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MOBILE TECHNOLOGY SUPPLY FACTORS AND MOBILE MONEY INNOVATION: THRESHOLDS FOR COMPLEMENTARY POLICIES[1]

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Abstract

This study complements the extant literature by assessing how enhancing supply factors of mobile technologies affect mobile money innovations for financial inclusion in developing countries. The mobile money innovation outcome variables are: mobile money accounts, the mobile phone used to send money and the mobile phone used to receive money. The mobile technology supply factors are: unique mobile subscription rate, mobile connectivity performance, mobile connectivity coverage and telecommunications (telecom) sector regulation. The empirical evidence is based on quadratic Tobit regressions and the following findings are established. There are Kuznets or inverted shaped nexuses between three of the four supply factors and mobile money innovations from which thresholds for complementary policies are provided as follows: (i) Unique adults' mobile subscription rates of 128.500%, 121.500% and 77.750% for mobile money accounts, the mobile used to send money and the mobile used to receive money, respectively; (ii) the average share of the population covered by 2G, 3G and 4G mobile data networks of 61.250% and 51.833% for the mobile used to send money and the mobile used to receive money, respectively; and (iii) a telecom sector regulation index of 0.409, 0.283 and 0.283 for mobile money accounts, the mobile phone used to send money and the mobile phone used to receive money, respectively. Some complementary policies are discussed, because at the attendant thresholds, the engaged supply factors of mobile money technologies become necessary, but not sufficient conditions of mobile money innovations for financial inclusion.

Keywords: Mobile money; technology diffusion; financial inclusion; inclusive innovation
JEL Classification: D10; D14; D31; D60; O30

1. Introduction

There are three main motivational factors that justify the focus of this study on understanding how supply factors of mobile money innovation affect financial inclusion in developing countries, notably: (i) the growing potential of mobile phones in development outcomes in developing countries; (ii) the importance of financial inclusion in the post-2015 development agenda, with specific relevance to poverty-oriented and inequality-related sustainable development goals (SDGs); and (iii) gaps in the attendant mobile money innovations for financial inclusion literature. These three factors are put in more perspective in the subsequent paragraphs in the same chronology, as highlighted.

First, over the past decade, the use of mobile phones has grown considerably in developing countries, increasing possibilities for socio-economic and human developments because of, *inter alia*, associated positive development externalities pertaining to mobile money usage, adoption and innovation (Sy, 2019). Relative to developed countries, which have almost reached points of saturation in the penetration of mobile technologies, developing countries are characterised by a higher potential for mobile phone penetration and by extension, the inclusive development and socio-economic opportunities associated with the attendant higher prospect of penetration (Gosavi, 2018; Tchamyou, Asongu, Odhiambo, 2019). One of the advantages of mobile phone innovation that facilitates inclusive socio- economic development is financial inclusion[1].

Secondly, mobile money is a financial inclusion service that is provided by mobile phones. Whereas access to traditional banking services is not always possible due to a number of inhibiting factors that are inherent to traditional banking services, the fact that mobile phones are almost available to everybody in developing countries has enabled hundreds of millions of people to benefit from mobile banking services (Sy, 2019; Asongu, Biekpe & Cassimon, 2020, 2021). According to the narrative, mobile accounts which are now above bank accounts in numerical value have equally surpassed traditional bank accounts in providing financial inclusion because large swathes of the previously unbanked, the youth, the poor, the old, and women are now benefiting from mobile banking innovations (Klapper, El- Zoghbi & Hess, 2016; Uduji & Okolo-Obasi, 2018a, 2018b). To put this point into greater perspective, according to Sy (2019), in Africa and Asia, respectively, 10% and 7% of gross domestic product (GDP) of transactions are made via mobile money because most citizens in

[1] "Mobile" and "mobile phone" are used interchangeably throughout the study. "Mobile money" and "mobile money innovations" are also used interchangeably throughout the study.

developing countries (compared to other regions where just about 2% of GDP transactions are linked to mobile money operations) are growingly taking advantage of services offered by mobile money to send/receive money nationally and internationally, as well as leverage on mobile money services to, *inter alia*, pay for goods and services, receive wages and pay bills (Sy, 2019; Tchamyou, Erregers & Cassimon, 2019). In light of these attendant advantages, mobile money-oriented externalities have been documented to represent an opportunity for developing countries to reach some poverty- and inequality-oriented SDGs. In this light, assessing supply factors that drive mobile money innovations is both scholarly-worthwhile and policy-relevant, especially given that such a focus fills the existing gap in the extant scholarship on financial inclusion.

Thirdly, the closest research to this study in the literature is Lashitew, van Tulder and Liasse (2019), in which the determinants of mobile money innovations in developing countries are investigated. To improve the extant literature, in this study, it is argued that simply providing nexuses between determinants of financial inclusion and financial inclusion is not enough because of policy concerns surrounding the perspective that some drivers of financial inclusion may not be yielding the expected effects on financial inclusion in developing countries (Klapper et al., 2016). Such concerns may arise from the fact that the nexuses between drivers of financial inclusion and mobile money innovations are not linear, as presented and estimated by Lashitew et al. (2019). This study argues that the nexuses could be non-linear such that specific critical masses or thresholds of the underlying drivers determine whether complementary policy mechanisms are needed for the attendant drivers of financial inclusion to have the expected effects on mobile money innovations. Therefore, this research argues that supply factors, such as mobile phone connectivity coverage, mobile connectivity performance, telecommunications sector regulation and unique mobile subscription rate, are not simply linear determinants of mobile money innovations for financial inclusion. By extension, it is also argued that policy makers should be provided with actionable turning points for complementary policies. It follows that the research question being examined by the present research is the following: At what thresholds should supply- oriented drivers of mobile money innovation policies be supported with complementary policies in order to have the anticipated relationships with mobile money innovations that favour financial inclusion?

In order to provide an answer to the above question, this study employs the same dataset and estimation technique (i.e. Tobit regressions) as in the study closest to it (i.e.

Lashitew et al., 2019). Thus, by focusing on interactive regressions instead of understanding drivers of mobile money innovations within the framework of linear additive modeling (i.e. as in Lashitew et al., 2019), this study shows that at certain critical masses of mobile money supply factors, governments of sampled countries should take on board complementary policies in order for the engaged supply factors to favorably affect mobile money innovations for financial inclusion. These established thresholds for complementary policies are as follows: (i) Unique adults' mobile subscription rates of 128.500%, 121.500% and 77.750% for mobile money accounts, the mobile used to send money and the mobile used to receive money, respectively; (ii) the average share of the population covered by 2G, 3G and 4G mobile data networks of 61.250% and 51.833% for the mobile used to send money and the mobile used to receive money, respectively; and (iii) a telecom sector regulation index of 0.409, 0.283 and 0.283 for mobile money accounts, the mobile phone used to send money and the mobile phone used to receive money, respectively.

The rest of the study is organized as follows. In Section 2, insights are provided into the theoretical underpinnings, while the data and methodology are presented in Section 3. The empirical results are disclosed and discussed in Section 4. In Section 5, the study is concluded with policy implications and future research directions.

2. Theoretical underpinnings

It is important to clarify upfront the distinction between mobile banking and mobile money. Accordingly, in the study, the outcome variables are mobile money innovations which entail aspects of mobile banking such as mobile money accounts, the mobile phone used to send money and the mobile phone used to receive money (Firpo, 2009; Lashitew et al., 2019). The theoretical framework underlying the nexuses being examined in the present study can be articulated in three principal strands: (i) how bank accounts and mobile money innovation are connected; (ii) the free market model and (iii) the information asymmetry theory (Asongu, 2020). It is important to note that the first strand is consistent with the unique mobile subscription rate, mobile connectivity performance and mobile connectivity coverage; the second strand is in line with telecommunications (hence telecom) sector regulation while the third strand is consistent with all the four mobile money innovation supply factors considered for the study (i.e. unique mobile subscription rate, mobile connectivity coverage, mobile connectivity performance and telecom sector regulation). These strands are elucidated in the passages below in the same chronology as highlighted.

First, the linkages between mobile money innovations and bank accounts which have been documented by Asongu (2013) and Ondiege (2013) provide the fundamentals that underpin the use of mobile phones in mobile banking, in light of the fact that this study is concerned with mobile money innovations associated with mobile phones. In essence, the notion of mobile banking as considered in the theoretical literature is in accordance with the understanding of innovations in mobile money used in this study, namely: mobile money accounts, the mobile used to send money and the mobile used to receive money. In light of the corresponding literature, four perspectives on the nexus between mobile money innovations and mobile phones can be emphasized. (i) The mobile denotes a virtual bank card via which bank clients and institutions can build upon to mitigate bank costs pertaining to the manner in which traditional bank cards are managed and distributed. Accordingly, given that the mobile is characterised by a subscriber identity module (SIM), such a mobile, reflects a smartcard that can be performant in usage as the virtual bank card. (ii) The point of sale (POS) function is also consistent with the mobile in light of the fact that the mobile phone provides a means of communicating and transacting with banks by providing the latter with complementary channels in the authorization and solicitation of transactions. It is worthwhile to also note that some functionalities pertaining to the traditional bank account can be taken on board with the mobile as it acts as a POS terminal. (iii) The characteristics of the automated teller machine (ATM) are also inherent within the mobile especially in light of the fact that the POS features attributed to mobile phones can be used for the payment and receipt of bills, which is consistent with the mobile money adoption proxies used in the present study. (iv) When a mobile phone is equipped with the internet, it also plays the function of an internet banking terminal given that it enables the user to *inter alia*, easily and instantly have access to a bank account and make payments.

Second, Pradeep (2011) has documented a free-market model which can be used to substantiate the framework of the present study in light of the fact that the model is based on financial exclusion as a consequence of lack of government regulation while the present study uses telecommunications sector regulation as a driver of financial inclusion within the framework of mobile money innovations. Consistent with the free market model, unchecked banking sector deregulation may not only exacerbate concerns about financial exclusion, but also lead to issues in the financial spaces of countries. As argued by Pradeep (2011), there are two main potential avenues that can be the consequence of excessive lack of regulation. One can be an unregulated financial system that fosters existing polarization in society between the financially-included and the financially-excluded. The other entails, the number of groups that

are excluded in society and under circumstances whereby such exclusion is enhanced by more deregulation. Telecom sector regulation which elucidates the degree of deregulation in the telecom sector determines dynamics of competition and market power (or bank concentration) that influence whether more financial access is made possible through mobile money innovations or if banks leverage on their market power to improve their margins of profit instead of fulfilling one of their fundamental missions of enhancing financial access in society.

Third, the information asymmetry theory is a fundamental determinant of financial inclusion or financial access because it is associated with concerns of adverse selection (i.e. ex-ante of the process of borrowing) and moral hazard (i.e. ex-post of the borrowing process). Accordingly, the attendant information asymmetry limits financial access because the lack of sufficient information on the credit history of clients can motivate the bank to increase associated bank charges and interests in order to hedge against the attendant risks (Asongu & Biekpe, 2018). Connecting the theory to the framework of this study, it is argued that information asymmetry concerns can also influence how a client benefits from mobile banking services through the use of a mobile phone that is connected to a formal bank account. In essence, mobile money innovations are not exclusively limited to the informal sector because most banks are now offering options of managing formal bank accounts with a money phone and the externalities of mobile money innovations characterizing mobile banking in the non-formal financial sector are also offered by such mobile banking services associated with the formal banking sector. It is essentially for the purpose of avoiding information asymmetry that information sharing offices in the perspectives of private credit bureaus and public credit registries are being increasingly instituted in developing countries (Kusi, Agbloyor, Ansah-Adu & Gyeke-Dako, 2017; Boateng, Asongu, Akamavi & Tchamyou, 2018; Kusi & Opoku-Mensah, 2018; Asongu & Odhiambo, 2018a). It follows that concerns underlying information asymmetry can influence: (i) the number of bank clients that are offered wide ranging mobile banking services that engender more financial access; (ii) what connectivity networks in terms of coverage and performance are adopted by banks which may endow customers with connectivity depending on their credit histories and (iii) the telecommunications sector regulation can be used to avoid credit risks related to financial access. The underlying three points capture the supply factors of mobile money innovations engaged in this study.

3. Data and methodology

3.1 Data

Consistent with the problem statement being envisaged in the present study, the dataset is in line with that used by the closest studies to this research (Lashitew et al., 2019; Asongu et al., 2020, 2021)[2]. These attendant sources as articulated in Appendix 1 (i.e.which informs the study on the definitions of variables and corresponding sources) include: (i) the World Development Indicators (WDI) of the World Bank; (ii) the World Governance Indicators (WGI) of the World Bank; (iii) Waverman and Koutroumpis(2011); (iv) the Global System for Mobile Communications Association (GSMA); (v) the Financial Inclusion Indices (Findex) database and (vi) the Global Financial Structure Database (GFSD). Hence, consistent with Lashitew et al. (2019) and Asongu, Agyemang-Mintah and Nting (2021), the corresponding data entail averages from 2010 to 2014 and involve all developing countries for which data was available at the time of the study.

The adopted mobile money innovations that are in line with the corresponding mobile money inclusion literature are sourced from the Findex database and include: mobile money accounts, the mobile used to send money and the mobile used to receive money (Lashitew et al., 2019; Asongu et al., 2020, 2021). Three main categories are used for the independent variables of interest and control variables, namely: macro-related, supply and demand factors. Consistent with the problem statement in the previous sections, this study adopts supply factors as the independent variables while the macro-level and demand factors are acknowledged and used as the corresponding control variables.

First, adopted supply variables which are informed by the underlying literature are: (i) telecommunications sector regulation (hence telecom regulation) from Waverman and Koutroumpis (2011); (ii)"gross and unique subscription" rates from the GSMA; (iii) mobile penetration rate from the WDI and (iv) dynamics of mobile connectivity (i.e. mobile connectivity coverage and mobile connectivity performance) from the GSMA. Second, the corresponding demand factors which are from the GFSD are: "percentage of adults with a bank account in a formal banking institution"; the number of automated teller machines (ATMs) and bank sector concentration. Third, the adopted macro-levels variables are from WDI (i.e.urbanization rate, GDP growth and GDP per capita) and WGI (i.e. the rule of law) of the World Bank. It is also worthwhile to articulate that, the above control variables are for the

[2]The study focuses on developing countries because this is the dataset used by Lashitew et al. (2019) (i.e. the study that is being extended) is based on developing countries. In the regression analysis, regional dummies are employed for control for specific regions of developing countries in order not to render "developing countries" all encompassing.

most part, with the exception of bank concentration or market power, expected to boost mobile money innovation,. The choice of attendant control variables is largely informed by the relevant literature on financial inclusion (Mas & Morawczynski, 2009; Waverman & Koutroumpis, 2011; Muwanguzi & Musambira, 2009; Demirguc-Kunt & Klapper, 2012; Demirgüç-Kunt & Klapper, 2013; Gruber & Koutroumpis, 2013; Van der Boor, Oliveira & Veloso, 2014; Demirgüç-Kunt, Klapper & Van Oudheusden, 2015; World Bank, 2016; Tchamyou & Asongu, 2017; Asongu & Odhiambo, 2018b; Asongu & Asongu, 2018; Murendo, Wollni, De Brauw & Mugabi, 2018; GSMA, 2018; Tchamyou, 2019, 2020, 2021). In essence, bank sector concentration is a proxy for market power in the banking industry (De Guevara, Maudos & Pérez, 2005; Ryan, O'Toole & McCann, 2014) and has been documented to limit financial access in developing countries (Asongu, Nwachukwu & Tchamyou, 2016; Asongu & Biekpe, 2018).

Appendix 1 discloses the sources and corresponding definitions of the adopted variables while Appendix 2 focuses on the summary statistics. The correlation matrix is provided in Appendix 3 in which, the concerns about multicollinearity in light of a threshold of 0.600 are highlighted in bold. The choice of the multicollinearity threshold and how it informs the selection of variables used in the specifications is further elicited in the last paragraph of the methodology section.

3.2 Methodology

The empirical strategy adopted by this study is consistent with contemporary literature on mobile money innovations that have adopted similar outcome variables (Lashitew et al., 2019; Asongu, 2020). Accordingly, this attendant literature is on the same wavelength with other strands of economic development literature that have not focused on the mobile money innovations as the outcome variable (Kumbhakar & Lovell, 2000; Koetter & Vins, 2008; Ariss, 2010; Coccorese & Pellecchia, 2010; Asongu & Nwachukwu, 2016; Ajide, Raheem & Asongu, 2019). A common denominator of both strands of research is the position that the Tobit estimation strategy is worthwhile when the dependent variable is captured within the specified minimum and maximum limits.

To put the above narrative into perspective, it is imperative to link the underpinnings to the behavior of the adopted outcome variables in this study. Accordingly, the adopted mobile money innovation variables are practically and theoretically situated between 0% and 100% adoption rate. In essence, as shown in Appendix 2, these variables are defined within the highlighted range, notably: mobile money account ranges from 0.00% to 58.39%, the

mobile phone used to send money varies from 0.00% to 60.48% and the mobile phone used to receive money ranges from 0.00% to 66.65%. It follows that these adopted outcome variables are censored within the range of 0.00% to 100% with the former (latter) being the minimum (maximum) possible value. Given that these attendant variables are censored both in the left-hand and in the right-hand sides, an Ordinary Least Squares (OLS) technique is not tailored to take on board variations in the conditional probabilities of limited observations as may be apparent in countries that reflect 100% adoption rate or 0% adoption rate (Amemiya, 1984). In light of this clarification, it follows that the Tobit regression strategy adopted for this study is consistent with the behavior of the outcome variables because it can censore both sides of the conditional distribution of the corresponding dependent variables. Hence, the double censored Tobit model is used to assess the problem statement of the present study, notably: how enhancing supply factors of mobile money innovations influence financial inclusion and by extension, what corresponding thresholds are relevant for complementary policies.

In light of seminal research pertaining to Tobit estimations (Tobin, 1958; Carson & Sun, 2007), Equations (1) and (2) below reflect the main Tobit estimation process.

$$y^*_{i,t} = \alpha_0 + \beta X_{i,t} + \varepsilon_{i,t}, \qquad (1)$$

where $y^*_{i,t}$ is a latent response variable, $X_{i,t}$ is an observed $1\times k$ vector of explanatory variables and $\varepsilon_{i,t} \approx$ i.i.d. N(0, σ^2) and is independent of $X_{i,t}$. As opposed to observing $y^{*i,t}$, we observe $y_{i,t}$:

$$y_{i,t} = \begin{cases} y^*_{i,t}, \; if \; y^*_{i,t} > \gamma \\ 0, \; if \; y^*_{i,t} \le \gamma, \end{cases} \qquad (2)$$

where γ is a non-stochastic constant. It follows that, the value of $y^*_{i,t}$ is missing when it is less than or equal to γ.

It is also relevant to note that, the following underpinnings are consistent with the Tobit approach: (i) residuals pertaining to the regression strategy are distributed normally and (ii) evidence is apparent of latent dependent variables that are characterised by an unbounded and a linear function of the independent variables of interest (Amemiya, 1984). Moreover, there are two main marginal nexuses linked with the attendant independent variables of interest (i.e. unique mobile subscription rate, mobile connectivity performance, mobile connectivity coverage and telecommunications sector regulation). The first reflects the marginal nexus of the independent variables of the unobserved latent mobile money adoption rate whereas the other reflects the observed and censored rate of mobile money adoption. In light of contemporary mobile money innovation literature closest to the present study (Lashitew et al., 2019; Asongu et al., 2020, 2021), only marginal nexuses related to the censored and observed mobile money innovation adopted rates are provided because in accordance with the attendant literature, the disclosure of these marginal nexuses provide a more worthwhile analytical interpretation.

Before presenting the empirical results, it is also important to note that, the specifications are tailored to address concerns of multicollinearity that were not taken on board by Lashitew et al. (2019), though addressed by subsequent replication research that has built on the same dataset (Asongu et al., 2020, 2021). Following the related studies, a threshold of 0.600 is retained as the critical point used to determine potential concerns of multicollinearity. 0.600 is the average of thresholds from the two contending strands in the multicollinearity literature. Accordingly, Obrien (2007) and Wichers (1975) have posited a 0.500 threshold whereas Kennedy (2008) has argued for a 0.700 threshold. Hence, the retained 0.600 is the average of the two contending thresholds. The corresponding concerns of multicollinearity are highlighted in bold in Appendix 3. It follows that owing to the identified concerns of multicollinearity, in the present study, some combinations of variables, as entered into the same specification in Lashitew et al. (2019), are avoided in the same specifications of this study in light of more contemporary literature that has addressed the concern of multicollinearity (Asongu et al., 2020, 2021). Hence, some variables from Lashitew et al. (2019) are not included in the specifications of this study, *inter alia*: the percentage of adults who have an account at a formal financial institution, GDP per capita and the rule of law.

4. Empirical results

4.1 Presentation of results

The empirical results disclosed in this section are tailored to answer the concern motivating this study, notably, how enhancing each of the four supply factors underlined in Lashitew et al.

(2019) affects mobile money innovations. The attendant findings in Tables 1-2 are provided in four main categories with each table emphasizing two main categories. Table 1 focuses on unique mobile subscription rates and mobile connectivity performance while Table 2 is concerned with mobile connectivity coverage and telecom sector regulation. In either table, each category corresponding to a supply factor entails three main specifications pertaining to each of the mobile money innovation proxies, namely: mobile money accounts, mobile used to send money and mobile used to receive money.

In order to assess the overall incidence of enhancing the supply factors on the corresponding mobile money innovations, net relationships are computed in accordance with contemporary literature on interactive (Asongu & Odhiambo, 2020a, 2020b; Agoba, Abor, Osei & Sa-Aadu, 2019) and quadratic (Boateng et al., 2018; Asongu & Odhiambo, 2020c, 2020d) regressions. To put the computation of the corresponding net relationship into greater perspective, let us consider the second column (i.e. first specification) of Table 1 in which the net relationship of enhancing the unique mobile subscription rate on mobile money accounts is 0.133 ($2\times[-0.001 \times 61.78] + [0.257]$). In this calculation, 0.257 is the unconditional relationship between unique mobile subscription rate and financial inclusion (i.e. mobile money accounts), 61.78 is the average value of unique mobile subscription, -0.001 is the conditional or marginal relationship of unique mobile subscription while the leading 2 corresponds to the quadratic derivation. Following the same computational framework: (i) positive net relationships are apparent from enhancing the unique mobile subscription rate for financial inclusion; (ii) net relationships cannot be computed in regressions pertaining to mobile connectivity performance because at least one estimated coefficient needed for their computation in respective specifications is not significant; (iii) negative net relationships are apparent from enhancing mobile connectivity coverage and (iv) the enhancement of telecom sector regulation also engenders net negative nexuses. Most of the significant control variables display the anticipated signs, *inter alia*, the negative relationship from bank concentration or market power in influencing financial inclusion by means of mobile money innovations and the leading role of Africa in driving mobile money innovations, compared to other continents.

Table 1: Mobile subscription, mobile connectivity performance and financial inclusion

	Dependent variables: Mobile money accounts, Mobile used to send money & Mobile used to receive money					
	Unique Mobile Subscription			Mobile Connectivity Performance		
	Mobile money accounts	**Mobile used to send money**	**Mobile used to receive money**	**Mobile money accounts**	**Mobile used to send money**	**Mobile used to receive money**
Supply Factors						
Unique Mobile Subscription (UMS)	**0.257*** **	**0.243** **	**0.311** **	---	---	---
	(0.005)	**(0.024)**	**(0.020)**			
UMS×UMS	**-0.001*** **	**-0.001** **	**-0.002** **	---	---	---
	(0.007)	**(0.034)**	**(0.024)**			
Mobile Connectivity Performance (MCP)	---	---	---	-0.001	-0.057	-0.056
				(0.988)	(0.617)	(0.666)
MCP×MCP	---	---	---	0.0004	-0.004	**-0.006***
				(0.803)	(0.103)	**(0.060)**
Control variables						
Demand Factors						
ATM penetration	-0.010	**-0.044** **	**-0.056** **	-0.019	-0.020	-0.030
	(0.250)	**(0.024)**	**(0.015)**	(0.133)	(0.253)	(0.159)
Banking sector concentration	**-0.047** **	**-0.036***	**-0.050** **	**-0.054** **	-0.028	-0.038
	(0.021)	**(0.069)**	**(0.037)**	**(0.018)**	(0.207)	(0.143)
Macro-level factors						
GDP growth	**0.550*** **	0.161	0.111	**0.428** **	0.067	-0.009
	(0.001)	(0.423)	(0.668)	**(0.029)**	(0.741)	(0.972)
Urbanization	**-0.044***	-0.019	-0.017	-0.018	0.019	0.033
	(0.094)	(0.570)	(0.671)	(0.470)	(0.648)	(0.521)
Region dummies						
Africa	**8.052*** **	**3.998** **	**5.665** **	**8.170*** **	2.475	**3.776***
	(0.000)	**(0.022)**	**(0.012)**	**(0.000)**	(0.153)	**(0.074)**
Asia	**3.018***	-0.358	0.248	**3.449***	-0.329	0.273
	(0.056)	(0.778)	(0.874)	**(0.060)**	(0.834)	(0.885)
Americas	**5.346*** **	0.011	0.572	**5.612*** **	-1.859	-1.899
	(0.001)	(0.991)	(0.637)	**(0.003)**	(0.200)	(0.236)
Middle East	**6.002*** **	-0.313	0.736	**5.554*** **	-1.939	-1.327
	(0.002)	(0.843)	(0.669)	**(0.006)**	(0.289)	(0.489)
Net Relationship	0.133	0.119	0.063	na	na	na
Thresholds	128.500	121.500	77.750	na	na	na
Observations	132	134	134	129	131	131

GDP: Gross Domestic Product. PPP: Purchasing Power Parity. *,**,***: significance levels of 10%, 5% and 1% respectively. The average value of unique mobile subscription rate is 61.78. The average value of mobile connectivity performance is 11.92..na: not applicable because at least one estimated coefficient needed for the computation of net relationship is not significant.

Table 2: Mobile connectivity coverage, telecom sector regulation and financial inclusion

	Dependent variables: Mobile money accounts, Mobile used to send money & Mobile used to receive money					
	Mobile Connectivity Coverage			Telecom Sector Regulation		
	Mobile money accounts	**Mobile used to send money**	**Mobile used to receive money**	**Mobile money accounts**	**Mobile used to send money**	**Mobile used to receive money**
Supply Factors						
Mobile Connectivity Coverage (MCC)	0.088	**0.245*** **	**0.311*** **	---	---	---
	(0.232)	**(0.005)**	**(0.003)**			
MCC×MCC	-0.0005	**-0.002*** **	**-0.003*** **	---	---	---
	(0.361)	**(0.001)**	**(0.000)**			
Telecom Sector Regulation (TSR)	---	---	---	**20.605** **	**26.164** **	**31.155** **
				(0.013)	**(0.022)**	**(0.014)**
TSR×TSR	---	---	---	**-25.146***	**-46.168** **	**-54.886*** **
				(0.070)	**(0.011)**	**(0.007)**
Control variables						
Demand Factors						
ATM penetration	-0.018	**-0.029***	**-0.042** **	-0.010	**-0.037***	**-0.047** **
	(0.100)	**(0.091)**	**(0.049)**	(0.311)	**(0.061)**	**(0.049)**
Banking sector concentration	**-0.051** **	-0.032	**-0.045***	-0.049	-0.031	**-0.046***
	(0.017)	(0.123)	**(0.070)**	(0.038)	(0.179)	**(0.094)**
Macro-level factors						
GDP growth	**0.423** **	0.131	0.071	**0.677*** **	0.171	0.075
	(0.030)	(0.526)	(0.795)	**(0.000)**	(0.486)	(0.811)
Urbanization	-0.023	0.010	0.018	-0.033	-0.004	0.001
	(0.393)	(0.811)	(0.739)	(0.191)	(0.914)	(0.979)
Region dummies						
Africa	**8.721*** **	2.495	**4.102***	**7.309*** **	2.254	**3.984***
	(0.000)	(0.130)	**(0.051)**	**(0.000)**	(0.174)	**(0.067)**
Asia	**3.724** **	-1.198	-0.693	**2.980***	-1.505	-1.017
	(0.036)	(0.408)	(0.684)	**(0.083)**	(0.307)	(0.561)
Americas	**5.495*** **	-1.670	-1.386	**4.582*** **	-1.181	-0.597
	(0.001)	(0.201)	(0.348)	**(0.005)**	(0.354)	(0.694)
Middle East	**5.558*** **	-2.150	-1.182	**5.928*** **	-1.339	0.451
	(0.006)	(0.224)	(0.514)	**(0.006)**	(0.528)	(0.851)
Net relationship	na	-0.0037	-0.0620	-0.0147	-11.693	-13.851
Thresholds	na	61.250	51.833	0.409	0.283	0.283
Observations	129	131	131	112	116	116

GDP: Gross Domestic Product. PPP: Purchasing Power Parity. *,**,***: significance levels of 10%, 5% and 1% respectively. The average value of mobile connectivity coverage is 62.18. The average value of telecom regulation is 0.41. na: not applicable because at least one estimated coefficient needed for the computation of net relationshipis not significant.

4.2 Extended analysis with thresholds for complementary policies

Despite different tendencies in net relationships as apparent in Tables 1-2, a common denominator in the quadratic nexuses is that in regressions for which net relationships are computed, the unconditional relationships are consistently positive while the corresponding marginal or conditional relationships are also consistently negative. This implies that a Kuznets or inverted U shape nexus is consistently apparent. It also translates the perspective that at a critical mass of the supply factors, the positive unconditional relationship is completely nullified owing to an increasing negative marginal relationship. At the corresponding thresholds or turning points, complementary policies are relevant in order to maintain the unconditional positive relationship between supply factors and financial

inclusion. In other words, promoting the supply factors is a necessary but not a sufficient condition for mobile money innovation once the attendant supply factors have been enhanced to a critical mass or specific threshold.

To put the above notion of threshold into more perspective, let us consider the same example used in the previous section, notably, the first specification or second column of Table 1. Hence, from the example, the corresponding threshold is 128.500 = 0.257/ (2×0.001). It follows that at a 128.500 unique mobile subscription rate (or 128.500 % of adults subscribing to mobile phone), the unconditional positive incidence of unique mobile subscription on mobile money accounts is completely nullified or crowded-out. Using the same framework of computation, complementary policies are needed at the following thresholds in order to maintain the positive unconditional relationship between supply factors and mobile money innovations: (i) Unique adults' mobile subscription rates of 128.500%, 121.500% and 77.750% for respectively, mobile money accounts, the mobile used to send money and the mobile used to receive money; (ii) the average share of the population covered by 2G, 3G and 4G mobile data networks of 61.250% and 51.833% for the mobile used to send money and the mobile used to receive money, respectively; and (iii) a telecom sector regulation index of 0.409, 0.283 and 0.283 for respectively, mobile money accounts, the mobile phone used to send money and the mobile phone used to receive money. The computation of thresholds is consistent with contemporary literature related to interactive (Asongu, le Roux & Tchamyou, 2019) and quadratic (Asongu & Odhiambo, 2020c) regressions literature.

For the established policy thresholds above to make economic sense and be relevant to policy makers, they should be situated within the statistical limits imposed by the summary statistics. After comparing the thresholds with the corresponding maximum and minimum limits imposed by the summary statistics, it is apparent that the attendant thresholds make economic sense and are relevant to policy makers. Accordingly, the established thresholds for unique mobile subscription rate, mobile connectivity coverage and telecom regulation are respectively between "4.23 and 133.64", "8.88 and 99.60" and "0.00 and 0.74" units of the supply factors disclosed in the summary statistics.

5. Concluding implications and future research directions

This study has complemented the extant literature by assessing how enhancing supply factors of mobile technologies affect mobile money innovations for financial inclusion in

developing countries. The mobile money innovation outcome variables are mobile money accounts, the mobile phone used to send money and the mobile phone used to receive money. The mobile technology supply factors are unique mobile subscription rate, mobile connectivity performance, mobile connectivity coverage and telecommunications (telecom) sector regulation. The empirical evidence is based on quadratic Tobit regressions. The following findings are established.

The following overall net nexuses are obtained from the findings: (i) Positive net relationships are apparent from enhancing the unique mobile subscription rate for financial inclusion; (ii) net relationships cannot be computed in regressions pertaining to mobile connectivity; (iii) negative net relationships are apparent from enhancing mobile connectivity coverage; and (iv) the enhancement of telecom sector regulation also engenders net negative nexuses.

The Kuznets or inverted U-shaped nexuses that are significant in three of the four supply factors have motivated an extended analysis to establish supply factor thresholds for complementary policies which are as follows: (i) Unique adults' mobile subscription rates of 128.500 %, 121.500 % and 77.750 % for mobile money accounts, the mobile used to send money and the mobile used to receive money, respectively; (ii) the average share of the population covered by 2G, 3G and 4G mobile data networks of 61.250% and 51.833% for the mobile used to send money and the mobile used to receive money, respectively; and (iii) a telecom sector regulation index of 0.409, 0.283 and 0.283 for mobile money accounts, the mobile phone used to send money and the mobile phone used to receive money, respectively. The computed thresholds for complementary policies make economic sense and are policy-relevant because they are within the statistical ranges disclosed in the summary statistics. Moreover, at the attendant thresholds, the engaged mobile technology supply factors become necessary, but not sufficient conditions in mobile phone innovations for financial inclusion. Hence, at the established thresholds, complementary policies should be taken on board.

Some of the complementary policies could be tailored along the lines of, *inter alia*, (i) moving up the value chain of the financial services; (ii) engaging in more digital inclusion and innovation; and (iii) considering financial technologies (i.e. fintechs) beyond financial services (Sy, 2019). First, moving up the value chain of financial services may improve the importance of the supply factors at the established thresholds because it allows for innovations in terms of opening up savings accounts, taking up loans, purchasing insurance,

investing in the securities of government and borrowing electricity with mobile phone applications. Secondly, greater digital innovation and inclusion are also worthwhile, especially when at the established critical masses, and transitions from fintech services to the digital economy can be accelerated. In this view, such digital economic innovations are likely to spur economic prosperity that is accompanied by jobs and other positive development externalities. For these to materialize, the right policies that provide the relevant infrastructure (*inter alia*, electricity and the Internet) and a good regulatory framework that adapts with changes to mobile money innovations, are worthwhile. Thirdly, fintech related to mobile money innovations should go beyond financial services such that entrepreneurs and policy makers should consider fintechs beyond the more restricted scope of financial services. Accordingly, engaging untapped resources and increasing productivity, *inter alia*, can engender economic prosperity and structural transformation that require the use of mobile money services for more economic activities.

The findings in this study obviously leave room for future research regarding how complementary policies can be taken on board by policy makers when supply factors of mobile money innovations have reached certain thresholds. Moreover, as more data become available, reconsidering the established nexuses within causal empirical frameworks is worthwhile in order to inform policy makers about findings that are not robust exclusively from the perspective of relationships, but which can also be extended to causalities.

It is also relevant to point out that this study is an extension of Lashitew et al. (2019); hence, the dataset shared by the authors of the study being extended has only telecom regulation as a proxy for regulatory framework. This has a number of shortcomings which should be considered in future research. For instance, the regulatory framework governing mobile money is broader than telecom regulation, because, *inter alia*, payments regulation and law, as well as electronic money regulation (which are largely issued by Central Banks) articulate some principal requirements that are applicable to mobile money and associated innovations. Moreover, in considering the dynamics of competition and market power, as discussed in Section 2, telecom sector regulation, as well as cross-sectoral competition regulation/law has some relevance. Hence, in light of these caveats, telecom sector regulation should not be exclusively considered in future studies.

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Appendices

Appendix 1: Definitions and sources of variables

Variables	Descriptions	Sources
Dependent variables		
Mobile Accounts	Percentage of adults who have personally used mobile phone to pay bills, send or receive money in the past 12 months using a GSMA recognized mobile money service	Financial Inclusion Indices (Findex) database
Sending Money	Percentage of adults who used a mobile phone to send money in the past 12 months	
Receiving Money	Percentage of adults who used a mobile phone to receive money in the past 12 months	
Demand factors		
Account at formal financial institution	Percentage of adults who have an account at a formal financial institution	Global Financial Structure Database (GFSD)
ATM access	Number of ATMs per 100,000 people	
Banking sector concentration	The percentage share of the three largest commercial banks in total banking assets	
Supply factors		
Mobile phone penetration - Gross & unique subscription rates	Gross mobile subscription rates refer to the percentage of adults in a country with subscriptions to mobile phones based on data from WDI. We used additional data from GSMA (2014) to calculate unique mobile subscription rates by correcting for double SIM-card ownership, which differs between rural and urban areas. This correction is based on survey evidence that urban and rural users own 2.03 & 1.18 active SIM-cards respectively.	World Development Indicators (WDI), GSMA
Mobile connectivity quality	Measures the average speed of uploading and downloading data through mobile network in 2014 &2015.	GSMA
Mobile connectivity coverage	Measures the weighted average of share of population covered by 2 G, 3 G and 4 G mobile data networks (normalized to range between 0 and 100).	GSMA
Telecom regulation	Measures the regulatory quality of the telecom sector in terms of four major criteria: transparency, independence, resource availability, and enforcement capability of the regulator. The index is based on dozens of indicators taken from the International Telecommunication Union's regulatory database.	Waverman and Koutroumpis (2011)
Macro-level factors		
Rule of Law	A measure of the extent to which agents have confidence in and abide by the rules of society	WGI
GDP per capita	GDP per capita in purchasing power parity	WDI
GDP growth	The rate of total GDP growth	WDI
Urbanization rate	Percentage of population living in urban areas	WDI

Notes: Mobile Accounts is based on the second wave of the survey (2014) and Sending Money and Receiving Money are based on the first wave (2011). The variablestelecom regulation is based on data for 2011. The two variables measuring mobile connectivity are based on average values for the years 2014 & 2015. For the remainingvariables, averages are taken over the years 2010–2014 to smooth out potential year-to-year variations.

Appendix 2: Summary Statistics

Variables	Mean	S.D	Min	Max	Obs
Dependent variables					
Mobile accounts (%)	3.30	7.90	0.00	58.39	145
Sending money (%)	3.10	7.58	0.00	60.48	146
Receiving money (%)	4.47	9.58	0.00	66.65	146
Demand factors					
Account at formal fin. Institution (%)	45.72	31.73	0.40	99.74	147
ATM penetration	43.28	45.03	0.33	279.71	148
Banking sector concentration	71.94	20.70	9.49	100.00	143
Supply factors					
Unique mobile subscription rate	61.78	23.29	4.23	133.64	199
Mobile connectivity (performance)	11.92	14.69	0.04	67.19	147
Mobile connectivity (coverage)	62.18	27.29	8.88	99.60	147
Telecom regulation	0.41	0.17	0.00	0.74	128
Macro-level factors					
GDP per capita (PPP)	17,874	19,677	648	132,468	152
GDP growth	3.90	2.82	-4.92	11.10	153
Rule of Law	-0.09	1.01	-2.42	1.98	157
Urbanization (%)	58.22	22.85	8.81	100	155

Notes: The average values for the dependent variables are calculated across all countries, including those in which mobile money services are not available.

Appendix 3: Correlation matrix

	Mobile inclusion variables			**Demand Factors**			**Supply Factors**				**Macro-level Factors**				**Region dummies**			
	MMA	SendM	Receiv.M	BankAc	ATM Pen	BankSC	UMSr	MCP	MCC	TSR	GDPpc	GDPg	RL	Urban	Africa	Asia	Americas	Middle East
MMA	1.000																	
Send M	0.640	1.000																
Receiv.M	0.597	0.980	1.000															
Bank Ac	-0.292	-0.227	-0.266	1.000														
ATM Pen	-0.319	-0.248	-0.279	**0.708**	1.000													
BankSC	-0.079	-0.028	-0.026	0.051	-0.171	1.000												
UMSr	-0.237	-0.116	-0.142	0.411	0.305	-0.045	1.000											
MCP	-0.320	-0.272	-0.300	**0.821**	**0.779**	-0.053	0.270	1.000										
MCC	-0.385	-0.300	-0.323	**0.815**	**0.701**	-0.091	0.525	**0.780**	1.000									
TSR	-0.088	-0.070	-0.067	0.549	0.363	-0.008	0.237	0.466	0.473	1.000								
GDPpc	-0.420	-0.209	-0.228	**0.825**	**0.690**	-0.078	**0.644**	**0.729**	**0.872**	0.535	1.000							
GDPg	0.376	0.189	0.176	-0.532	-0.481	-0.058	-0.300	-0.477	-0.527	-0.433	-0.553	1.000						
RL	-0.271	-0.273	-0.308	**0.850**	**0.623**	0.040	0.374	**0.838**	**0.772**	**0.605**	**0.772**	-0.457	1.000					
Urban	-0.396	-0.212	-0.220	0.566	0.567	-0.051	0.364	0.598	0.731	0.349	**0.788**	-0.381	0.583	1.000				
Africa	0.533	0.415	0.444	-0.558	-0.519	0.123	-0.462	-0.487	**-0.681**	-0.288	**-0.683**	0.407	-0.418	-0.560	1.000			
Asia	-0.101	-0.076	-0.088	0.087	0.077	-0.009	-0.013	0.153	-0.006	-0.129	0.007	0.244	0.014	-0.075	-0.199	1.000		
Americas	-0.098	-0.116	-0.095	-0.176	-0.016	-0.004	0.092	-0.198	-0.029	0.001	0.045	0.025	-0.221	0.158	-0.268	-0.278	1.000	
Middle East	-0.086	-0.072	-0.082	-0.0001	0.047	0.019	-0.010	0.035	0.124	-0.131	0.140	0.040	0.017	0.237	-0.101	-0.105	-0.141	1.000

MMA: Mobile Money Accounts. Send M: Sending Money. Receiv M: Receiving Money. Bank Ac: Bank Accounts. ATM Pen: ATM Penetration. BankSC: Bank Sector Concentration. UMSr: Unique Mobile Subscription rate. MCP: Mobile Connectivity Performance. MCC: Mobile Connectivity Coverage. TSR: Telecom Sector Regulation. GDPpc: Gross Domestic Product per capita in PPP (in logs). GDPg: GDP growth. RL: Rule of Law. Urban: Urbanization.

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