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Asymmetric threshold effects of digitization on inflation in emerging markets

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Abstract

This paper analyzes the dynamic asymmetric effects of digitization on domestic inflation for a sample of 54 advanced economies (AEs) and emerging markets (EMs) over the period 2004–2018. Using Katz and Calorda's Digital Ecosystem Development Index and employing the system Generalized Method of Moments (GMM) estimation methodology, the results of the paper reveal that the improvement in digitization has a statistically significant nonlinear deflationary effect with an exact threshold level of 43.22 points, that is, that the marginal effect of the digital penetration is larger when its level is lower than the threshold level. For EMs, with a level of digitization below the average of our full sample, policymakers must continue to invest in and expand on their digital ecosystem until the threshold level is achieved. Our results show that investment in human capital and improvement in governance can reinforce these deflationary effects. Hence, to obtain the maximum positive impact of increasing digitization on domestic inflation, EM governments should focus on maximizing school enrollment, controlling corruption, establishing rule of law, protecting the right to freedom of opinion and expression, and implementing accountability measures.

Keywords: Inflation, Digitization, System GMM, Advanced economies, Emerging markets

JEL Classification: C23, G21, O47

Introduction

In recent years, digitization has emerged as one possible explanation for the low and stable inflation trend in both emerging markets (EMs) and advanced economies (AEs), especially since the Great Recession. Digitization—including Internet of Things (IoT), big data analytics, machine learning, blockchain, artificial intelligence and beyond—is unquestionably transforming industries worldwide. In the United States alone, the digital economy grew at an average annual rate of 5.6% from 2006 to 2016, almost 4 times higher than 1.5% growth rate for the overall economy (Bureau of Economic Analysis 2018). It seems increasingly possible that the rapid digitization is influencing inflation in several ways, most notably, by enhancing productivity and lowering marginal costs, which might lead to lower inflation.

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Since the Great Recession, two major trends in inflation, particularly affecting AEs around the world, have been documented extensively in the economic literature. First, inflation remained higher than expected and quite stable in the Great Recession's immediate aftermath (International Monetary Fund IMF 2018; Coibion and Gorodnichenko 2015). Researchers refer to this phenomenon as the "missing disinflation," because, in light of higher unemployment and reduced consumer confidence and demand, a global recession would normally have lowered the prices of goods and services. Second, inflation, particularly core inflation, seems to have remained consistently below the central banks' targets in those years (Bhatnagar et al. 2017).

While surprising, the low and stable inflation trends are not necessarily new phenomena. Economists started noticing a potential "flattening" of the Phillips Curve in AEs in the mid-1970s (Kuttner and Robinson 2010). That is, the downward-sloping relationship between inflation and unemployment had already weakened before the Great Recession. Many explanations have been given for this. Some have argued that central banks have simply done a better job at communicating essential information and thus anchoring people's inflation expectations, which affect the level of inflation (Williams 2006). Others have argued that lower inflation is a result of globalization and an ever-expanding global supply chain (Borio and Filardo 2007). But given the overwhelming evidence that digitization contributes to economic growth (Katz and Callorda 2020), it might also influence other macroeconomic variables, including inflation.

The adoption of digital tools in the workplace transforms transactions and increases efficiency in communication and production, and technological advances across sectors and industries—from agriculture and manufacturing to IT—in return create new jobs. In EMs, the OECD (2019) estimated that an additional 10% of internet usage contributes 1.17 percentage points to the gross domestic product (GDP). Such digitization digitization can lead to greater efficiency and productivity gains in the economy, as it allows for faster and easier communication, automation of tasks, and access to more data. This can lead to lower production costs and lower prices for consumers, which can reduce inflationary pressures (Csonto 2019). As well, online shopping and price comparison websites can increase competition among retailers, leading to lower prices (Cavallo et al. 2014; Cavallo 2017). The rise of digital currencies and payment systems can also change the way people save and spend money, potentially affecting the money supply and therefore inflation (Bordo and Levin 2018; Fernandez-Villaverde and Sanches 2019). Digitization can affect the labor market by altering the demand for certain types of jobs and skills. This can lead to changes in wages and employment levels, which can affect inflation (Bresnahan, et al. 2002; Acemoglu and Restrepo 2018). For example, if digitization leads to the automation of certain tasks, it can reduce demand for certain types of labor and put downward pressure on wages and prices. Digitization can also affect the financial sector, potentially changing the availability and cost of credit and other financial products. This can affect the overall level of economic activity and, therefore, inflation (WEF 2018; Emara 2022).

The effects of digitization on inflation may not be even across AEs and EMs because of their differing inflation dynamics. Specifically, as shown in Fig. 1 inflation is usually higher and considerably less stable in EMs than in AEs (Barefoot et al. 2018). While the average inflation rate for EMs approaches 12% in 2008 and drops as low as 1% in 2015,

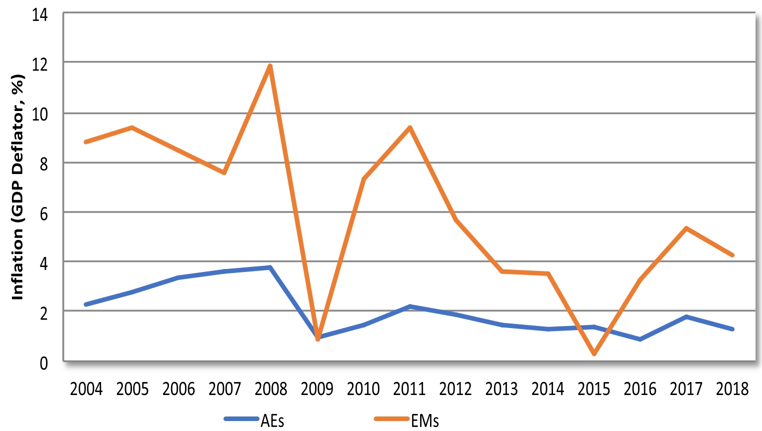

Fig. 1 Average inflation (GDP deflator)

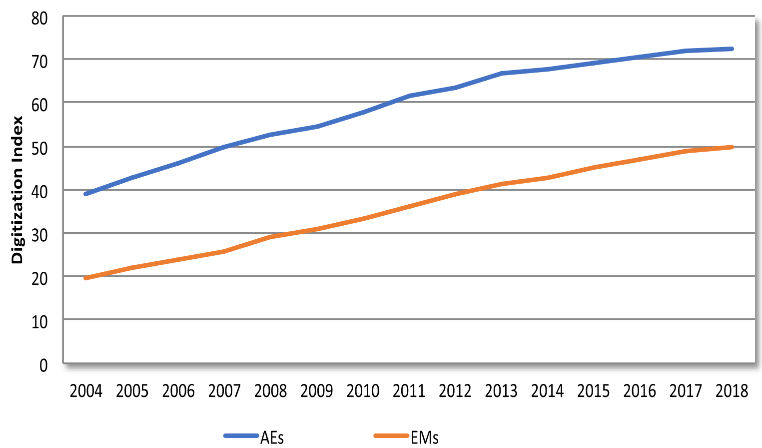

Fig. 2 Average digitization

the average inflation rate in AEs never increases above 4% and remains relatively stable throughout the years.[1] These differences may also create a difference in the impact of digitization on domestic inflation. For instance, the weaker institutions and lower qualify of human capital in EMs may mean that it is impossible to combat inflationary pressures by the means available in AEs, and thus reduced marginal costs and enhanced productivity for businesses in EMs, which digitization produces, has a greater effect. At the same time, the level of digitization itself is lower in EMs than in AEs. As seen in Fig. 2 below, the average digitization levels in AEs and EMs follow a similar trend over the years: they both increase significantly from 2004 to 2018, and the increases seeming to flatten out toward the end of the period.

The impact of digitization on inflation is a complex issue that can be influenced by various factors, including the level of education and the quality of governance. On one hand, higher levels of education can lead to a more skilled workforce that is better equipped to take advantage of the efficiencies that digitization can provide, potentially

[1] The IMF identified two possible explanations for EMs' more unstable and higher inflation in the 2018 World Economic Outlook Report. First, a higher proportion of overall consumption in EMs consists of food and other similar commodities, and prices of these goods tend to be more volatile than those of other products (IMF, 2018). Second, the central bank may have less ability to control inflationary pressures when they arise because monetary policy and economic institutions overall tend to be less developed, reliable, and consistent in EMs (IMF, 2018).

leading to lower inflation (Wardana, et al. 2023; Reddy et al. 2023). On the other hand, good governance can help ensure that digitization delivers its potential benefits in terms of increased competition, improved productivity, and better information for consumers, which can help reduce inflation. However, poor governance can limit these benefits and even contribute to inflation (Ben Ali 2022c, a, b; Sassi and Ben Ali 2017).

Economists have long theorized the impact of major macroeconomic factors on domestic inflation. Nevertheless, the literature on the impact of digitization as an important determinant for lower and more stable inflation in EMs is very thin. Hence, our aim in this study is to fill the gaps in the literature by studying the impact of digitization on domestic inflation, exploring the functional form of this digitization-inflation link, and analyzing whether the level of education and good governance in EMs reinforces this link. To do so, our study explores four research questions: (1) What is the effect of digitization on domestic inflation? (2) Is the effect different in EMs than in the full sample? (3) Is this relationship linear or non-linear? (4) What is the potential role of policy complementarities in the digitization-inflation link including good governance and high levels of education enrollment?

The rest of the paper is organized as follows: Sect. "Literature review" presents a literature review on inflation and digitization, Sect. "A simple theoretical model" presents a simple theoretical model, Sect. "Data" describes our data set, Sect. "Estimation methodology" explains our estimation methodology, "Estimation results" section includes a description and interpretation of our estimation results, "Robustness check" section includes robustness checks on our estimation methodology, and "Conclusion and policy Implications" section provides concluding remarks and policy implications. References details can be found in reference section, while the appendix appears at the end of the paper and includes additional tables referenced, but not otherwise included, throughout the paper.

Literature review

Economists have long theorized and analyzed the relationship between inflation and other major macroeconomic factors. The traditional Phillips Curve establishes a downward-sloping relationship between the level of the inflation and the unemployment rate: as unemployment increases, inflation decreases. The accelerationist version of the Phillips Curve establishes a relationship between the unemployment or output gap and the change of rate in inflation. Valadkhani (2014) finds that the output gap positively influenced inflation in Canada, the UK, and the US between 1970 and 2013. More recently, Jasova et al. (2020) use a New-Keynesian Phillips Curve model on a panel of both AEs and EMs from 1994Q1 to 2017Q4. They found that both domestic and global output gaps are significant drivers of inflation before and after the Great Recession, especially for countries targeting inflation.[2]

However, research has increasingly questioned whether the Phillips Curve still holds today, especially in AEs such as the United States, where inflation has remained remarkably low, even when unemployment was low and decreasing. Kuttner and Robinson (2010) identified empirical evidence in support of a "flattening" of the Phillips Curve hypothesis, a potential weakening of inflation's sensitivity to the output (or

[2] see also Svensson (1999) and Gerlach and Svensson (2003).

unemployment) gap. The IMF (2013) also found evidence that inflation has indeed become less responsive to unemployment than in the past—in AEs. While Jasova et al. (2020) found a significant decline in the impact of domestic output gaps on inflation in AEs, they found no empirical evidence in support of a flattening of the Phillips Curve hypothesis when estimating the New-Keynesian Phillips curve for EMs.

Other major macroeconomic factors that influence inflation—such as inflation expectations, the exchange rate, and globalization—have become increasingly important over time, potentially further altering traditional Phillips Curve dynamics. The expectations-augmented Phillips Curve predicts that inflation expectations for the next time period also affect the present level of inflation—that is, that an increase in inflation expectations leads to an increase in the actual rate of inflation. Many have suggested that a framework of inflations expectations explains recently observed inflation dynamics. Bernanke (2010), for instance, argued that better anchored inflation expectations explain the relatively low and stable inflation which has been observed in many countries around the world, and that the fact that people expect inflation to remain relatively constant throughout time muted any effect of the Great Recession on inflation rates. The IMF (2013) concurred that better anchored inflation expectations has strengthened the relationship between past and current levels of inflation.

Most importantly and relevant for our study, inflation expectations play a particularly important role in determining domestic inflation in EMs, where inflation is higher and generally less stable than in AEs. Domestic factors, and not global ones, are the most important determinants of domestic inflation in EMs, and inflation expectations are a key determinant. In 2018, the IMF, which has done considerable work in the area of EMs, found evidence that inflation expectations affect both the level of and the variation in inflation.

Moreover, consistent with the New Keynesian Phillips Curve, research demonstrates a strong relationship between lagged inflation and the current inflation rate. For instance, using a panel regression model, Csonto et al. (2019) found a significant positive effect of lagged inflation on current inflation rate. However, endogeneity inevitably poses a concern when it comes to the Phillips Curve estimates with lagged inflation. Accordingly, Hondroyiannis et al. (2007) use GMM estimation for the New Keynesian Phillips Curve; they similarly find a highly significant and positive effect for lagged inflation. Nevertheless, when using time varying coefficient (TMV) estimation, they find that the "role of lagged inflation in the NKPC [New Keynesian Phillips Curve] is spurious."

Bailliu et al. (2003) analyze the nominal exchange rate, another potentially important determinant of inflation in EMs, in a study focusing on inflation determinants in Mexico, an emerging market, after it adopted a floating exchange rate regime. Based on their hypothesis that nominal exchange rate affect inflation mainly by influencing the prices of imports, Bailliu et al. (2003) found that a one-percent exchange rate depreciation increased inflation by 0.34%.

Relatedly, oil prices have a positive and significant effect on inflation. Choi et al. (2018), for instance, found in their analysis of a panel of 72 advanced and developing economies around the world from 1970 to 2015 that a 10% increase in global oil inflation causes a rise in domestic inflation by 0.4 percentage points. Mukhtarov et al. (2019) also find that oil prices have positive effects on inflation over the long term in Azerbaijan: a 1%

increase in oil prices leads to a 0.58% increase in inflation. Similarly, the study of Kamber and Wong (2020) reports commodity price shocks largely drive inflation gaps and that inflation targeting might have reduced the role of foreign shocks in the overall trends of inflation.

A robust analysis of digitization's role in new inflation dynamics has not yet occurred. This is in part because, while it is broadly accepted that digitization has impacted every aspect of human life worldwide, especially economic aspects, the exact impact of digitization on a given economy is notoriously difficult to measure. In addition to a lack of exact measurement of digitization, it has no universal definition (Barefoot et al. 2018). The most comprehensive measure of digitization, to our knowledge, is theba one we use here, Katz and Callorda's Digital Ecosystem Development Index (2018; 2020a).

Recent attempts to formally measure the impact of digitization on various aspects of the economy have offered significant empirical evidence that increases in digitization have positive effects on economic growth. For instance, using their index, Katz and Callorda (2018) show that an increase of 1% in the digitization index leads to a 0.13% growth in GDP per capita in a panel of 73 countries from 2004 to 2015. More recently, the same researchers' (2020b) study of the impact of digitization on the economy of the Arab States region over the period from 2010 to 2017 found that a 10% increase in penetration of mobile broadband led to a 1.81% increase in GDP per capita, while a 10% increase in the digitization index led to a 2.49% rise in GDP per capita. Similarly, Emara and Katz (2023) found that in the structural model, increased penetration of mobile unique subscribers and mobile broadband-capable devices significantly contributed to Egypt's GDP growth from 2000 to 2019. A 1% rise in these penetrations was associated with a 0.172% and 0.016% increase, respectively, in average annual GDP growth.

By contrast the impact of digitization on inflation is a relatively underexplored topic. Yi and Choi (2005) test the hypothesis that the Internet can lead to lower inflation through improved productivity; using panel data from 1991 to 2000, they find that increasing the Internet users-to-population ratio has a significantly negative effect on the inflation rate. However, Internet usage is just one of many complex aspects of digitization. Csonto et al. (2019) used the number of existing IP addresses in a country as a proxy to quantify the extent of digitization and conducted a panel study to analyze the impact of digitization on inflation using sample of 36 AEs and EMs. Using a traditional Phillips Curve, they found that a 1% increase in the extent of digitization lowers inflation by 0.006%. Regarding the mechanism behind these results, the paper concluded that digitization impacts inflation mainly through a cost-productivity channel.

Chao et al. (2021) developed a consensus model that could gather diverse opinions on how digitization impacts inflation, providing a comprehensive understanding of this relationship. This understanding is further enhanced by the work of Kou et al. (2021b), who showed that the use of digital data sources in bankruptcy prediction models could influence inflation through increased efficiency and new business models.

Building on this, Kou et al. (2021a) discussed how Fintech solutions, such as payment and money transferring systems, could lead to cost savings and competitive pricing, potentially impacting inflation. Finally, Li et al. (2022) demonstrated that digitization of financial data analysis could reveal economic trends and behaviors influencing inflation, tying together the insights from the previous studies.

However, evidence on the topic is somewhat mixed. For example, a study of the possible disinflationary effects of digitization in Canada found no conclusive evidence (Charbonneau et al. 2017). The study's authors argue that this result might be due to the fact that the so-called "digital economy" is an insignificant part of the Canadian economy overall. For instance, only a very small share of retail sales was online. Additionally, there essentially is an oligopoly in telecommunications in Canada, which might be working to keep the prices up, or at least prevent them from dropping, thereby outweighing any potential downward effects of digitization on inflation (Charbonneau et al. 2017).

Overall, past findings suggest the impact of digitization on inflation depends on a range of factors, including the level of education and the quality of governance. On one hand, high levels of education contribute to lower inflation rates by improving human capital, enhancing productivity, and reducing information asymmetries. In addition, education can increase public awareness of inflation and its causes, which can lead to more informed policy-making and better inflation outcomes (Reinsdorf 2022). Education can also play an important role in the digitization-inflation link. Higher levels of education can lead to greater digital literacy and more effective use of digital technologies, which can contribute to improvements in productivity and reduced inflationary pressures (Wardana, et al. 2023; Reddy, et al. 2023).

On the other hand, good governance is essential for economic growth and development.[3] It can help to reduce corruption and improve policymaking, which can contribute to lower inflation rates. In contrast, poor governance can lead to mismanagement of fiscal and monetary policy, which can contribute to higher inflation rates (Ben Ali and Sassi 2017; Sabir, et al. 2019; Emara and Rebolledo 2021; Emara and El Said 2021; Ben Ali 2022a, b, c). For example, using panel data for a sample of developed and developing countries over the period 1991 to 2007, Salahodjaev and Chepel (2014) show that the improvement in the quality of governance has a statistically significant impact in reducing inflation rates. Likewise using a panel system-GMM on a sample of 160 countries over the period 1960 to 1999, Aisen and Veiga (2008) showed that political instability, social polarization, and lower levels of democracy are associated with more inflation volatility. Along the same lines, using cross-sectional data of 70 countries covering the 1980's, Cukierman (1992) found a positive association between unstable and polarized political system and inefficient tax structures, and hence, more seigniorage and inflationary pressure.

Studies have also looked at the relationship between inflation and corruption. Ben Ali and Sassi (2016), for example, studied a variety of measures of corruption of 100 developed and developing countries covering the period 2000 to 2017 and found all had a significant, positive correlation with inflation. Corrupt governments often find sources of revenue that lead to higher monetary expansion, such as seigniorage. The greater money expansion contributes to higher inflation rates under these governments. Ben Ali and Sassi (2016) also found corruption has a disparate impact on inflation in different regions, which can be understood through differences in stable institutions in developing nations.

[3] see for example, Ullah et al. 2022b; Mehanna et al. 2010; Emara and Jhonsa 2014; Emara and Chiu 2016; Han et al., 2014; Ullah et al. 2021; Ullah et al. 2022a.

Digitization has many positive impacts on different economic sides such as education, corruption, democracy, and economic development, including inflation. Digitization has had a significant impact on education in recent years. The widespread adoption of digital technologies and the internet has changed the way people access, consume, and create educational content (Pettersson 2021; Haleem et al. 2022). More digitized economies are correlated with more banking stability and less corruption, due to the automation of banking (Ben Ali 2022a, b, c; Ben Ali and Diallo 2022). Similarly, digitization can result in a decline in levels of corruption with quality legal enforcement in place (Ben Ali and Sassi 2017). Likewise, digitization, through information and communication technology (ICT) diffusion can act as a mechanism to control corruption (Ben Ali 2017). Digitization can also lead to an increase in the level of democracy, and that as more individuals are connected to ICT, digitization has increased effectiveness in promoting democracy (Ben Ali 2020a, b). Additionally, digitization can lead to economic growth, can impact inequality, can drive socioeconomic wellbeing, and can support financial inclusion (Swaleheen et al. 2019; Hasan, et al. 2021; Ben Ali 2022a, b, c).

Some studies have suggested that the effect of ICT on economic growth or productivity may follow a non-linear functional form. As the level of ICT adoption increases, the level of economic growth increases; however, the effect diminishes at higher levels of adoption (Lang 2009; Hawash and Lang 2010; Vu 2011; Emara and Zhang 2021). This may be due to diminishing returns to ICT investment or that fully realizing the benefits of ICT requires the presence of complementary factors such as good governance or high quality of human capital. Other studies have found evidence of an inverted U-shaped relationship between ICT measures and economic growth or productivity, where ICT has a positive effect on growth or productivity peaks at a certain level of ICT adoption and then declines beyond that point (Albiman and Sulong 2017; Emara and Zhang 2021). This may be due to factors such as technology spillovers, the availability of complementary resources or skills, or the presence of network effects. Yet to the best of our knowledge, no previous studies have explored whether digitization and inflation reflect a non-linear relationship, a gap this study addresses.

A simple theoretical model

This section presents a theoretical model to show the multiple channels through which inflation affects digitization. Charbonneau et al. (2017) describe three main channels: First, digitization is likely to enhance productivity and lower operational costs for firms. Second, digitization can change the overall market structure—on the one hand by diminishing barriers to entry for new firms, for whom technology is more readily available than ever before, but on the other hand by allowing mega-companies like Amazon and the like to emerge and dominate the market. The third, and the most direct mechanism is that digitization can directly cause a decline in the prices of telecommunications or information goods and services.

In line with Rudd and Whelan (2007), Charbonneau et al. (2017) and Coffinet and Perillaud (2017), Csonto et al. (2019) present a simple New Keynesian type Phillips curve model that relates our study variables with a firms' objective in minimizing the deviation of their prices from optimal levels. The model assumes that labor is the only factor of production in a Cobb–Douglas production function setting and combines the general formulation of prices changes in standard models of price stickness with the equation of prices as a markup over marginal cost. Hence, the optimal levels of inflation are determined by Eq. (1) as follows[4]:

$$\pi_t(d) = \left(1 - \frac{\beta}{1-\alpha}\right)\pi_t(d) + \frac{\beta}{1-\alpha}E_t\pi_{t+1}(d) + \frac{\alpha(1-\phi)}{(1-\alpha)\phi}\widetilde{y}_t(d) - \frac{\alpha}{(1-\alpha)\phi}\widetilde{a}_t(d) + \frac{\alpha}{(1-\alpha)\phi}\left(\widetilde{w}_t(d) - \widetilde{p}_t(d)\right) + \frac{\alpha}{(1-\alpha)}[(\mu_t(d) - \nu_t(d))] \tag{1}$$

In line with the New Keynesian type Phillips curve model, the above model presents the multiple channels through which digitization affects inflation. These channels are the inflation expectations, $\frac{\beta}{1-\alpha}E_t\pi_{t+1}(d)$, the output gap, $\frac{\alpha(1-\phi)}{(1-\alpha)\phi}\widetilde{y}_t(d)$, the technology, $\frac{\alpha}{(1-\alpha)\phi}\widetilde{a}_t(d)$, the real return of production, $\frac{\alpha}{(1-\alpha)\phi}\left(\widetilde{w}_t(d) - \widetilde{p}_t(d)\right)$, the price markup over marginal costs, $\frac{\alpha}{(1-\alpha)}\mu_t(d)$, and the labor mark-up, $\frac{\alpha}{(1-\alpha)}\nu_t(d)$. Also, d stands for the degree of digitization in the economy. The parameter α refers to the Cobb–Douglas elasticity of labor demand, β refers to the intertemporal discount factor, and ϕ is the demand elasticity of substitution across different variety of goods.

The productivity channel and the lower barriers to entry hypothesis both seem especially relevant to our study and the case of EMs specifically. Indeed, as mentioned above, the integration of the IoT alone in EMs has the potential to lower costs of production significantly. EMs are usually experiencing rapid growth, or at least many simultaneous structural changes. While they often no longer rely on agriculture as their main productivity sector, many industries and sectors, just like many institutions—political or economic—may not yet be fully developed in EMs. Digital platforms and advanced technologies, now readily available, help facilitate access to information, goods, and services—not just from one's country, but from around the world, thereby expanding these countries' exposure to and integration in the global economy. They also make it significantly less expensive and difficult for many new businesses to emerge, and for market competition to grow, which could in theory lower prices.

Most of the research in economic growth focusing on the endogenous growth models started in the early 1990s. These models basically assume that growth arises from human capital accumulation. The endogenous growth models were found to be important for analyzing the different government policy measures on long run growth in the economy. Lucas (1988), Romer (1990), and Rebelo—with (1990), and without King (1991)—were among the first economists to analyze the long-run implications of these models on economic growth. Hence, in line with the endogenous growth theory models, it is safe to assume that investment in human capital and improvement in governance affect digitization and hence inflation through their impact on labor productivity, a_t, and output,y_t, as presented in Eq. (1). More specifically, improvement in either human capital or governance is expected to have deflationary effects either directly through the impact on increasing the level of output or indirectly through their impact on increasing labor productivity.

[4] Where the tilde represents deviations from equilibrium.

Data

This study draws on a panel data set on a sample of 54 AEs and EMs over the period 2004–2018.[5] Table 1 of the Appendix provides a list of all the abbreviations used in our study and Table 2 provides the list and classifications of countries in our data set. The data on all relevant macroeconomic variables are collected from the World Development Indicators (WDI) database. Tables 3 provides the definition and sources of all variables. We included data on the annual inflation rate using the GDP deflator expressed as percentages. Additionally, we included data on the exchange rate of every country, expressed as local currency to US dollar ratio, foreign direct investment net inflows, expressed as a percentage of GDP, and pump gasoline (*oil*) prices, expressed in US dollars. For the output gap variable, we followed Hodrick and Prescott (1997) and Corbae and Ouliaris (2002), computing it as the percentage difference between GDP and potential GDP. Following Nguyen (2014), the latter is estimated using the trend component filtered using the Hodrick-Prescott (HP) filter on the GDP expressed in billions of constant 2010 US dollars.[6]

Following Cebula (2015) we use a linear weighted average methodology for determining inflation expectations, as shown in the formula listed below; this gives more importance to the present inflation rate than the previous inflation rates by weighing the current actual inflation rate more heavily.

$$\pi_t^e = \frac{3 \cdot \pi_t + 2 \cdot \pi_{t-1} + 1 \cdot \pi_{t-2}}{6} \tag{2}$$

The decision of which countries and years to include was largely motivated by the availability of the data on the Digital Ecosystem Development Index of Katz and Callorda (2018),[7] or digitization index from here onwards, which consists of eight pillars including infrastructure, digital competition, digital industries, digitization of production, digital factors of production, household digitization, digital connectivity, and regulatory framework and public policy. We use school enrollments on the primary, secondary, and tertiary levels, all percentage gross, and their principal component analysis to give us one holistic measure of education. We measure governance by the principal component analysis of six governance measures including control of corruption, government effectiveness, political stability, regulatory quality, rule of law, and voice and accountability measures. The decision of which countries and years to include was largely motivated by the availability of the data on these measures.

To provide some basic information about each variable, Table 4 presents the descriptive statistics for both the full and the EMs samples for 14 variables: inflation (*inf*), output gap (*outgap*), unemployment (*unemp*), exchange rate (*exch*), foreign direct investment (*fdi*), pump price for gasoline (*oil*), and the development index (*digindex*), which has eight components. Each variable has a different number of observations, ranging from 1,020 to 1,841. The table provides summary statistics for each variable, including the mean, standard deviation, minimum value, and maximum value.

[5] Data will be made available on reasonable request.

[6] For more details on the HP filter, please check Nguyen (2014).

[7] Professor Raul Katz has privately shared with us the Digital Ecosystem Development Index dataset.

As the summary statistics indicate and confirming the average inflation time trends discussed in Fig. 1, the mean of *inf* in EMs is higher than the full sample (0.05 vs. 0.04) confirming the fact that weaker institutions, less developed financial system, and higher levels of corruption make it more difficult for these economies to achieve low and stable inflation. Additionally, as highlighted in the introduction, since EMs are typically characterized by greater economic volatility and political instability, we see it reflected by the higher standard deviation as compared with the full sample (0.08 vs. 0.07). Moreover, many EMs face a range of challenges in adopting and leveraging digital technologies, such as limited access to technology infrastructure and lower levels of digital literacy among the population, resulting in a lower level of digitalization overall, which is reflected in a lower mean *digindex* than the full sample (35.67 vs. 46.68), confirming the average digitization time trends discussed in Fig. 2. Additionally, the standard deviation of the digitization index varies widely depending on the specific country and time period being analyzed. According to our data, EMs have lower levels of variability in *digindex* compared to the full sample (12.36 vs. 17.20), due to factors such as government policies and investment in digital infrastructure.

Estimation methodology

The inflation model is estimated using panel System GMM panel estimation methodology proposed by Arellano and Bover (1995), Blundell and Bond (1998), and Blundell et al. (2001)[8] to examine the impact of changes in the macroeconomic variables and digitization levels on the variation of the domestic price level. Our main model is as follows,

$$\begin{aligned} inf_{i,t} =& \alpha + \rho inf_{i,t-1} + \beta_1 outgap_{i,t} + \beta_2 inf\_exp_{i,t} + \beta_3 exch_{i,t} + \beta_4 fdi_{in_{i,t}} + \beta_5 loil_{i,t} \\ &+ \delta digindex_{i,t} + \varepsilon_{i,t} \qquad i = 1, 2, \ldots \mathrm{N}, t = 2004, \ldots \mathrm{T} \end{aligned} \tag{3}$$

where inf_{it} refers to inflation measured by the GDP deflator (% annual) for country i at time t, $infl_{it-1}$ is the AR(1) endogenous variable, and the set of regressors including output gap "*outgap*", inflation expectation "*inf_exp*", exchange rate "*exch*", inflows of foreign direct investment "*fdi_in*", and the logarithm of the pump price for gasoline "*loil*". The variable $digindex_{i,t}$ represents the logarithm of digitization index or the logarithm of one of its eight pillars, each one in a turn. Finally, the variable ε_{it} is the error term of the regression.

To test for the potential non-linear deflationary effects of digitization, we expand the previous model by adding the quadratic term of digitization, or $digindex^2$, as follows,

$$\begin{aligned} inf_{i,t} =& \alpha + \rho inf_{i,t-1} + \beta_1 outgap_{i,t} + \beta_2 inf\_exp_{i,t} + \beta_3 exch_{i,t} + \beta_4 fdi\_in_{i,t} + \beta_5 loil_{i,t} \\ &+ \delta digindex_{i,t} + \gamma digindex_{i,t}^2 + \varepsilon_{i,t} \qquad i = 1, 2, \ldots \mathrm{N}, t = 2004, \ldots \mathrm{T} \end{aligned} \tag{4}$$

The nonw-linear effect of digitization on inflation is derived by computing the first derivative of Eq. (2) with respect to the $digindex_{i,t}$ variable. We expect a negative δ coefficient and a positive γ coefficient which implies that a one unit increase in the digitization index decreases inflation by a magnitude of δ, however, this effect is decreasing at an increasing rate of "2γ". The statistical significance of the total effect

[8] For more details on the estimation methodology, check Emara and El Said (2020).

of digitization on inflation is estimated using the standard errors of the coefficients δ and γ. Additionally, the threshold level of the digitization index, or $digindex^{*}_{i,t}$, is calculated as $\left|\frac{\delta}{2\gamma}\right|$ where any level of $digindex_{i,t}$ below $digindex^{*}_{i,t}$ will result in a decrease in inflation and any level above it results in a rate increase. Next, to test whether the effect of digitization on inflation is different in EMs versus the full sample, we restrict the sample to EMs and re-estimate the regression models of Eqs. (3) and (4).

Finally, the last part of our empirical analysis analyzes the effect of two policy tools; education and governance by testing whether investing in human capital and/or improving governance maximizes the deflationary impact of digitization. To do so, we expand our model as shown in Eq. (5) to add the variable "*policy*" which is replaced by the three variables of school enrollments and their principal component, "*edu*," each one in a turn.

Similarly, to analyze the impact of the improvement in governance, the variable *policy* is replaced with the six areas of governance and their principal component "*gov*," each one in a turn.

$$\begin{aligned} inf_{i,t} =& \alpha + \rho inf_{i,t-1} + \beta_1 outgap_{i,t} + \beta_2 inf_{exp} + \beta_3 exch_{i,t} + \beta_4 fdi_{in_{i,t}} + \beta_5 loil_{i,t} \\ &+ \delta digindex_{i,t} + \gamma digindex^2_{i,t} + \vartheta\left(digindex_{i,t} * policy_{i,t}\right) \\ &+ \varphi\left(digindex^2_{i,t} * policy_{i,t}\right) + \varepsilon_{i,t} \qquad i = 1, 2 \ldots N, t = 2004 \ldots T \end{aligned} \tag{5}$$

Based on Eq. (5) we analyze how policy tools affects the impact of the improvement in digitization on inflation by computing the first derivative with respect to digitization as follows, $\frac{\partial inf_{i,t}}{\partial digindex_{i,t}} = \delta + 2\gamma digindex_{i,t} + \vartheta policy_{i,t} + 2\varphi digindex_{i,t}.policy_{i,t}$. This derivative shows that the marginal effect of digitization on inflation is now dependent on the level of digitization and the policy variable, where the impact of digitization on inflation is computed at different values of digitization and policy variables. To find the variance of the marginal effect, $\delta + 2\gamma digindex_{i,t} + \vartheta policy_{i,t} + 2\varphi digindex_{i,t}.policy_{i,t}$, we first need to know the variances and covariances of the individual terms. Let $var(\delta) = \sigma_1^2$, $var\left(2\gamma digindex_{i,t}\right) = 4\gamma^2 var\left(digindex_{i,t}\right)$, $var\left(\vartheta policy_{i,t}\right) = \sigma_2^2$, and$var\left(2\varphi digindex_{i,t}.policy_{i,t}\right) = 4\varphi^2 var\left(digindex_{i,t}\right).\ var\left(policy_{i,t}\right) + 4Cov(digindex_{i,t}, policy_{i,t})$. Assuming the terms are uncorrelated and independent, the covariance term simplifies to zero, so the final expression for the variance is: $\sigma_1^2 + 4\gamma^2 var\left(digindex_{i,t}\right) + \sigma_2^2 + 4\varphi^2 var\left(digindex_{i,t}\right) var\left(policy_{i,t}\right)$, and the standard error is just the square root of that.

Finally, for all the regression models, the set of instruments used include the lagged levels as well as lagged differences of our variables starting from the second lag and the Arellano and Bond test is performed to ensure the absence of serial correlation in second order. Additionally, the Hansen test is performed to ensure that the chosen instruments are overidentified. All test results are reported on the estimation tables in the Appendix.

Estimation results

To estimate the impact of digitization on domestic inflation we begin by highlighting the linear model using alternative measures of digitization for the full sample, then we outline our results for EMs sample, we next present the results for the non-linear specification, and then we proceed to discuss the role of human capital, proxied by school enrollments, and institutional quality, proxied by governance indicators, in affecting the role of digitization on inflation. In all tables presenting estimation results, the symbols ***, **, *, and *' indicate statistical significance at the 1%, 5%, 10%, and 15% significance levels, respectively. For all regression tables,[9] the Arellano and Bond serial correlation test as well as the Hansen overidentification test are presented. The tests confirm that there is no serial correlation in second order and that the set of instruments used is overidentified.

Column (1) of Table 5 shows that the persistence of inflation is strongly negative, where a one percentage point increase in lagged inflation, "*l.inf,*" leads to a decrease in this year's actual inflation by about 0.59 percentage point, confirming a short term autoregressive first order relationship consistent with the empirical results of Csonto et al. (2019) and Hondroyiannis et al. (2007).

The results also show that a one percent increase in the output gap, "*outgap*," leads to a 0.11 percentage point increase in the actual inflation rate. This result is expected and is in line with the empirical findings of the Philips curve—see, for instance, Valadkhani (2014); Jasova et al. (2020). Additionally, a one percentage point increase in inflation expectations, "*inf_exp*," leads to about 0.21 percentage point increase in the actual level of inflation rate. This result is consistent with both the theory—as inflation expectations increase, we expect the current level of inflation to also increase—and the empirical evidence—see, for instance, Csonto et al. (2019), Bernanke (2010), and IMF (2018).

Next, a one percent increase in the real effective exchange rate, "*exch*," leads to an increase of 0.66 percentage point in the inflation rate, which goes in line with the empirical findings of Bailliu et al. (2002). A one percent increase in foreign direct investment, "*fdi*," results in 0.56 percentage point increase in inflation rate. An expected result in the context of aggregate demand analysis increases in foreign direct investment inflows lead to increases in spending, which is then reflected in an increased aggregate demand, leading to a demand-push inflation. In the seventh row, a one percentage point increase in oil prices "*oil*," leads to a 0.71 percentage point increase in the actual inflation rate, consistent with the results of Choi et al. (2018) and Mukhtarov et al. (2019).

Finally, a one percent increase in the digitization index, "*digindex*," leads to a 0.64 percentage point decrease in the inflation rate, consistent with the results of Csonto et al. (2019) and Hoon Yi and Choi (2005). In Column (2) and (3), a one percent increase in the Infrastructure of Digital Services Index, "*infra*," and Digital Connectivity Index, "*conn*," leads to a 0.66 and 0.60 percentage point decrease in the inflation rate, respectively. Columns (4) and (5) indicate that a one percent increase in the coefficients of the Household Digitization Index, "*dighou*," and the Digitization of Production Index, "*digprod*," leads to a 0.67 and 0.63 percentage point decrease in the inflation rate, respectively. Next, in Column (6) a one percent increase in Digital Industries Index, "*comp*," decreases inflation by 0.59 percentage points. In Column (7) Factors of Digital Production Index, "*eco*," has the largest impact on inflation rate, where a one percent increase in this pillar leads to 0.83 percentage point decrease in the inflation rate. Column (8)

[9] It is important to note that the p values of the Inverse Chi-squared statistic of the Fisher-type unit-root test (based on augmented Dickey-Fuller tests) confirm the absence of unit root in our panels under the given test conditions (panel means and time trend). Hence our model is trend stationary.

shows that a one percent increase in Digital Competitive Intensity Index, "*fp*," results in 0.67 percentage point decrease in the inflation rate. Finally, in Column (9) Regulatory Framework and Public Policies Index, "*instr*," where a one percent increase leads to 0.60 percentage point decrease in the inflation rate.

Next, the results of the linear model for EMs are presented in Table 6, where in Column (1) a one percentage point increase in *l.inf* decreases in the current inflation rate by about 0.57 percentage point. A one percent increase in *outgap* and *inf_exp* increases inflation by about 0.18 and 0.21 percentage point, respectively. A one percent increase in *exch* increases inflation by 0.16 percentage points. A one percent increase in *fdi* and *oil* result in a 0.72 and 0.37 percentage points increase in inflation rate, respectively. These results align with the full sample results and all the macroeconomic coefficients are robust to the different specifications in Columns (1) through (9).

Furthermore, like our findings for the full sample, the results confirm that all the digitization measures have deflationary effects in EMs. In Column (1), a one percent increase in the *digindex* decreases the actual inflation rate by about 0.91 percentage points. The highest deflationary impact derived from the *eco* pillar while the lowest is derived from the *comp* pillar, where a one percent increase in each pillar results in 1.3 and 0.79 percentage points decrease in inflation rate, as shown in Columns (7) and (6), respectively. Columns (2), (3), (5) and (9) show that the impacts of *infra*, *conn*, *digprod*, and *instr* on inflation rate, where a one percent increase in these four pillars lead to a about 0.95, 0.84, 0.93, and 0.83 percentage points decrease in inflation rate, respectively. Finally, Columns (4) and (8) shows that *dighou* and *fp* have the same impact on inflation rate, where a one percent increase in any of these two pillars leads to about 1 percentage points decrease in inflation, respectively.

Based on the above empirical results which confirms that all digitization measures have deflationary effects in the full sample as well as EMs, it would have several implications for policymakers and businesses operating in these economies. First, central banks may need to adjust their monetary policy frameworks to take into account the deflationary effects of digitization (Williams 2006). For example, if inflation is consistently lower than target due to digitization, central banks may need to adopt a more accommodative monetary policy stance to support economic growth and employment. Second, the deflationary effects of digitization may contribute to greater price stability in emerging markets, which can help to anchor inflation expectations and reduce the volatility of the business cycle (Yi and Choi 2005). Third, the deflationary effects of digitization may contribute to lower economic growth rates in the short-term, as lower inflation reduces aggregate demand and slows down the pace of economic activity. However, in the long-term, the productivity gains from digitization may lead to higher economic growth rates (Katz and Callorda 2018; 2020).

Next, Table 7 shows the results of the non-linear model for the full sample, computed as explained in the previous section. The estimation results of Column 1 confirms that a one percent increase in this index results in a decrease in inflation rate by about 2.29 percentage points, however, this rate is decreasing at an increasing rate of two times 0.43, or 0.86 percentage point, with a threshold level of about 43.22 points, which is on the 50th percentile of the index, as shown on Fig. 3. Additionally, the total effect of a one percent increase in *digindex* decreases inflation rate by about 1.87 percentage points, aligning

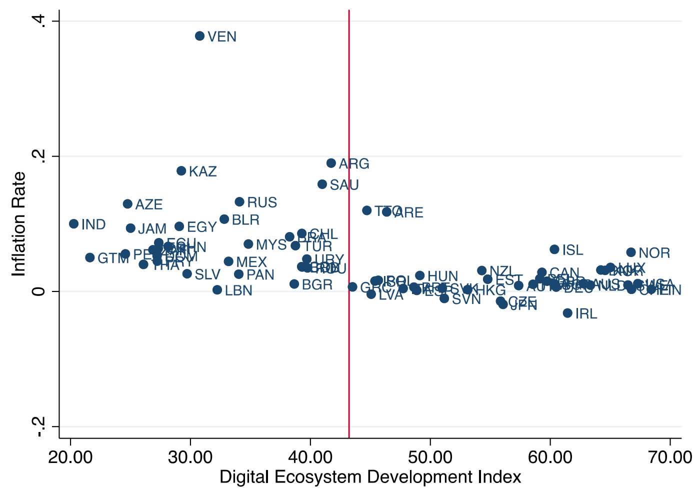

Fig. 3 Inflation and digitization – Threshold level *Source* Authors

with previous findings of Lang (2009), Hawash and Lang (2010), Vu (2011), Albiman and Sulong (2017), Emara and Kasa (2020), Emara and Zhang (2021), and Emara (2022).

This deflationary non-linear total effect of digitization on inflation is mainly derived from the *infra* pillar, followed by *instr*, *eco*, *conn*, *fp*, *digprod*, *dighou*, and then *comp*, where a one percent increase in each of these pillars results in a decrease in inflation rate by about 2.69, 2.50, 2.44, 2.36, 2.23, 2.11, 2.1, and 1.97 percentage points, respectively, with threshold levels for each pillar reported on the table.

These results on the non-linear effect of digitization-inflation imply that digitization lowers inflation only up to a certain point (for instance, by initially lowering costs of production), but have positive inflationary pressures at higher digitization levels leading to an increase in the rate of inflation. As per the theoretical model of "A simple theoretical model" section, digitization reduces average cost of production and enhances productivity, and thus creates economies of scale. Nevertheless, our results imply that once the digitization index reaches a threshold level further improvement in digitization tends to decrease as penetration increases, giving rise to diseconomies of scale, an increase in the average cost of production, and thus an increase in the rate of inflation.

Next, Table 8 reports the non-linear estimation results for EMs, where Column (1) shows that a one percent increase in *digindex* decreases inflation rate by about 2.38 percentage points, however this rate is decreasing at an increasing rate of 2 times 0.40, or 0.8, percentage points, leading to a total effect of − 1.98 and a threshold level of 36.28. The highest two total effects are derived from the *eco* and *instr* pillars, where a one percent increase in each of these pillars decreases inflation rate by about 2.59 and 2.56 percentage point, respectively. Additionally, the third highest total effect is derived from the *infra* pillar followed by the *digprod*, *fp*, and *dighou*, where a one percent increase in each of these pillars leads to a total deflationary effect of about 2.55, 1.96, 1.86, and 1.55 percentage points, respectively. Finally, the impact of the *comp* and *conn* pillars have the lowest total deflationary effects, where at one percent increase in these two pillars leads to a fall in inflation rate by about 1.50 and 1.18 percentage points, respectively.[10] It is important to note that the average non-linear deflationary effects of the eight pillars of digitization are smaller in EMs versus that of the full sample (1.96 vs. 2.30). This result is consistent with Katz and Callorda (2018), which found that the impact of the digital ecosystem on growth as well is higher in AEs than in EMs.

Our results on non-linear effect of digitization on inflation in EMs imply that digitization in these economies may have a beneficial effect on inflation at low levels, but at some point, the benefits begin to diminish and may even turn negative. One possible explanation for this quadratic relationship is that digitization can lead to increased productivity and efficiency, which can reduce costs and lower prices. However, as digitization becomes more pervasive in EMs, the gains from increased efficiency may be offset by other factors such as market concentration, regulatory constraints, and higher demand for digital goods and services.

Next, we expand the empirical model to test whether education complements digitization in reducing inflation in EMs. Table 9 computes the total effects of digitization when interacted with the three levels of school enrollments: primary, "*schp*," secondary, "*schs*," tertiary, "*scht*," and their linear combination using the principal component analysis, "*edu*," each one in a turn. As per the results of the first row of the table, when *digindex* is interacted with the variable *edu*, the impact of digitization is magnified where a one percent increase in *digindex* in the presence of high levels of school enrollments decreases the actual inflation by 0.201 percentage points. This impact is mainly derived from the effect of *schp* and *scht* where a one percent increase *digindex* when interacted with each of these two variables, each one in a turn, leads to decreases actual inflation by about 0.11 and 0.04, respectively. The effect of the interaction term of *digindex* with *schs* is however insignificant.

Our result of the statistical significance of education interaction with digitization implies that education matters and is a pre-condition for the digitization to have a stronger deflationary effect. Education can complement digitization by enabling individuals to take advantage of the opportunities and benefits offered by digitization (Reinsdorf 2022). For example, individuals with higher levels of education may be more likely to use digital technologies to access information, compare prices, and make more informed purchasing decisions, which can put downward pressure on prices and reduce inflation. Moreover, education can also contribute to the development of digital skills, which can enhance productivity and innovation (Wardana, et al. 2023; Reddy et al. 2023). By providing workers with the skills needed to use digital technologies effectively, education can help to promote digitization and its associated benefits, such as increased efficiency and lower costs.

Finally, we test whether effective governance and digitization can work together to create a favorable economic environment that reduces inflation. Table 10 shows that one percent increase in *digindex* when interacted with governance, "*gov*," decreases actual inflation by about 0.033 percentage points. This deflationary effect is mainly derived from the impact of the improvement in corruption, "corrup," rule of law, "rl," and voice and accountability, "*vacc*," where a one unit increase in each

[10] The threshold levels of each pillar are reported on the table.

of these subindices decreases inflation by about 0.0215, 0.0217, 0.0156 percentage points, respectively. Lower levels of corruption and improvements in the rule of law are necessary for the smooth functioning and stability of institutions, as well as for the overall health of the economy. This implies that the deflationary effect of digitization is maximized in places with less corruption and stronger rule of law and accountability.

The statistical significance of the governance interaction with digitization index imply that effective governance can complement digitization in several ways. First, good governance can help to create a stable and predictable business environment, which can encourage investment and promote economic growth (Emara and Jhonsa 2014; Emara and Chiu 2016; Ullah et al. 2022a). This, in turn, can stimulate the adoption of digital technologies and create opportunities for increased efficiency and lower costs, which can help to reduce inflation. Second, good governance can also facilitate the development of digital infrastructure, such as broadband networks, that are essential for the widespread adoption of digital technologies (Dawes 2009; Estevez and Janowski 2013; Addo and Senyo 2021). This can create new opportunities for businesses and individuals to use digital technologies to enhance productivity and reduce costs, which can also contribute to reducing inflation. Finally, good governance can also ensure that the benefits of digitization are shared more broadly across society (Donner 2009; Bogliacino 2014). This can help to mitigate the risks of market concentration and ensure that the benefits of increased efficiency and lower costs are passed on to consumers in the form of lower prices.

Robustness check

To confirm the relevance of our results, robustness checks are performed using two methods of estimation methodologies. First, we started with ordinary least squares (OLS) basic regression encompassing only inflation (in log) and the digitization index (in log). As presented in Table 11, the regression provides negative and significant coefficient (− 0.056) at the 99% confidence level, which is in line with theoretical predictions and correlations in Table 5. Next, we control for other explanatory variables by adding the output gap, inflation expectation, exchange rate, inflows of foreign direct investment, and the logarithm of the pump price for gasoline, the point estimate of the effect of digitization index falls -in absolute value- but keeps the negative and significant sign (− 0.002). The non-linear effect is also confirmed, where the negative impact digitization on inflation tends to decrease as penetration increases, with a negative statistically significant total effect at the 10% (− 0.008).

Next, to deal with endogeneity effectively, in Table 12 we use the instrumental variables (IV) method to estimate the effect of digitization on inflation. The estimation provides a significant and negative coefficient that is comparable to the one obtained using OLS (− 0.002), with all control maintaining the same sign and statistical significance as the ones obtained with OLS regressions. Lastly, the total negative non-linear effect of FinTech on poverty is also confirmed (− 0.008) at the 10% significance level.

Conclusion and policy implications

Using system panel GMM estimation methodology, this paper analyzes the impact of digitization on domestic inflation for a sample of 54 AEs and EMs over the period 2014–2018. The results confirm the improvement in digitization has a non-linear deflationary effect on domestic inflation in both the full sample and EMs sample. This result implies that improvement in digitization has significant asymmetric deflationary effect. However, once digitization reaches a threshold level of 43.22 points, further improvement in digitization reduces the magnitude of this effect. Furthermore, for EMs, level of education and the improvement in governance strengthens the deflationary effect of digitization.

Our results have three policy implications. First, governments should undertake a careful consideration of the optimal level of digitization that balances the benefits of increased efficiency with the potential risks of market power and other negative effects. Second, investment should be made in both education and digitization to promote long-term economic growth and price stability. Finally, investing in both effective governance and digital infrastructure in order to create an environment that is conducive to productivity, innovation, and efficiency can ultimately lead to lower inflation and improved economic outcomes.

Research on the implications of digitization should grow as digitization itself continues to grow and impact economies worldwide. Future research on digitization and inflation should examine the deflationary effect on the micro level using, for example, the DiGix index developed by Camara and Tuesta (2017) which covers a hundred developed and developing countries on multiple dimensions and sub-dimensions. These include infrastructure, households' adoption, enterprises' adoption, costs, regulation, and contents, for a total of 21 sub-indicators. Such research would be helpful to assess the impact of digitization on factors, agents' behavior, and institutions and also address micro level data limitations inherent in the research presented in our study. Nonetheless our findings point the way for valuable policy changes along with this future research.

Appendix

For all estimation results' tables, the ***, **, * and *' denotes statistical significance at the 1%, 5%, 10%, and 15% levels respectively. Numbers in round parentheses (.) are the robust standard errors See Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

Table 1 List of abbreviations

Abbreviation	Definition
AEs	Advanced economies
EMs	Emerging markets
GMM	Generalized method of moments
HP	Hodrick-Prescott
TMV	Time varying coefficient

Table 2 List of countries

Advanced economies (AEs)	Emerging markets (EMs)
Australia	Argentina
Canada	Azerbaijan
Czech Republic	Barbados
Denmark	Belarus
Hong Kong SAR, China	Brazil
Iceland	Bulgaria
Israel	Chile
Japan	China
Korea Rep	Colombia
Latvia	Costa Rica
New Zealand	Dominican Republic
Norway	Ecuador
Singapore	Egypt
Sweden	El Salvador
Switzerland	Estonia
Taiwan	Guatemala
United Kingdom	Hungary
United States	India
	Kazakhstan
	Lebanon
	Malaysia
	Mexico
	Panama
	Paraguay
	Peru
	Argentina
	Azerbaijan
	Poland
	Romania
	Russian Federation
	Saudi Arabia
	South Africa
	Thailand
	Turkey
	United Arab Emirates
	Uruguay
	Venezuela, RB

Table 3 Definition and sources of variables

Variable name	Definition	Abbreviation	Source
Inflation	Percentage change in GDP deflator (base year varies by country)	*inf*	WDI (2021)
Output gap	Following Hodrick and Prescott (1997) and Corbae and Ouliaris (2002), this variable is computed as the difference between Growth rate of real GDP per capita (constant 2000 US$) and the potential growth rate of real GDP per capita, where the latter is estimated using the trend component filtered using the Hodrick-Prescott (HP) filter on the GDP expressed in billions of constant 2010 US dollars	*outgap*	Authors' computation based on data from WDI (2021)
Inflation expectation	Author computation following Cebula (2015) using $\pi_t^e = \frac{3\bullet\pi_t+2\bullet\pi_{t-1}+1\bullet\pi_{t-2}}{6}$, as explained on Page 9	*inf_exp*	Authors' computation based on data from WDI (2021)
Exchange rate	Real effective exchange rate index (2010 = 100)	*exch*	WDI (2021)
Foreign direct investment	Foreign direct investment, net inflows (% of GDP)	*fdi*	WDI (2021)
Oil	Pump price for gasoline (US$ per liter)	*oil*	WDI (2021)
Digital ecosystem development index	Composite Index of the following eight pillars	*digindex*	Katz and Callorda (2018)
Infrastructure of digital services index	Investments, quality of services, coverage, and service infrastructure of the digital ecosystem using 15 indicators such as average broadband download speed and number of satellites	*infra*	Katz and Callorda (2018)
Digital connectivity index	Affordability, penetration, and ownership in the digital ecosystem using eleven indicators such as monthly fixed and penetration of computers and smartphone users	*conn*	Katz and Callorda (2018)
Household digitization index	Internet use, E-government, E-commerce, and over the top media services (OTTs) using seven indicators that characterize the household digital ecosystem	*dighou*	Katz and Callorda (2018)
Digitization of production index	Digital infrastructure, digital supply chain, digital distribution, and digital processing using six indicators that characterize the digital ecosystem of the enterprise sector	*digprod*	Katz and Callorda (2018)
Digital industries index	Weight of digital industries, IoT, and content production using seven indicators such as high tech and ICT services exports, and Machine-to-Machine (M2M) connections	*comp*	Katz and Callorda (2018)

Table 3 (continued)

Variable name	Definition	Abbreviation	Source
Factors of digital production index	Human capital, schools, innovation, investment in innovation, and economic development in the digital ecosystem using eight indicators such as GDP per capita, and USPTO patents	*eco*	Katz and Callorda (2018)
Digital Competitive Intensity Index	Level of competition using 4 indicators: the Herfindahl–Hirschman Index (HHI) fixed and mobile broadband, pay TV, and mobile telephony	*fp*	Katz and Callorda (2018)
Regulatory framework and public policies index	Role of government in the digital ecosystem and cybersecurity and piracy using four indicators such as % of regulatory agency attributions and % of non-licensed installed software	*instr*	Katz and Callorda (2018)
Education	The principal component of the next three variables	*edu*	*Authors' computation*
Primary school enrollment	Primary education provides children with basic reading, writing, and mathematics skills along with an elementary understanding of such subjects as history, geography, natural science, social science, art, and music	*schp*	WDI (2021)
Secondary school enrollment	Secondary education completes the provision of basic education that began at the primary level, and aims at laying the foundations for lifelong learning and human development, by offering more subject- or skill-oriented instruction using more specialized teachers	*schs*	WDI (2021)
Tertiary school enrollment	Tertiary education, whether or not to an advanced research qualification, normally requires, as a minimum condition of admission, the successful completion of education at the secondary level	*scht*	WDI (2021)
Governance	The principal component of the next six indicators	*gov*	*Authors' computation*
Control of corruption	Perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests	*corrup*	WDI (2021)
Government Effectiveness	Perceptions of the quality such as public services, the quality of the civil service and the degree of its independence from political pressures	*goveff*	WDI (2021)
Political stability and absence of violence/terrorism	Perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism	*pols*	WDI (2021)

Table 3 (continued)

Variable name	Definition	Abbreviation	Source
Regulatory quality	Perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development	*regq*	WDI (2021)
Rule of law	Perceptions of the extent to which agents have confidence in and abide by the rules of society, and the likelihood of crime and violence	*rl*	WDI (2021)
Voice and accountability	Perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media	*vacc*	WDI (2021)

Table 4 Descriptive statistic – full sample

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
inf	1,841	0.044	0.070	−0.323	0.561
outgap	1,838	0.000	0.045	−0.963	0.810
unemp	1,394	8.847	6.452	0.140	47.500
exch	1,466	0.020	0.097	−0.325	1.460
fdi	1,804	0.072	0.220	−0.583	4.516
oil	1,464	1.125	0.503	0.000	2.540
digindex	1,020	46.676	17.197	6.708	81.530
infra	1,020	37.734	18.007	2.581	93.614
conn	1,020	57.037	22.318	5.589	95.723
dighou	1,020	40.353	21.109	6.031	91.444
digprod	1,020	58.155	29.694	1.451	100.000
comp	1,020	66.058	18.323	5.727	96.759
eco	1,020	18.325	10.093	3.172	55.784
fp	1,020	37.027	20.718	4.456	83.622
instr	1,020	55.428	18.279	1.007	88.491
EMs sample					
inf	1,310	0.054	0.080	−0.323	0.561
outgap	1,307	0.000	0.049	−0.963	0.810
unemp	866	9.691	7.372	0.140	47.500
exch	1,195	0.024	0.101	−0.325	1.460
fdi	1,296	0.049	0.058	−0.180	0.578
oil	1,009	0.943	0.451	0.000	2.540
digindex	540	35.656	12.360	6.708	64.101
infra	540	29.283	14.831	2.581	78.414
conn	540	47.225	21.162	5.589	95.723
dighou	540	28.590	14.696	6.031	68.445
digprod	540	37.605	19.392	1.451	76.968
comp	540	59.840	19.764	5.727	95.724
eco	540	13.130	5.829	3.172	37.179
fp	540	22.776	11.305	4.456	52.444
instr	540	46.756	17.669	1.007	82.165

Table 5 Inflation and digitization–full sample

Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
l.inf	−0.585***	−0.585***	−0.584***	−0.585***	−0.588***	−0.585***	−0.584***	−0.589***	−0.588***
	(0.017)	(0.016)	(0.016)	(0.016)	(0.018)	(0.017)	(0.016)	(0.017)	(0.019)
outgap	0.112**	0.117**	0.111**	0.115**	0.112**	0.106**	0.130**	0.128**	0.106**
	(5.463)	(5.540)	(5.561)	(5.564)	(5.393)	(5.372)	(5.660)	(5.570)	(5.351)
inf_exp	0.208***	0.207***	0.207***	0.208***	0.209***	0.208***	0.208 ***	0.208***	0.208***
	(10.606)	(10.275)	(10.523)	(10.379)	(10.819)	(10.710)	(10.060)	(10.715)	(10.238)
exch	0.661**	0.685**	0.681**	0.700**	0.644**	0.641**	0.651**	0.660**	0.608**
	(2.990)	(3.070)	(3.073)	(3.028)	(3.002)	(2.956)	(2.900)	(3.033)	(2.752)
fdi	0.558*	0.547*	0.512*	0.556*	0.591*	0.556*	0.488*	0.472*	0.565*
	(3.109)	(3.028)	(2.861)	(2.986)	(3.518)	(3.038)	(2.890)	(2.868)	(3.172)
loil	0.712*′	0.658*′	0.666*′	0.773*	0.809*	0.656*′	0.820*	0.798*	0.631*′
	(0.466)	(0.466)	(0.457)	(0.461)	(0.491)	(0.450)	(0.475)	(0.481)	(0.434)
digindex	−0.64***								
	(0.191)								
infra		−0.66***							
		(0.199)							
conn			−0.596***						
			(0.180)						
dighou				−0.673***					
				(0.198)					
digprod					−0.627***				
					(0.189)				
comp						−0.591***			
						(0.172)			
eco							−0.830***		
							(0.235)		
fp								−0.670***	
								(0.205)	
instr									−0.604***
									(0.166)
Observations	529	529	529	529	529	529	529	529	529
No. Countries	55	55	55	55	55	55	55	55	55
AB, AR(1) p-value	0.0229	0.0241	0.0223	0.0215	0.0228	0.0235	0.0241	0.0236	0.0202
AB, AR(2) *p*-value	0.136	0.133	0.129	0.132	0.140	0.137	0.151	0.132	0.148
Hansen *p*-value	0.977	0.974	0.974	0.976	0.982	0.981	0.982	0.973	0.980

Table 6 Inflation and digitization–EMs sample

Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
l.inf	− 0.574*** (0.013)	− 0.574*** (0.012)	− 0.573*** (0.012)	− 0.572*** (0.013)	− 0.577*** (0.015)	− 0.574*** (0.013)	− 0.569*** (0.013)	− 0.579*** (0.013)	− 0.577*** (0.014)
outgap	0.175*′ (11.798)	0.181*′ (11.970)	0.170*′ (11.844)	0.188*′ (12.567)	0.186*′ (11.693)	0.169*′ (11.573)	0.212* (12.822)	0.196* (11.976)	0.177* (12.118)
inf_exp	0.205*** (12.854)	0.204*** (12.518)	0.205*** (12.728)	0.205*** (12.562)	0.207*** (13.251)	0.206*** (12.993)	0.206*** (12.453)	0.205*** (13.138)	0.205*** (12.803)
exch	0.159*** (0.537)	0.163*** (0.552)	0.161*** (0.538)	0.174*** (0.567)	0.166*** (0.552)	0.152*** (0.523)	0.178*** (0.580)	0.160*** (0.531)	0.155*** (0.561)
fdi	0.716** (0.323)	0.673** (0.312)	0.679** (0.309)	0.738** (0.328)	0.780** (0.343)	0.711** (0.319)	0.750** (0.330)	0.497* (0.274)	0.771** (0.358)
loil	0.369 (0.578)	0.321 (0.602)	0.331 (0.568)	0.434 (0.574)	0.490 (0.613)	0.360 (0.560)	0.577 (0.651)	0.412 (0.576)	0.347 (0.581)
digindex	− 0.905*** (0.307)								
infra		− 0.947*** (0.326)							
conn			− 0.836*** (0.286)						
dighou				− 0.998*** (0.335)					
digprod					− 0.931*** (0.322)				
comp						− 0.788*** (0.264)			
eco							− 1.303*** (0.417)		
fp								− 1.000*** (0.350)	
instr									− 0.835*** (0.272)
Observations	356	356	356	356	356	356	356	356	356
No. Countries	36	36	36	36	36	36	36	36	36
AB, AR(1) *p*-value	0.0237	0.0249	0.0221	0.0182	0.0221	0.0263	0.0207	0.0218	0.0236
AB, AR(2) *p*-value	0.0695	0.0689	0.0651	0.0598	0.0693	0.0748	0.0737	0.0630	0.0860
Hansen *p*-value	0.280	0.258	0.266	0.286	0.268	0.311	0.266	0.264	0.280

Table 7 Inflation and digitization–Non-linear model–Full sample

Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
l.inf	− 0.586***	− 0.588***	− 0.590***	− 0.587***	− 0.587***	− 0.587***	− 0.587***	− 0.584***	− 0.588***
	(0.018)	(0.020)	(0.019)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.019)
outgap	0.931*′	0.726*′	0.811*′	0.859*′	0.952*	0.967*	0.761*′	0.668	0.990*
	(0.60)	(0.520)	(0.524)	(0.534)	(0.555)	(0.552)	(0.512)	(0.526)	(0.574)
inf_exp	0.210***	0.213***	0.211***	0.209***	0.207***	0.209***	0.208***	0.209***	0.209***
	(0.011)	(0.011)	(0.010)	(0.011)	(0.010)	(0.011)	(0.011)	(0.010)	(0.011)
exch	0.528*′	0.380*′	0.429*′	0.445*′	0.552*	0.562**	0.527*	0.509*	0.594**
	(0.346)	(0.270)	(0.302)	(0.290)	(0.286)	(0.280)	(0.282)	(0.284)	(0.304)
fdi	0.594*	0.541*	0.692*	0.561*	0.614*	0.617*	0.673*	0.642**	0.551**
	(0.314)	(0.314)	(0.369)	(0.342)	(0.326)	(0.317)	(0.348)	(0.324)	(0.273)
loil	0.478	0.479	0.460	0.308	0.203	0.557	0.212	0.249	0.517
	(0.486)	(0.364)	(0.422)	(0.415)	(0.388)	(0.427)	(0.381)	(0.420)	(0.381)
digindex	− 2.294*								
	(1.304)								
digindexsq	0.429								
	(0.343)								
infra		− 3.453***							
		(0.813)							
infrasq		0.760***							
		(0.178)							
conn			− 2.916***						
			(0.562)						
connsq			0.561***						
			(0.114)						
dighou				− 2.619***					
				(0.697)					
dighousq				0.533***					
				(0.144)					
digprod					− 2.621***				
					(0.629)				
digprodsq					0.507***				
					(0.119)				
comp						− 2.394***			
						(0.842)			
compsq						0.425**			
						(0.173)			
eco							− 3.285***		
							(0.989)		
ecosq							0.848***		
							(0.263)		
fp								− 2.814***	
								(0.644)	
fpsq								0.589***	
								(0.129)	
instr									− 3.132***
									(1.208)
instrsq									0.628**
									(0.266)
Total Effects	− 1.865*	− 2.693***	− 2.355***	− 2.086 ***	− 2.114***	− 1.969***	− 2.437***	− 2.225***	− 2.503***
	(0.965)	(0.636)	(0.454)	(0.555)	(0.512)	(0.672)	(0.727)	(0.517)	(0.942)
Threshold Levels	43.22	36.51	48.95	42.04	53.97	57.23	21.48	39.36	43.67

Table 7 (continued)

Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Observations	529	529	529	529	529	529	529	529	529
No. Countries	55	55	55	55	55	55	55	55	55
AB, AR(1) *p*-value	0.0237	0.0216	0.0238	0.0255	0.0211	0.0220	0.0193	0.0206	0.0209
AB, AR(2) *p*-value	0.144	0.159	0.157	0.146	0.132	0.144	0.128	0.148	0.154
Hansen *p*-value	0.971	0.983	0.983	0.987	0.977	0.980	0.986	0.981	0.990

Table 8 Inflation and digitization–non-linear model–EMs sample

Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
l.inf	− 0.575***	− 0.576***	− 0.572***	− 0.581***	− 0.578***	− 0.576***	− 0.576***	− 0.576***	− 0.580***
	(0.013)	(0.013)	(0.014)	(0.013)	(0.014)	(0.013)	(0.013)	(0.013)	(0.014)
outgap	0.159	0.144	0.177	0.110	0.155	0.155	0.151	0.156	0.143
	(0.128)	(0.120)	(0.137)	(0.116)	(0.120)	(0.114)	(0.111)	(0.129)	(0.113)
inf_exp	0.204***	0.207***	0.204***	0.202***	0.206***	0.206***	0.202***	0.206***	0.205***
	(0.012)	(0.012)	(0.011)	(0.099)	(0.013)	(0.012)	(0.013)	(0.013)	(0.013)
exch	0.152**	0.137**	0.169**	0.988*	0.146***	0.144***	0.145***	0.147**	0.139***
	(0.061)	(0.055)	(0.070)	(0.058)	(0.056)	(0.051)	(0.048)	(0.058)	(0.050)
fdi	0.106**	0.101**	0.892**	0.495*	0.899**	0.818**	0.119*	0.816**	0.828**
	(5.362)	(5.036)	(4.019)	(2.811)	(4.149)	(3.701)	(6.391)	(3.613)	(3.998)
loil	0.267	0.370	0.302	0.190	0.275	0.315	0.128	0.315	0.330
	(0.515)	(0.494)	(0.547)	(0.440)	(0.561)	(0.543)	(0.440)	(0.556)	(0.505)
digindex	− 2.382**								
	(0.961)								
digindexsq	0.404*								
	(0.232)								
infra		− 3.188***							
		(1.055)							
infrasq		0.638***							
		(0.230)							
conn			− 1.293**						
			(0.640)						
connsq			0.113						
			(0.185)						
dighou				− 1.858***					
				(0.666)					
dighousq				0.305*					
				(0.163)					
digprod					− 2.340***				
					(0.613)				
digprodsq					0.385***				
					(0.130)				
comp						− 1.727**			
						(0.811)			
compsq						0.225			
						(0.168)			
eco							− 3.418**		
							(1.672)		

Table 8 (continued)

Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ecosq							0.833*		
							(0.490)		
fp								− 2.230***	
								(0.545)	
fpsq								0.368**	
								(0.143)	
instr									− 3.164*
									(1.751)
instrsq									0.601
									(0.391)
Total Effects	− 1.978***	− 2.550***	− 1.180**	− 1.553***	− 1.955***	− 1.502**	− 2.585**	− 1.862***	− 2.563*
	(0.743)	(0.831)	(0.475)	(0.519)	(0.505)	(0.654)	(1.186)	(0.442)	(1.360)
Threshold Levels	36.28	30.84	59.01	37.50	42.05	64.54	16.29	26.88	42.74
Observations	356	356	356	356	356	356	356	356	356
No. Countries	36	36	36	36	36	36	36	36	36
AB, AR(1) *p*-value	0.0236	0.0268	0.0188	0.0394	0.0235	0.0277	0.0256	0.0245	0.0268
AB, AR(2) *p*-value	0.0651	0.0798	0.0532	0.0872	0.0744	0.0774	0.0728	0.0746	0.0915
Hansen *p*-value	0.288	0.298	0.255	0.991	0.277	0.289	0.292	0.265	0.261

Table 9 Impact of education on the inflation-digitization link in EMs

Regressors	Total effects
digindex & Education	− 0.207* (0.010)
digindex & Primary School Enrollment	− 0.108** (0.048)
digindex & Secondary School Enrollment	− 0.009 (0.013)
digindex & Tertiary School Enrollment	− 0.040*** (0.014)

Table 10 Impact of governance on the inflation-digitization link in EMs

Regressors	Total effects
digindex & Governance	− 0.033*** (0.011)
digindex & Control of Corruption	− 0.022* (0.011)
digindex & Government Effectiveness	− 0.005 (0.011)
digindex & Political Stability	− 0.017 (0.017)
digindex & regulatory Quality	− 0.009 (0.021)
digindex & Rule of Law	− 0.022* (0.012)
digindex & Voice and Accountability	− 0.016** (0.007)

Table 11 Inflation & digitization—OLS robustness check

Regressors	(1)	(2)	(3)
outgap		0.290***	0.281***
		(0.0829)	(0.081)
infdef_exp		1.092***	1.115***
		(0.0626)	(0.076)
exch		0.040*	0.034*′
		(0.022)	(0.023)
fdi_in		0.0204*	0.021*
		(0.011)	(0.011)
loil		0.003	0.0019
		(0.004)	(0.0044)
digindex	− 0.056***	− 0.002**	− 0.011*′
	(0.00414)	(0.001)	(0.0068)
digindexsq			0.0022
			(0.0016)
Total Effect			0.008*′
			(0.005)
Observations	948	529	529
R-squared	0.136	0.872	0.873

Table 12 Inflation & digitization—IV robustness check

Regressors	(1)	(2)	(3)
outgap		0.290***	0.281***
		(0.0825)	(0.0809)
infdef_exp		1.092***	1.115***
		(0.0622)	(0.0756)
exch		0.0400*	0.0340
		(0.0216)	(0.0225)
fdi_in		0.0204*	0.0214*
		(0.0113)	(0.0112)
loil		0.00259	0.00192
		(0.00445)	(0.00435)
digindex	−0.0562***	−0.00195**	−0.0105
	(0.00414)	(0.000839)	(0.00671)
digindexsq			0.00218
			(0.00157)
Total effect			−0.008*
			(0.005)
Observations	948	529	529

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NE participated in concept development, created and estimated model, and editing. DZ has developed the idea further and has written the first draft. NE has revised the first and second drafts. Both authors read and approved the final manuscript.

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Declarations

Competing interests
The authors declare that they have no competing interests.

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