined the impact of financial development on the SE and the use of financial technologies, conducted their research for the BRICST countries by considering the period 2004-2018. The research findings pointed out that both variables negatively affect the SE and that financial technology moderates financial development. Lahura and Vargas (2021) examined the impact of financial development and financial inclusion on the SE from a broad perspective. The 152 countries included in the research sample were grouped as developing, developed, the entire sample, and Latin American countries. The effect of the number of ATMs included in financial inclusion on the SE is negative in developed and Latin American countries; no finding was obtained for the number of ATMs in developing countries, and the effect of loans was decreasing. Yan et al. (2024) examined the impact of the proliferation of information and communication technologies (ICT) on the SE in Latin American and Caribbean countries. The results show that positive ICT developments can reduce the SE's size by increasing financial inclusion, especially in developing countries. Studies in recent literature generally suggest that the use of financial technologies contributes to the development of the sector and increases participation in the financial system (Yan et al., 2024; Muganyi et al., 2022; Wang & He, 2020).

Based on the literature review, the impact of both financial development and financial technologies on the SE is complex. The main point determining the direction of the effect is the policies countries follow while catching up with the technological transformation. During the creation of the necessary technological infrastructure for financial technology, the definition of regulatory and supervisory mechanisms for the subject and the establishment of the required laws come to the forefront regarding whether the impact will be positive or negative. The results of studies in the literature reveal diverse relationships between ATMs and the shadow economy across various countries. So, the expectation regarding the first hypothesis of the research is as follows.

H₁: Financial technology products have a significant impact on the shadow economy.

SHADOW ECONOMY AND THE RULE OF LAW

The effect of the rule of law (*r_{law}*) on the SE has been negative for countries at all levels of development in the recent past. This effect is seen in the studies of

Khan et al. (2023) for countries that are members of the Organization of Islamic Cooperation and those that are not, Gokmenoglu and Amir (2023) for the Baltic countries, Bulut (2022) for 67 developing countries, Canh et al. (2021) for a global sample of 112 countries, Alarcon-Garcia et al. (2020) for 82 countries, and Imamoglu et al. (2018) for European Union countries. Notably, the SE's size is smaller in countries where the *r_{law}* is high than in countries where the rule of law is lower (Alarcon-Garcia et al., 2020). Canh and Thanh (2020) investigated the relationship between the SE and financial development in a multifaceted manner for 114 countries. Therefore, the average of six different institutional quality indicators, including the rule of law, were considered. It is seen that the effect of institutional quality on the SE is negative and statistically significant only in the short term. Kelmanson et al. (2019) examined the SE in 40 European countries using a new estimation. The results emphasize that regulatory reforms are essential for strengthening the *r_{law}* and eliminating corruption. It is argued that improving the *r_{law}*, regulations made within this framework, and financial restrictions will enhance the effect on the SE.

After the literature review on the *r_{law}* and the SE, another hypothesis of the study was determined.

H₂: The rule of law has a negative impact on the shadow economy.

SHADOW ECONOMY AND INFLATION

The effect of inflation (*inf*) on the SE may vary depending on different dynamics. It may cause an increase in the SE due to the increasing tax burden and costs, or it may create market pressure to reduce the SE by paving the way for a forced decrease in cash usage in periods of high *inf*. Recent literature on the subject provides strong empirical evidence for the expansionary effect of *inf* on the SE. Ciucci (2024) for a sample of 133 countries, Barra et al. (2024) for 42 developed and developing countries, Gokmenoglu and Amir (2023) for the Baltic countries, Nguyen et al. (2023) for 124 countries and Abu-Lila et al. (2021) for Jordan reveal this effect. One of the limited studies that concluded that the effect was negative was conducted by Henri et al. (2020) for 41 Sub-Saharan countries.

Bansah and Mohsin (2024) attribute the positive relationship between *inf* and the SE in developing countries to the fact that the size of the SE in these countries is higher than in developed countries, and inflation rates are generally higher, too. It is also noted that increases in the *inf* rate reduce the SE as long as access to credit is allowed, but high *inf* can harm the economy by lowering financial development. In this context, it is crucial to limit the increases in *inf* due to access to credit at a point. In a study examining 27 Sub-Saharan African countries, Nsi Ella and Mabilia (2024)

show that inf positively affects the SE. The explanation for this effect is based on the fact that the inflationary shock effect created by the Russia-Ukraine war, after an economy damaged by the COVID-19 pandemic, was felt more in African countries. It is stated that in countries with high inf, the monetary policies to be determined by the central bank should focus on determining the primary source of inf and that the transition from the SE to the formal economy should be encouraged through an effective fiscal policy. Tran et al. (2022) considered ASEAN countries in their study investigating the determinants of the SE. The results indicate that high inf paves the way for economic difficulties and thus encourages the SE. The nonlinear relationship between the SE and the level of development in 158 countries was examined by Wu and Schneider (2019). It has been determined that there is a U-shaped relationship between the SE and the level of development. Many models were considered in the research, and it was determined that the coefficient showing the effect of inf on the SE was positive, but the coefficient was significant in some models and not others. In their study on the determinants of three different SE variables, Goel and Nelson (2016) focused on 142 countries. The general results of the survey indicated that inf is the driving force of the SE. If it is not controlled, it will pave the way for new shadow operators to enter the economies of both developed and developing countries. Ergene (2015) investigated the effects of economic growth, inf, and interest rates on the SE in the context of OECD countries. In the study, the much higher impact of economic growth and interest rates on the SE made the effect of inf on the SE unclear. It was revealed that the driving force of inf in these countries was the interest rate.

After the literature review, the theoretical expectation for the effect of inf on the SE in the study is positive. In this context, the third hypothesis of the study is presented as follows.

H₃: An increase in inflation leads to an expansion of the shadow economy.

RESEARCH GAP AND CONTRIBUTION

The research gap revealed by the literature review and the area to be filled by this study can be summarized as follows. The combined effects of financial technology products (ATM), macroeconomic conditions, and institutional quality on the SE are an understudied area. Most studies consider the number of ATMs per 100,000 adults as an indicator of financial inclusion and access to technology. However, the direction of this indicator's relationship with the informal economy has not been clearly established. Studies that assume the impact of ATM penetration is asymmetric rather than uniform and examine this through cross-country comparative analyses are quite limited. Therefore, a comprehensive study that analyzes ATM usage, inflation, and the rule of law in both developed and developing countries can better explain the interactions and differences between these factors. In conclusion, the shortcomings in this area point to a significant research gap, and the need for more in-depth research using scientific methods clearly emerges.

ECONOMETRIC METHODOLOGY

DATA AND SAMPLE

The study used a panel data set of 24 advanced and 47 emerging and developing economies selected within the framework of the definition made by the IMF for 2002-2021. The sample and period used in the study were determined according to data availability, and some countries were exempted from the sample because they could not produce sufficient data for the analysis. The data for the study were compiled from the official websites of the World Bank. The data were included in the analyses based on their nominal values. The data set, where the SE is the dependent variable and the financial technology product, inflation, and rule of law variables are the independent variables, has an unbalanced panel data feature due to a lack of data for some years. Table 1 below shows more information about the countries and variables examined in the study.

Table 1: Explanatory information regarding the data

Variable	Abbreviation	Source
Shadow economy (%GDP)	SE	https://www.worldbank.org/en/research/brief/informal-economy-database
Financial technology product (Automated teller machines (ATMs) (per 100,000 adults)	ATM	https://databank.worldbank.org/source/world-development-indicators
Inflation, consumer prices (annual %)	inf	https://databank.worldbank.org/source/world-development-indicators
Rule of law	r_law	https://www.worldbank.org/en/publication/worldwide-governance-indicators

Source: Author's own work.

Countries in the sample. Advanced economies: Australia, Austria, Belgium, Croatia, Cyprus, Czech Rep., Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, UK.

Emerging and developing economies: Albania, Algeria, Bahamas, Bangladesh, Belize, Bhutan, Bolivia, Botswana, Brazil, Bulgaria, Cambodia, Chad, Chile, China, Colombia, Kongo, Ecuador, Egypt, El Salvador, Equatorial Guinea, Fiji, Honduras, Hungary, India, Jamaica, Jordan, Kenya, Kyrgyz Republic, Lesotho, Madagascar, Malawi, Malaysia, Mauritius, Mexico, Nicaragua, Nigeria, Pakistan, Peru, Philippines, Poland, Qatar, Romania, Russian Federation, Rwanda, South Africa, Tunisia, Vietnam.

Examining the impact of inflation, the rule of law, and financial technology (ATM usage) variables on the SE is critical for decision-making and policy implementation because these variables reflect the key incentives and disincentives for operating in the shadow sector. Accordingly, high inflation erodes purchasing power and creates uncertainty in the economy. People and businesses seek to protect their income and wealth by shifting to the SE (such as undeclared earnings). The SE thrives where law enforcement is weak. Issues such as ineffective judiciary, corrupt tax systems, and corruption are strong enablers of the SE. FinTech/ATM usage is an indicator for measuring trends such as access to the formal financial system and the digitalization of transactions. The impact of ATM usage on the SE may vary across country contexts. For example, the effects of ATM usage on the SE cannot be expected to be uniform between countries with high levels of financial and digital literacy, strong technological infrastructure, and high levels of human development, and those experiencing challenges in these areas. In this context, examining inflation, rule of law and ATM usage together provides a holistic perspective on how they expand or contract the informal economy.

The study also used the number of ATMs per 100,000 adults as a financial technological product. First and foremost, the number of ATMs per capita indicates that a larger segment of the population, including those in the shadow sector, has physical access to formal financial services across a wider geography - not just in cities but also in rural areas. Furthermore, data on the number of ATMs and the adult population are reliably collected, standardized across countries, and frequently updated. This allows for consistent comparisons across countries. The number of ATMs is concrete and objective data. Because of this objectivity, it is a frequently used metric by international financial institutions such as the World Bank and the IMF. Therefore, it serves as a robust and measurable indicator of

a phenomenon that is inherently difficult to measure directly. In this context, studies using the number of ATMs per 100,000 adults as an indicator of fintech/financial access can be given as examples (Azmeah, 2025; Ananzeh et al., 2025; Olaoye et al., 2025; Cama et al., 2024; Basnayake et al., 2024; Amaliah et al., 2024; Al-Smadi, 2023; Gharbi & Kammoun, 2023; Syed et al., 2021).

METHOD

According to the Jarque-Bera test results presented in the basic statistical tests, none of the variables meet the normality assumption. In the context of these findings, it was evaluated that non-parametric methods in the analysis process would be more accurate. Since it enables a thorough and reliable analysis of the coefficients at several levels of the SE, the moment-quantile regression (MM-QREG) approach was chosen to estimate the coefficients. Compared to other approaches, this estimator has a few advantages. For instance, heterogeneity is not taken into account by the conventional quantile regression methods. Panel data can be analyzed using the MM-QREG technique, particularly when there are heteroskedasticity or non-normal distributions present and the variability of the error component varies among observations (Omar et al., 2025; Kilinc-Ata et al., 2024). The MM-QREG method introduced by Machado and Silva (2019) is a tool designed for conducting panel data analysis. The approach delivers strength, flexibility, and thorough forecasts in situations where standard regression methods often fail due to non-normal distributions, outliers, and data that varies in spread (Chen et al., 2025; Almulhim et al., 2025). In contrast to regression methods that primarily focus on predicting a variable's mean, quantile regression is developed to calculate the conditional median or other quantiles. This approach offers insight into the connection between variables at various locations within the data set. This approach generally yields more robust and inherently more efficient estimators. Using the MM-QREG approach is advantageous when the residuals of the regression model are not normally distributed, which is a common situation in real-world datasets (Zaidi et al., 2024). The mathematical representation of the method can be done as follows:

$$Q_{\tau}(\tau | X_{it}) = (\alpha_i + \delta_i q(\tau)) + X'_{it}(\beta + \gamma_i q(\tau)) \quad (1)$$

Here, $Q_{\tau}(\tau | X_{it})$ shows the conditional quantile distribution of the explained variable depending on the position of the explanatory variables; $(\alpha, \beta, \delta, \gamma)$ shows the parameter estimates. X'_{it} shows a vector of independent variables including ATM, \inf v_e r_law , τ ; shows the quantile level and takes values between $0 < \tau < 1$. In this direction, the model, including the variables used in the study, can be shown as follows.

$$Q_{\tau}(SE_{it}) = \alpha_{\tau} + \beta_{1,\tau} atm_{it} + \beta_{2,\tau} inf_{it} + \beta_{3,\tau} r_law_{it} + \varepsilon_{it,\tau} \quad (2)$$

EMPIRICAL ANALYSIS

The econometric strategy followed in the study is as follows. First, basic statistical tests were performed to understand the general structure of the data. In the next stage, the cross-sectional dependency of the series was checked, and a homogeneity test was per-

formed on the slope coefficients. In the next stage, the stationarity of the series was tested with panel unit root tests. The last stage included coefficient estimates using the fundamental analysis method.

BASIC STATISTICAL TEST

Descriptive statistical tests were conducted to see the general structures and characteristics of the data used in the study, which are given in Table 2 below.

Table 2: Descriptive statistics

Advanced economies				
Variable	SE	ATM	inf	r_low
Mean	17.920	99.500	1.770	1.360
Median	16.870	93.100	1.760	1.480
Max.	31.290	288.590	12.290	2.120
Min.	9.130	27.150	-4.440	-0.140
Std. Dev.	5.690	51.290	1.540	0.520
Skewness	0.370	1.210	1.330	-0.810
Kurtosis	2.170	5.020	11.840	2.800
Jarque-Bera	23.240	174.700	851.220	53.780
p-value	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Emerging and developing economies				
Variable	SE	ATM	inf	r_low
Mean	32.040	32.620	5.160	-0.320
Median	31.340	25.400	4.260	-0.410
Max.	63.780	185.410	33.810	1.410
Min.	8.010	0.000	-16.850	-1.620
Std.Dev.	10.260	31.370	4.480	0.640
Skewness	0.350	1.650	1.540	0.470
Kurtosis	3.440	6.380	8.920	2.540
Jarque-Bera	26.420	776.050	1745.010	43.670
p-value	(0.000)***	(0.000)***	(0.000)***	(0.000)***

Note: Significance level, *** 1%

Source: Author's own work.

Accordingly, the mean and median values of the SE variable are larger in emerging and developing economies. The difference between the maximum and minimum values, due to the standard deviation of SE, is larger in this country group. When the ATM numbers are examined, advanced economies have higher values. The inf variable in emerging and developing economies has higher rates than in advanced economies. Advanced economies have better figures for the r_low. The skewness and kurtosis values for the standard normal distribution are 0 and 3, respectively (Sun et al., 2025; Alomari et al., 2024). Accordingly, since all variables' skewness and kurtosis values are far from 0 and 3, they provide preliminary information that the normality assumption is not met. In fact, according to the Jarque-Bera test statistics and probability values, none of the variables meet the normality assumption. These

findings signal that conducting non-parametric analyses would be more appropriate during the analysis phase.

CROSS-SECTIONAL DEPENDENCE

Cross-sectional dependence (CSD) in a panel dataset arises from correlations between units, which can be distinct countries or firms. Many models that assume independence across different cross-sections may produce inaccurate results if they fail to account for correlated standard deviations, resulting in underestimated standard errors (Liu et al., 2025). Accounting for CSD helps improve model accuracy and ensures that the observed effects are accurate and applicable across units. Neglecting this effect can lead to ineffective and inconsistent estimates (Nordin et al., 2025). Analyses were conducted with commonly used tests for cross-sectional dependence of the variables used in the study, and the results are shown in Table 3 below.

Table 3: Cross-sectional dependency test results

Advanced economies				
Test	SE	ATM	inf	r_low
Breusch-Pagan LM	4148.140 (0.000)***	1509.980 (0.000)***	2008.490 (0.000)***	1220.730 (0.000)***
Pesaran CD	63.750 (0.000)***	10.970 (0.000)***	38.730 (0.000)***	9.530 (0.000)***
Emerging and developing economies				
Test	SE	ATM	inf	r_low
Breusch-Pagan LM	16185.530 (0.000)***	12352.570 (0.000)***	3235.520 (0.000)***	5615.740 (0.000)***
Pesaran CD	112.810 (0.000)***	103.760 (0.000)***	34.620 (0.000)***	-0.490 (0.620)

Note: Significance level, *** 1%

Source: Author’s own work.

This investigation employed the Pesaran (2004) CD test and the Breusch-Pagan (1980) Lagrange Multiplier (LM) test to examine cross-sectional dependency. The LM test necessitates panel datasets, with the time dimension (T) being significantly larger than the cross-sectional dimension (N). The Pesaran CD test provides more reliable outcomes when N is greater than T (İlarslan, 2024). The null hypothesis of Breusch-Pagan LM and Pesaran CD tests is expressed as there is no cross-sectional dependency between units. Accordingly, the null hypothesis of no cross-sectional dependency for four variables in advanced economies was rejected at a 1% significance level. Conversely, for the Breusch-Pagan LM test in Emerging and developing economies, the null hypothesis was rejected at a 1% significance level for four variables. It is rejected for three variables except r_low according to Pesaran CD

results. Therefore, cross-sectional dependency was observed between the variables, and it was evaluated that it was appropriate to use second-generation panel unit root tests for the stationarity of the series. However, using first-generation panel unit root tests, stationarity testing can be performed for the r_low variable in developing countries.

HOMOGENEITY TEST

In the next stage of the analysis process, the heterogeneity of the regression parameters was tested using the Pesaran and Yamagata (2008) test. The test’s null hypothesis is that the slope coefficients are homogeneous among the cross-sectional units, and the alternative hypothesis is that the slope coefficients are heterogeneous among the cross-sectional units (Pejovic et al., 2025). The test results are given in Table 4 below.

Table 4: Slope homogeneity test results

Test	Advanced economies		Emerging and developing economies	
	Test Statistic	p-value	Test Statistic	p-value
Delta	10.394	(0.000)***	21.466	(0.000)***
Adj. Delta	12.430	(0.000)***	25.653	(0.000)***

Note: Significance level, *** 1%

Source: Author’s own work.

As shown from the Delta and Adjusted Delta statistics results in Table 4, the null hypothesis that the homogeneous slope coefficients are rejected at the 1% significance level. Therefore, it can be said that the coefficients of the variables are heterogeneous.

STATIONARY ANALYSIS

Stationary series fluctuate around a fixed long-term mean, and the variance does not change over time. However, non-stationary series do not tend to follow a deterministic path in the long term. Therefore, the variance of the series changes over time (Ucler & Ozsa-

hin, 2024). Ensuring the series is stationary is essential for obtaining reliable results in econometric analysis. A series is termed to have a unit root if it is non-stationary. In econometrics, a series’ stationarity is evaluated by performing a unit root test, as outlined in Shrestha and Bhatta (2018). These tests play an important role in panel data analysis, especially in the fields of econometrics and finance, as they help researchers evaluate the stationarity of variables. This assessment is critical to ensure the accuracy and reliability of the statistical analysis (Qamruzzaman & Karim, 2024). The Cross-Sectionally Augmented IPS (CIPS) test,

one of the second-generation panel unit root tests used to test the stationarity property of series, is considered an appropriate test for cases where cross-sectional dependence exists because it gives better results than tests that assume independence between units (Zaidi et al., 2024). The CIPS test allows unit root testing between series included in the panel. The null hypothesis (H0) of the test suggests that the series contains a unit root (i.e., they are not stationary) (Merdan,

2024). The CIPS test results for the stationarity of the series for both country groups are given in Table 5 below. In addition, since cross-sectional dependence was not observed for the r_law variable in Emerging and developing economies, the stationarity of this variable was tested with the Levin-Lin and Chu (LLC) test, which are first-generation panel unit root tests, and the results are shown in Table 5.

Table 5: CIPS and LLC unit root test results for stationarity testing

Test	Advanced economies				Emerging and developing economies			
	SE	ATM	inf	r_law	SE	ATM	inf	r_law
CIPS	-2.132*	-1.633*	-2.964***	-2.777**	-2.317***	-2.126*	-2.884***	
LLC								-3.296***

Note: Significance level, *** 1%, ** 5%, * 10%

Source: Author's own work.

According to the CIPS and LLC unit root tests conducted for the stationarity test of the variables in both country groups, the null hypothesis that the series contains a unit root was rejected at different significance levels. The variables do not include a unit root. In other words, they have a stationary structure. Therefore, the variables can be used with their level values in the analyses.

MODEL ESTIMATION RESULTS

The coefficient estimates made using the fundamental analysis method of the study, MM-QREG, are shown in Table 6 below.

Table 6: MM-QREG Analysis results

Panel A Advanced economies					
Quantile Levels					
	10	20	30	40	50
ATM	-0.013 (0.007)***	-0.011 (0.006)***	-0.010 (0.007)***	-0.009 (0.009)***	-0.008 (0.016)**
inf	0.487 (0.001)***	0.415 (0.001)***	0.357 (0.001)***	0.310 (0.003)***	0.265 (0.008)***
r_law	-10.034 (0.000)***	-9.591 (0.000)***	-9.241 (0.000)***	-8.953 (0.000)***	-8.675 (0.000)***
c	27.357 (0.000)***	28.248 (0.000)***	28.952 (0.000)***	29.532 (0.000)***	30.090 (0.000)***
Quantile levels					
	60	70	80	90	
ATM	-0.007 (0.043)**	-0.005 (0.122)	-0.004 (0.204)	-0.004 (0.329)	
inf	0.203 (0.040)**	0.141 (0.172)	0.106 (0.324)	0.068 (0.555)	
r_law	-8.300 (0.000)***	-7.921 (0.000)***	-7.708 (0.000)***	-7.472 (0.000)***	
c	30.844 (0.000)***	31.607 (0.000)***	32.036 (0.000)***	32.511 (0.000)***	
Panel B Emerging and developing economies					
Quantile levels					
	10	20	30	40	50
ATM	0.044 (0.001)***	0.036 (0.001)***	0.030 (0.001)***	0.027 (0.002)***	0.023 (0.006)***
inf	0.188 (0.087)*	0.198 (0.027)**	0.205 (0.009)***	0.208 (0.005)***	0.213 (0.003)***

Panel B Emerging and developing economies					
	Quantile levels				
	10	20	30	40	50
r_law	-7.165 (0.000)***	-8.150 (0.000)***	-8.864 (0.000)***	-9.178 (0.000)***	-9.674 (0.000)***
c	17.953 (0.000)***	21.429 (0.000)***	23.946 (0.000)***	25.054 (0.000)***	26.801 (0.000)***
	Quantile levels				
	60	70	80	90	
ATM	0.020 (0.019)**	0.015 (0.086)*	0.011 (0.231)	0.004 (0.726)	
inf	0.218 (0.002)***	0.223 (0.003)***	0.228 (0.004)***	0.237 (0.013)**	
r_law	-10.144 (0.000)***	-10.718 (0.000)***	-11.195 (0.000)***	-12.112 (0.000)***	
c	28.461 (0.000)***	30.485 (0.000)***	32.166 (0.000)***	35.399 (0.000)***	

Note: Significance level, *** 1%, ** 5%, * 10%

Source: Author's own work.

According to Table 6, the effect of ATM on SE is in different directions for both country groups. This asymmetric effect has a decreasing role in the SE in advanced economies and an increasing role in emerging and developing economies. In advanced economies, the coefficient is negative and statistically significant at lower and medium quantile levels (0.10-0.60). This can be interpreted as an indication that ATM reduces SE to a limited extent. In emerging and developing economies, the coefficients are positive and statistically significant within a certain quantile range (0.10-0.70).

Therefore, the impact of ATMs on SE is negative in advanced economies, whereas it is positive in emerging and developing economies. The following arguments can be put forward as possible reasons for this interesting result obtained from the study. In emerging and developing countries, ATMs facilitate a cash economy by meeting funding needs at both the individual and institutional levels, without any time constraints. Therefore, easier access to cash can lead to shadow economic activities. Based on this, it can be argued that emerging and developing countries prioritize the short-term financial and transactional conveniences of ATMs but have not yet focused on the role of cash supply, which can lead to shadow economic activities.

The study has shown that ATMs play a role in reducing SE in advanced economies. The reasons for this can be explained as follows. In advanced countries, ATMs may have more innovative and technologically advanced financial applications. For example, contactless transactions such as biometric authentication, QR code applications, and artificial intelligence applications can be used to prevent potential fraud. It is also conceivable that advanced countries may have implement-

ed measures, including legal and institutional limitations and restrictions, to ensure visibility into ATM transactions. In advanced economies, banking systems and financial transactions are strictly regulated and supervised. ATM use leaves a digital footprint on individuals, making it difficult to completely conceal income or business activities. In advanced economies, ATM use enables people to integrate into formal banking, reduce their reliance on cash transactions, increase transparency, and operate in compliance with stricter regulatory frameworks.

According to another result obtained from the study, inf has an increasing role in SE in both country groups. In advanced economies, the coefficient value decreases towards the upper quantiles and loses significance at higher quantiles (>0.60). In emerging and developing economies, this effect increases towards the higher quantiles and remains significant. The most explicit image obtained from the analysis is the effect of r_law on the SE. r_law has a decreasing impact on SE in both country groups, and this effect is confirmed at all quantile levels. It is clear that r_law is an important determinant in reducing SE in both country groups.

ROBUSTNESS CHECK

At this study stage, analyses were conducted within the generalized linear model (GLM) framework to test the accuracy and validity of the coefficient estimates obtained from the fundamental analysis method MM-QREG. The analysis is based on the generalized linear model (GLM) using the Newton-Raphson and Marquardt steps for long-term estimates. According to Avci's (2021) research, generalised linear models can be utilised as a substitute for the data transformation

method in instances where the dependent variable fails to exhibit a normal distribution, and the outcomes derived from these models yield more precise results than data transformation because there is no necessity for reverse transformation, and they possess a narrower confidence interval. Beyond linear mixed models, GLM considers that the response variables are heteroskedastic, have a linear relationship between the mean of the response variable and the predictor or explanatory

variables, and do not have a continuous scale (do not exhibit a normal distribution) (Ruiz et al., 2023). As stated in their study, Yang et al. (2023) argue that GLM effectively estimates parameters and can avoid transformation bias and interpretability problems when analyzing transformed data. In line with these reasons, long-term coefficient estimates made with GLM for both country groups are shown in Table 7 below.

Table 7: GLM estimation results

	Advanced economies	Emerging and developing economies
ATM	-0.008 (0.046)**	0.0240 (0.0000)***
inf	0.265 (0.015)**	0.2120 (0.0002)***
r_law	-8.678 (0.000)***	-9.6280 (0.0000)***
c	30.085 (0.000)***	26.6390 (0.0000)***

Note: Significance level, *** 1%, ** 5%

Source: Author's own work.

Accordingly, it is seen that the coefficient estimation results made with GLM are similar to the fundamental analysis findings in terms of both the direction of the relationship and the coefficient size. In both country groups, r_law has a decreasing effect on SE, while inf has an increasing impact. However, the effect of ATM on SE is asymmetric. ATM use in advanced countries has a decreasing role on SE, while it has an increasing role in emerging and developing economies. Within the framework of these findings, strong empirical evidence has been reached regarding the effects of atm, inf, and r_law on SE.

DISCUSSION

In this section, the findings will be discussed comparatively for each variable for the two country groups. The findings for the atm variable, used as a proxy for the financial technologies at the focus of the study, reveal different results for the two country groups. While the impact of ATMs on SE is negative in advanced economies, it is positive in emerging and developing economies. The following arguments can be put forward as potential reasons for this interesting result obtained from the study. ATMs in emerging and developing countries, create a cash economy by meeting funding needs at individual and institutional levels without time and time constraints. Therefore, since cash has become easy to access, it can cause shadow economic activities. Transactions made within the framework of a cash economy often cause tax losses as they do not leave a trace in the financial system, and the declarations do not reflect the truth, which leads to

informality. Based on this, it can be said that developing countries prioritize the short-term financial and transactional conveniences of ATMs, but they have not yet focused on the role of cash money supply, which can cause shadow economic activities. The study has shown that ATMs have a role in reducing the SE in advanced economies. The reasons for this can be explained as follows. Since sATMs pave the way for a cash economy, they encourage informality in economies. Advanced countries may have focused on cashless payments, such as digital payments, instead of cash, to ensure visibility in monetary transactions. Indeed, in most advanced countries in the sample, there has been a decrease in the number of ATMs per 100,000 adults compared to previous years. For example, in Australia, the number of ATMs per 100,000 adults was 170 in 2011, while this number was 123 in 2021. In Denmark, these numbers decreased from 61 to 41 in the same years; in Ireland, from 88 to 44; in Japan, from 128 to 116; in the Netherlands, from 56 to 33; in Norway, from 54 to 27; and in Spain, from 147 to 96. It is clearly seen that advanced countries are reducing the use of ATMs. This may be done to ensure and increase visibility in payments and money transfers. This situation can be interpreted as digital payment and transfer systems starting to replace ATMs in cash payments and money transfers. It can also be thought that advanced countries may have taken precautions with legal and institutional limitations and restrictions to ensure visibility in transactions made via ATMs. In this context, we can say that advanced countries have focused on the disadvantages of ATM use rather than its benefits, especially in recent years.

In advanced economies, banking systems and financial transactions are strictly regulated and supervised. Using ATMs leaves individuals with a digital footprint, making it difficult to completely conceal income or business activities. ATM use in advanced economies allows people to integrate into formal banking, reduces reliance on cash transactions, increases traceability, and operates in compliance with stronger regulatory frameworks. The digital footprints created by ATMs increase the risk of detection for those operating in the SE, leading them to seek formal employment. Furthermore, the maintenance and other costs of ATMs reduce bank profitability (Money & Lyoha, 2025), the replacement of ATMs by peer-to-peer digital payment systems (Gorka, 2024), and the significant reduction in cash withdrawals due to branch and ATM consolidation (Ueda, 2024), all of which contribute to a decline in the number of ATMs and transaction volume. All of these factors can be cited as potential reasons for the decline of the SE.

It's also worth highlighting another point in the study. The difference across quantiles for the atm variable suggests that the method used serves its purpose. In countries with relatively low and moderate levels of SE, strengthening financial technology infrastructure services reduces informality. However, the insignificant effect observed at higher quantiles leads to the disappearance of the additional contribution of financial technology developments on informality as the extent of informality increases. This suggests that the strengthened financial infrastructure through financial technologies, after exceeding a certain threshold, is more important in terms of institutional structure and regulatory framework than in terms of access to these services for many segments. The primary reasons for the insignificant effect in the upper quantiles may stem from the institutional structure and regulatory framework within the country. A similar pattern has been observed in emerging and developing economies. In countries with low and moderate levels of informality, financial technologies contribute to the increase in informality. This may be due to the weak institutional infrastructure and ineffective supervisory mechanisms in these countries. However, the disappearance of the significant effect at higher quantiles indicates that the effect may have been eliminated by strengthening the institutional infrastructure and implementing stricter control mechanisms in countries where the level of informality is very high.

The effect of the *inf* variable on SE indicates similar results in both country groups. Accordingly, due to the increase in *inf*, products and services become expensive, individuals and businesses may demand products of an unregistered nature and/or may have turned to production activities. Therefore, individuals and companies may consider gaining cost and price advantage

by turning to unregistered products and raw materials so as not to lose their competitive advantage due to the increase in *inf*. It can be argued that the widespread and significant nature of this effect, especially in developing economies, is related to the limited national income per capita in the relevant countries and the fragility of the enterprises. Notably, the increasing effect of *inf* on SE gradually decreases in advanced countries, whereas it increases in emerging and developing economies. This is because economic units in emerging and developing economies are more sensitive to inflation and turn to shadow activities to eliminate the destructive and damaging effects of inflation. Many studies in the literature reveal the expansionary effect of *inf* on the SE in countries with different income groups (Bansah & Mohsin, 2024; Nsi Ella & Mabiola, 2024; Tran et al., 2022; Goel & Nelson, 2016).

It is noteworthy that *r_law* has a clear negative effect on the SE. Many studies, such as Khan et al. (2023), Gokmenoglu and Amir (2023), Bulut (2022), Canh et al. (2021), and Alarcon-Garcia et al. (2020), point to similar results, regardless of country income groups. Accordingly, applying normative rules and principles to all segments of society, private/public, rich/poor, without discrimination, the accountability of decision-makers and their implementation, societies where justice prevails rather than arbitrariness are characterized by the rule of law. In this framework, the illegality inherent in informal activities either does not occur due to the fair application of the law or is punished by a fair trial if it does happen. The absolute application of the *r_law* in countries, regardless of social roles, does not lead to illegal actions. As a result, there is a decrease in shadow economic activities. It is also noteworthy that the reducing effect of *r_law* on the SE is greater than the effect of ATMs on both country groups. However, while the reducing impact of *r_law* is gradually decreasing in advanced countries, it is increasing in developing countries. This is because there is still much work to be done to ensure that the *r_law* prevails in the relevant country group.

CONCLUSIONS

The shadow economy, which occurs in the form of tax evasion or avoidance, and evasion of legal labor standards, can be defined as the totality of legal production activities deliberately hidden from public authorities. The existence of informality is one of the biggest obstacles to a well-functioning economic system. The shadow economy, which is seen in all countries, can reach enormous amounts, especially in underdeveloped or developing countries. Therefore, well-designed regulations and reforms are needed to combat the shadow economy. The policies to be followed within these regulations and reforms must first be de-

terminated. This study aims to provide empirical evidence for the determination of these policies.

The study, which uses a panel dataset of 24 advanced and 47 emerging and developing economies selected for 2002-2021, aims explicitly to obtain pragmatic evidence on the effects of automated teller machine use as a financial technology product, the rule of law, and inflation on the shadow economy. The data were prepared for econometric analysis with basic statistical tests, cross-sectional dependency, homogeneity, and stationarity tests. The study conducted analyses within the framework of the moment-quantile regression (MM-QREG) method, which is the fundamental analysis method. Then, the validity and robustness of the findings were tested using the Generalized Linear Model (GLM). As a result of these empirical analyses, the following conclusions were reached. First, the most interesting finding from the study is that the effect of automated teller machine use on the shadow economy is asymmetrical in both country groups. Accordingly, while automated teller machine use reduces the shadow economy in advanced countries, it increases it in emerging and developing countries. This result indicates that the acceptance/rejection of the first hypothesis H1, differs depending on the income level of the countries. While the hypothesis is confirmed in advanced economies, it is rejected in emerging and developing economies. The advanced countries have prioritized the effects of this technological product on the shadow economy since automated teller machine use facilitates cash access and use. Therefore, they have started to focus on alternative digital payments by reducing the number of automated teller machine. As a result, the size of the shadow economy is decreasing due to the restrictions imposed on automated teller machine use. Conversely, emerging and developing economies may have prioritized the impact of automated teller machine on access to finance. Therefore, it is likely that the relevant technological product will increase informality in economies due to its contribution to forming a cash economy through time and space convergence in the provision and transfer of funds. Secondly, inflation increases informality in both country groups. This effect is statistically significant at low and medium quantile levels in advanced countries and at all quantile levels in emerging and developing economies. Accordingly, products and services become expensive due to the increase in inflation, and as a result, economic units supply and demand shadow products and services. Therefore, it can be said that individuals and businesses aim to gain cost and price advantage by engaging in commercial activities without declaring taxable earnings in purchases and sales due to the in-

crease in inflation. Thirdly, the rule of law variable reduces the shadow economy in both country groups. This effect is remarkably increasing in emerging and developing economies. Accordingly, improvements in normative structures in countries, the dominance of accountability rather than arbitrariness in countries, prevent illegal activities in economies, deter individuals and businesses from potential criminal acts, and therefore, the size of the shadow economy decreases.

The following suggestions can be made for decision-makers, considering that the results obtained from the study have practical implications. Emerging and developing economies, mainly, can impose restrictions and limitations on automated teller machine usage and consider alternative digital payment systems such as mobile banking and internet banking as substitute tools. Since the shadow economy is larger in these countries, perhaps more contributions than access to finance can be made by reducing the shadow economy. In addition, inflation is a reason for the shadow economy in all countries. Therefore, reducing inflation can be an essential tool in combating the shadow economy. Before financial and economic measures, the normative structure should be strengthened and implemented consistently.

STUDY LIMITATIONS

While this study provides important empirical evidence on the effects of atms, inf, and the r_{law} on the SE from the perspective of advanced and emerging and developing countries, it also has some limitations. The number of ATMs per 100,000 adults, used as a financial technology product indicator, is widely used as a measure of financial access. However, this indicator is insufficient to represent broader digital financial technologies (e.g., mobile payments, internet banking, e-wallets) and remains relatively outdated. This limits its ability to capture the true scope of financial innovation during the relevant period. The selected period includes significant global shocks (e.g., the 2008 global financial crisis, the COVID-19 pandemic) that impacted SE, inf, and atm in complex ways. Therefore, structural breaks are likely to emerge in the interactions between variables. Furthermore, developments after 2021 (rapid digitalization, cryptocurrency adoption, and fintech regulations) are excluded, potentially limiting the validity of the current policy recommendations. Furthermore, other critical factors that are likely to affect the SE, such as tax rates, labor market regulations, corruption, political stability, unemployment, and digital financial innovations, are not included in the analysis.

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