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Is Digitalization Driving Domestic Inflation?

Prepared by Balazs Csonto, Yuxuan Huang, and Camilo E. Tovar[1]

Authorized for distribution by Rupa Duttagupta

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Abstract

This paper examines the extent to which digitalization—measured by a new proxy based on IP addresses allocations per country—has influenced inflation dynamics in a sample of 36 advanced and emerging economies over 2000-2017. Phillips curve estimates show that digitalization has a statistically significant negative effect on inflation in the short run. Its economic impact is not large but has increased since 2012 and mainly operates through a cost/competition channel. Principal components and cointegration analysis further suggest digitalization is a key driver of lower trend inflation.

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Authors' E-Mail Address: bcsonto@imf.org; yxhuang@gwmail.gwu.edu; ctovar@imf.org.

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I. INTRODUCTION

The digitalization process has been transforming the global economy over the past 25 years. Information and communication exchanges have exploded, triggering a major transformation of production and distribution processes (e.g., changing the integration of supply chains both vertically and horizontally), and financial and payments systems (e.g., through new services or allowing mobile payments), among many other activities. It also has disrupted and transformed agents' (i.e., consumer, producers, and governments) economic behavior and decision-making. Market structures have changed, new markets have emerged, and the global economy has become interconnected in an unprecedented manner.

Despite this fundamental transformation, the macroeconomic implications of digitalization are not well understood. The analysis of the economic effects of digitalization has mostly focused on measurement issues (e.g., GDP and productivity), its implications for economic activity, market dynamics—particularly for labor and financial markets (IMF, 2018c; Mühleisen, 2018; He et al., 2017)—, and public finance (Gupta et al., 2017). Moreover, the literature on the macroeconomic impact of digitalization on inflation, and more broadly on monetary policy is in its infancy, and thus far, mostly focused on individual country-specific effects (Charbonneau et al, 2017; Coffinet and Perillaud, 2017).

This paper aims at filling a gap in the literature by examining whether the digitalization process has affected inflation dynamics. Digitalization can affect price levels in a gradual and staggered manner and thus affect inflation through different channels. For instance, it can influence the prices of goods and services by lowering the costs of production and distribution and by improving efficiency.[2] Prices can also be affected through the creation of new higher quality products or by transforming existing market strutures and services. For example, the emergence of superstar firms (e.g., Amazon) has changed competition and triggered changes in price-setting strategies. Digitalization may have also changed the formation of inflation expectations by improving the flow of information. For these reasons, digitalization can result in a downward shift and/or the flattening of the Phillips curve.

Digitalization thus appears to be a relevant force explaining the persistently low inflation observed across the world over the past two decades (see discussion in Box 1). The difficulties in rationalizing these trends calls for considering factors beyond the traditional drivers of inflation. Much of the macroeconomic literature has focused on the role of global factors (e.g., global output gaps, global value chains, China's role in the global economy). However, to our knowledge, no study has conducted a systematic cross-country level analysis of the impact of digitalization on inflation at the aggregate level.[3] On the contrary,

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[2] For example, Goldfarb and Tucker (2019) argue it can lower search, replication, transportation, tracking, and verification costs.

[3] An exception is the cross-country study by Yi and Choi (2005).

most of the emerging literature has focused on the microeconomic formation of on-line prices, and compared its dynamics with off-line prices (Gorodnichenko et al., 2018; Cavallo and Rigobon, 2016; Cavallo, 2017, 2018a).

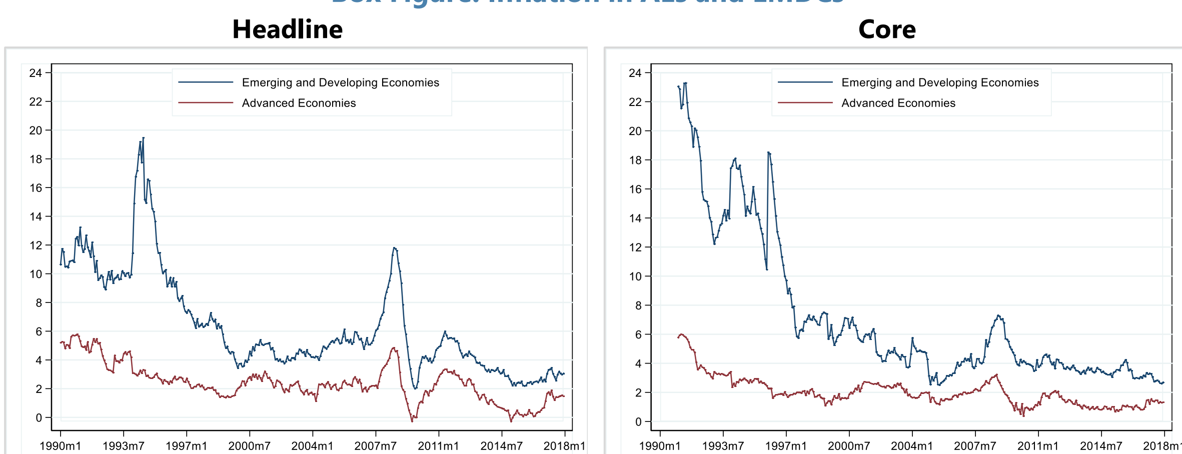
Assessing the impact of digitalization on inflation is challenging. As a multidimensional and dynamic concept, there is no fully agreed working definition for digitalization and no consensus on how to measure it (IMF, 2018c).[4] There have been attempts to develop cross-country indicators to gauge the degree of digitalization, but their coverage is limited and relies on annual data, often over short time spans. A further challenge is that existing national prices indexes may be distorted or biased due to the inadequate adjustments to the fast-changing quality of digital goods and services, the handling of new products, or problems with measuring new markets—e.g., e-commerce or the sharing economy (IMF, 2018c).

Box 1. Drivers of Inflation Over the Last Three Decades: Alternative Explanations

Inflation has displayed a sustained downward trend since the early 1990s. Moreover, since the early 2000s, it has remained low and stable (IMF, 2018a), averaging four percent—albeit with some spikes in late 2007 and early 2008 due to food and oil price shocks (Box Figure). These dynamics are consistently observed across advanced and emerging markets, reflecting a high degree of co-movement across countries.[1]

Rationalizing inflation trends over the past two decades has proven challenging for different reasons. Traditional *Phillips curve* models emphasize the role of domestic factors, such as domestic demand pressures (e.g., output gap) or inflation expectations. However, these factors fail to provide adequate explanations for domestic inflation trends across the world. This is evident, for instance, in the case of the sharp decline in inflation in the 1990s through the mid-2000s—a phenomenon known as the *Great Moderation* (Bernanke, 2007; Borio and Filardo, 2007).[2] Understanding the lack of responsiveness of inflation to high unemployment as well as the persistently low inflation relative to central banks' targets in recent years —i.e., the *missing disinflation hypothesis*—has been equally challenging (IMF, 2013 and 2018a; Coibon and Gorodnichenko, 2015).[3]

Box Figure: Inflation in AEs and EMDCs



Source: International Financial Statistics (IMF)

[4] In this paper, we do not address the challenges of measuring the distortions or biases that digitalization may imply for existing national price indexes. More generally, we acknowledge that some of the effects of digitalization are beyond measurement.

Box 1. Drivers of Inflation Over the Last Three Decades: Alternative Explanations (Continued)

The literature has proposed various potential explanations. First, a common view is that inflation dynamics is largely driven by upgraded monetary policy frameworks (e.g., the adoption of inflation targeting regime, or better communication) that have improved central bank credibility and helped anchor inflation and its expectations (IMF, 2013; Coibon and Gorodnichenko, 2015; Bernanke, 2007, Khor, et al, 2018). Second, there is empirical evidence that increasing retail competition also contributed to lower inflation (e.g., Basker, 2007; Igan and Suzuki, 2012). Third, the persistence of inflation could also have contributed to its lower level and lack of responsiveness to economic slack in the most recent period (Abdih et al., 2018). However, an alternative argument is that domestic inflation across the world largely reflects global factors (IMF, 2013, 2018a; Bianchi and Civelli, 2015; Bernanke, 2007; Rogoff, 2007). This has led many to incorporate measures of foreign output gaps in the Phillips curve estimates (IMF, 2018a). Alternatively, others suggest that the integration of production processes deems it necessary to control for global value chains (Auer et al., 2017) or that it is important to control for China's increasing role in the global economy—particularly since its incorporation to the World Trade Organization in 2001 (Rogoff, 2007).

Second, another hypothesis is that inflation has become increasingly driven by global forces. Specifically, the '*globalization hypothesis'* poses that domestic inflation has become more sensitive to global slack and, thus, less sensitive to domestic conditions (IMF, 2018a, 2013; Bianchi and Civelli, 2015; Bernanke, 2007, Rogoff, 2007). It builds on the notion that the growing integration of goods, labor, and financial markets have resulted in a wider and more direct and indirect competition among economies as well as on changing price-setting behavior driven by the use of imported goods, domestic producers' pricing market power, and/or productivity growth (Bernanke, 2007). This can have a twofold impact on the Phillips curve (Carney, 2017): (i) a downward shift of the curve due to a series of positive supply shocks (e.g., an increase in the global labor force pool); and (ii) a flattening of the curve thanks to increased competition and contestability in product and labor markets. Empirical results provide mixed evidence on the role of global factors:

- The empirical evidence supports the view that a *common global factor* is driving the reduction of inflation in recent decades (Bianchi and Civelli, 2015; Ciccarelli and Mojon, 2010).[4] However, the literature is less conclusive about the inclusion of measures of global slack in a Phillips curve setting (Bianchi and Civelli, 2015). In their study, Bianchi and Civelli find that global slack has a positive effect on inflation, but its importance relative to domestic output gap has not increased over time. In their view global integration does not significantly affect inflation dynamics or, while important, we have not yet observed changes in the degree of openness that would induce structural breaks in inflation dynamics. Other studies have further shown that inflation expectations are inflation's main determinant in emerging markets, with external factors playing a lesser role vis-à-vis domestic ones (IMF, 2018a).
- Others maintain that the rising and increasing role of China in the global economy has influenced inflation dynamics (Rogoff, 2007). Specifically, the integration of low-wage Chinese workers to the global economy may have exerted downward pressure on wages and prices across the globe. These effects may have affected the sensitivity of domestic economic relationships to external influences relative to domestic factors (IMF, 2013). Moreover, China has also influenced inflation dynamics in a different manner. Its increasing demand across the world pushed commodity prices up—particularly food and oil—for much of the early 2000s. However, this process stalled with the GFC. Investments triggered by high commodity prices in the early 2000s helped stabilize commodity prices following the crisis. Nonetheless, subsequent shocks (such as the 2014 oil shock) brought commodity prices down. Some studies have argued that much of the contribution of global factors to inflation dynamics is associated with commodity price shocks (Kamber and Wong, 2018). Moreover, they also argue that global factors help explain a sizeable portion of the inflation gap (i.e., the deviation of inflation from trend) but play a limited role in the evolution of trend inflation.

Box 1. Drivers of Inflation Over the Last Three Decades: Alternative Explanations (Concluded)

The international integration of global production processes resulting from new technologies and lower trade barriers also appears to have influenced inflation dynamics across the world (Auer et al., 2017). Specifically, global value chains (GVCs) understood as the cross-border trade in intermediate goods and services have been playing an increasingly important global role. Auer et al. (2017) report empirical evidence showing that GVCs have been a key factor behind the growing importance of the global output gap in determining domestic inflation. Resembling the global supply chain argument, the automation of the global economy could also change the responsiveness of inflation to domestic economic slack. Specifically, to the extent automation substitutes for labor, it could reduce workers' wage bargaining power. There is evidence showing that there is a link between the flattening of the Phillips curve and automation in Emerging Asia (IMF, 2018b).

1/ These trends are present even after excluding sharp fluctuations of commodity prices and other volatile components of inflation.

2/ The great moderation has been largely associated with the relatively stable macroeconomic environment.

3/ Other traditional approaches to inflation have also failed to adequately describe inflation trends. For instance, the traditional monetaristic argument that massive central bank balance sheet operations in advanced economies in the aftermath of the global financial crisis (GFC) would lead to higher inflation, failed to materialize.

4/ Ciccarelli and Mojon (2010) estimate that a common factor explains nearly 70 percent of inflation across 22 OECD countries.

In this paper, we aim to contribute to a better understanding of inflation dynamics over the past few decades. First, building on the observation that any digital connectedness requires IP addresses, we propose a new proxy for gauging the extent of digitalization: the number of IP addresses per country. This proxy captures the degree of penetration, use, and the resulting interconnectedness associated with the digitalization process. The indicator has global coverage and is available on a monthly basis for all countries in the world since the early 1990s. Second, we explore the role of digitalization as a driving factor of cross-country domestic inflation developments using existing national price indexes. Third, we quantify the impact of digitalization on inflation and we test for the relative importance of various transmission channels. Finally, we examine whether global factors are driving inflation and examine the extent to which these factors are correlated with our digitalization proxy.

Specifically, we conduct a cross-country econometric analysis to assess whether digitalization has been affecting inflation.[5] To this end, we estimate Phillips curves using panel regressions and test for the importance of key transmission channels in a sample of 36 economies. Our analysis finds evidence in favor of the hypothesis that digitalization has been a statistically significant driver of domestic inflation, contributing to lowering it since 2012. Our results suggest that since mid-2012 the digitalization process has contributed on average to reduce annual inflation by 0.05 percentage points. This is in line with some country studies showing that changes in prices of information and communication technology and e-commerce appear to account for only a small share of inflation developments over time (Charbonneau et al, 2017). Nonetheless, it is evident from the cumulative effect of these

[5] The sample is mainly restricted by the availability of adequate data at a high frequency.

estimates that digitalization has had a non-negligible effect on the price level over the same period. We also find that the impact of digitalization on inflation mainly operates through a direct and indirect cost/competition channel. However, we find no conclusive evidence that digitalization affects inflation through expectations formation. These conclusions echo country-case studies showing that the downward pressure of digitalization on inflation is most likely to occur through the impact of increased competition on productivity (Charbonneau et al, 2017).

Our paper also examines the importance of digitalization as a factor that drives trend inflation. Using principal component analysis, we show that inflation can be decomposed into three well-defined factors that explain over two-thirds of the variance of inflation in our cross-country sample. We then show that the second principal component, which captures the structural dynamics of inflation, is cointegrated with our digitalization proxy after controlling for other global factors, such as global value chains and the role of China in the global economy. This analysis suggests that a one-percentage point increase in our digitalization proxy leads to a 1.9 percentage point decline in the second principal component of inflation—which explains more than 10 percent of inflation variation in our sample of countries in the long run. This is evidence that digitalization acts as a global force that lowers inflation across the world.

The remainder of the paper is structured as follows. Section II provides an overview of the literature on inflation and puts in perspective the macroeconomic role of digitalization. Section III lays out a simple set up to rationalize the transmission channels through which digitalization can affect prices and inflation. Section IV delves into key concepts of digitalization. It elaborates how to measure it, and our motivations for using IP addresses as a proxy for digitalization. Building on this discussion, Section V presents the econometric analysis of how digitalization affects inflation. After discussing the sample and data employed, we discuss the panel estimates of the Phillips curve and the results on the channels through which it operates. This analysis is then complemented by exploring the presence of common factors driving inflation and whether these can be explained by our digitalization proxy vis-à-vis other global factors. A final section concludes.

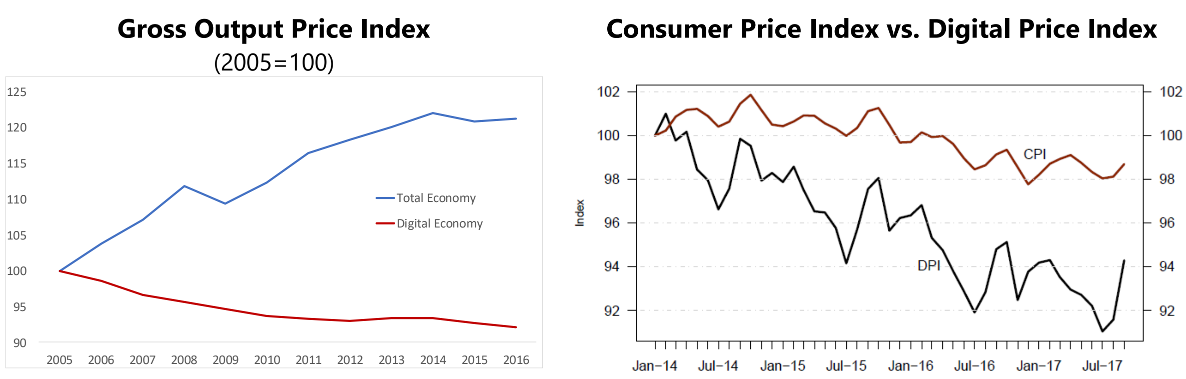
II. A Literature Review

An emerging strand of literature has examined the impact of digitalization on prices and inflation. This literature has mainly focused on the microeconomic formation of prices on-line and compared its dynamics with off-line prices (Gorodnichenko et al., 2018; Cavallo and Rigobon, 2016; Cavallo, 2017, 2018a). Some studies have used online price data to develop new price indexes at higher frequencies than prices collected by statistical agencies in consumer price indexes (CPIs). This helps mitigate measurement biases that distort evidence of price stickiness and the law of one price (Cavallo and Rigobon, 2011; Cavallo et al., 2014, 2015; Cavallo, 2018a, 2018b).[6] These new indexes are now being used to gain insight into the formation of prices, inflation expectations, and the international law of one price.

Online prices can exhibit very different patterns relative to official consumer prices indexes or scanner prices (Cavallo and Rigobon, 2016). These are also often considered to entail low search costs for consumers and firms face no "menu" costs. Online prices display less dispersion than prices in offline markets (Gorodnichenko et al., 2018). Online prices have also been used to show that inflation expectations are influenced not only on the basis of information contained in official price statistics, but also through other less representative information sources, such as individual goods price changes (Cavallo and Rigobon, 2016).

Studies have shown that online platforms' price levels and inflation are lower than those offline (Figure 1 and Goolsbee and Klenow, 2018). Also, they tend to be more flexible, display greater exchange rate pass-through, and faster convergence (Gorodnichenko et al., 2018). Furthermore, they have spillover effects on offline markets, promoting price flexibility and reducing price dispersion (Cavallo, 2018a). Nonetheless, online prices still exhibit imperfections, such as price stickiness and large cross-sectional dispersion that are also associated with offline prices (Cavallo, 2017; Gorodnichenko et al., 2018). Quite importantly, online prices have been found to be unresponsive to aggregate demand shocks and to closely follow individual demands (Gorodnichenko et al., 2018). A few papers have also compared prices across countries to test for purchasing power parity (PPP). The evidence shows that the law of one price for online prices generally holds well for countries using the same currency (Cavallo et al., 2014, 2015).

Figure 1. Digitalization and Prices: Some Evidence from the U.S.



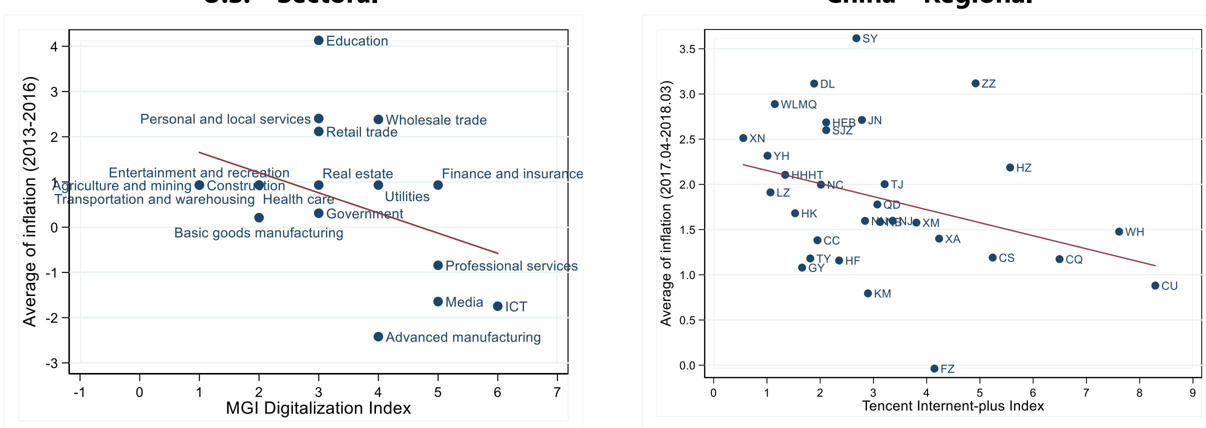
Source: BEA and Goolsbee and Klenow (2018), respectively.

[6] For example, reasearch has shown that traditional measurements of price dynamics carry measurement biases due to infrequent sampling and slow updates of the baskets (Cavallo, 2018; Cavallo and Rigobon, 2016, 2011).

While the advances in understanding the microeconomic formation of online prices and how they relate to off-line prices are important, only a handful of studies have focused on the macroeconomic impact of digitalization on price dynamics. Moreover, to our knowledge, no paper empirically examines these issues on a cross-country basis.[7] Scattered evidence suggests that there is a negative impact of digitalization on prices. For example, simple correlations show a clear relationship between the degree of digitalization and inflation across sectors in the U.S. or across regions in China. The former is evident by examining the correlation between the average annual inflation rates for U.S. industries between 2013-2016 with McKinsey's MGI Industry Digitization Index for 2016 (left-hand panel of Figure 2). As shown, industries with a higher level of digitalization (e.g., ICT sector, media sector, professional service sector) tend to have more muted price trends. The latter is evident from the negative correlation between Tencent Research Institute's digitalization index in 2017 and the average inflation rates for the 36 main cities in China over the previous 12 months (right-hand panel of Figure 2).

Figure 2. Sectoral and Regional Evidence

U.S.—Sectoral | **China—Regional**



Source: International Financial Statistics, National Bureau of Statistics of China, McKinsey Global Institute, and Tencent Research Institute.

III. A FRAMEWORK TO UNDERSTAND HOW DIGITALIZATION AFFECTS INFLATION

Digitalization can affect price levels in a gradual and staggered manner and thus affect inflation through different channels. For example, Charbonneau et al. (2017) describe three main channels: (i) a direct channel, in which prices of ICT-related goods and services decline

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[7] An early attempt is the paper by Yi and Choi (2005) who find evidence suggesting that a one percent increase in the number of internet users reduces inflation by 0.04-0.13 percentage points. See also the surveys by Charbonneau et al. 2017; Coffinet and Perillaud, 2017; Buchheim and Kedert, 2016.

as a result of technological change;[8] (ii) by changing the market structure and competition of different goods and services, including through possibly lower barriers to entry, the emergence of superstar firms, and the rise of e-commerce and thus easier price comparisons; and (iii) through enhanced productivity, thereby lowering operational costs.

To some extent, these channels can be captured in standard macroeconomic inflation models. To formally conceptualize the channels through which digitalization can affect inflation (π_t), we start from the observation that in standard models of price stickiness (e.g., Calvo pricing or optimal dynamic adjustment models) the general formulation for price changes is captured by[9]:

$$\pi_t = \alpha \pi_t^* + \beta E_t \pi_{t+1} \qquad \text{Eq. (1)}$$

where $\pi_t = \Delta p_t$ and $\pi_t^* = p_t^* - p_{t-1}$. That is, firms set prices so that the actual price change is determined by a weighted average of the desired optimal price change, π_t^*, and the expected future change in prices, $E_t \pi_{t+1}$—where p_t^* is the optimal price. Expressing this equation in terms of price levels and solving the forward-looking solution, it is possible to rewrite the equation (1) as:[10]

$$\Delta p_t = -\left(1 - \frac{\beta}{1-\alpha}\right)\pi + \frac{\alpha}{(1-\alpha)}(p_t^* - p_{t-1}) + \frac{\beta}{1-\alpha} E_t \Delta p_{t+1} \qquad \text{Eq. (2)}$$

Given the standard result that under imperfect competition prices are set as a markup over the marginal cost, digitalization can influence inflation through its impact on firms' marginal costs and their mark ups. Digitalization may reduce marginal costs due to increases in productivity (direct effect) or by reducing its response to demand pressures (indirect effect). The latter is possible if digitalization changes the market structure of the economy, say, by influencing the elasticity of final (e.g., the price elasticity of demand) or intermediate (e.g., the labor supply elasticity) goods. Formally, let optimal prices (p_t^*) be set as a mark-up (μ_t) over marginal costs (mc_t):

$$p_t^* = \mu_t + mc_t \qquad \text{Eq. (3)}$$

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[8] The extent of the impact depends on the share of these goods and services in the CPI basket, as well as on price measurement issues associated with the introduction of new goods and services or increased customization.

[9] We follow the discussion of inflation dynamics in a general equilibrium framework by Wickens (2011), in particular, Chapter 9.

[10] The intercept $-\left(1 - \frac{\beta}{1-\alpha}\right)\pi$ is included to ensure the equation has a solution in the long-run.

The markup is determined by the inverse of the price elasticity of demand, $\epsilon_{X,t}(d)$, which is assumed to be a function of the degree of digitalization of the economy, d.[11] That is $\mu_t(d) = \frac{1}{\epsilon_{X,t}(d)}$. Hence, to the extent that digitalization increases the range of substitute goods, the elasticity of demand is likely to change.

Moreover, assuming for simplicity a single factor of production, say, labor, firms' marginal costs can be expressed as a function of the labor mark-up ($v_t \cong \frac{1}{\epsilon_{D,t}(d)}$), the nominal wage ($w_t$), and the marginal product of labor (mp_t):[12]

$$mc_t(d) = v_t(d) + w_t(d) - mp_t(d) \qquad \text{Eq. (4)}$$

where each component has the potential to be influenced by the digitalization process. It is not difficult to rationalize why this would be the case, given the ample evidence showing that digitalization affects labor productivity, labor mark-ups, or wages (IMF, 2018c, Muro et al., 2017).

Now, assuming a Cobb-Douglas production function, it is possible to show that the marginal product of labor, mp, can be expressed as a function of labor productivity (a_t) and the level of output y_t:

$$mp_t(d) = \ ln\phi + \frac{a_t(d)}{\phi} - \frac{1-\phi}{\phi} y_t(d) \qquad \text{Eq. (5)}$$

where ϕ is the demand elasticity of substitution across different variety of goods.[13] Given that digitalization is a general-purpose technology, we can safely assume that labor productivity, a_t, and output, y_t, are directly influenced by the digitalization process.[14] Hence, combining equations (3-5) allows to derive the optimal price, which can be expressed as:

$$p_t^*(d) = \ -ln\phi + \mu_t(d) + v_t(d) + w_t(d) - \frac{a_t(d)}{\phi} + \frac{1-\phi}{\phi} y_t(d) \qquad \text{Eq. (6)}$$

[11] Formally, the digitalization process is a function of time. We simplify notation here and refer to this process as *d*, without using the time subscript t.

[12] The impact of digitalization on labor markets is probably the one that has received greatest attention in the macroeconomic literature so far.

[13] This expression is derived from a firm's profit maximization process taken as given the consumer demand for its goods. The standard first-order conditions determines that price is a markup over the marginal cost of an extra unit of output, i.e. $\frac{\phi}{1-\phi}\frac{W_t}{F_t'[n_t(i)]}$ where $\frac{W_t}{F_t'}$ is the marginal cost of an extra unit of output.

[14] This is possible, say, if digitalization improves production plans.

Next, combining equation (2) and (6) allow us to express inflation as a function of past and expected inflation, the output gap, technology, the real return of production factors (i.e. real wages), and cost push shocks (i.e., as captured by the markup over marginal cost and the labor mark-up). Formally, if firms minimize the deviation of their prices from optimal levels, inflation (π_t) is determined by:[15]

$$\pi_t(d) = \left(1 - \frac{\beta}{1-\alpha}\right)\pi(d) + \frac{\beta}{1-\alpha}E_t\pi_{t+1}(d) + \frac{\alpha(1-\phi)}{(1-\alpha)\phi}\tilde{y}_t(d) -$$

$$\frac{\alpha}{(1-\alpha)\phi}\tilde{a}_t(d) + \frac{\alpha}{(1-\alpha)\phi}\left(\tilde{w}_t(d) - \tilde{p}_t(d)\right) + \frac{\alpha}{(1-\alpha)}[\mu_t(d) + v_t(d)] \qquad \text{Eq. (7)}$$

where α is the Cobb-Douglas elasticity of factor (labor) demand, and β the intertemporal discount factor.[16]

We have shown that inflation can be influenced by the digitalization process and that its impact can be captured by a New Keynesian type Phillips curve setting (Rudd and Whelan, 2007). Specifically, Eq. (7) formalizes the various channels though which digitalization is assumed to affect inflation, mainly through (i) inflation expectations, (ii) by altering the price response to the output gap (i.e., by changing the slope of the Phillips curve), or (iii) by affecting marginal costs. That is, it could affect inflation by affecting technological change, the cost of factors of productions, and altering the degree of competition—including any barriers to entry—and therefore of market structures as captured by its mark-ups. This set up is in line with recent surveys on the impact of digitalization on inflation, which highlight the role of these various factors (Charbonneau et al. 2017; Coffinet and Perillaud, 2017).

IV. How Can Digitalization Be Measured?

Conceptually, digitalization is the process of converting any information into a digital format, that is, a string of zeros and ones.[17] The process is circumscribed by the generation, processing, sharing, and transaction of information that leads to economic and social transformation (Katz et al., 2014). It involves the infrastructure that gives rise to networks (including the internet and network platforms), information technology services (IT), and digital goods and services. Digitalization is a general-purpose technology, affecting many

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[15] Where deviations from equilibrium are denoted by a tilde e.g., $\tilde{p}_t(d) = p_t(d) - p_t^*(d)$

[16] This specification embeds different price-setting models generating price-stickiness, such as the Taylor model of overlaping contracts, the calvo model of staggered priced adjustment, or Rotenberg's optimal adjustment model.

[17] This narrow definition is also used to describe digitization. However, the literature usually uses the terms 'digitalization' and 'digitization' interchangeably. See Table 1.

sectors of economic activity, characterized by continued improvements over time and declining costs of use, while helping produce new products or generate new production processes.[18] It also transforms agents' economic behavior and market structures across the board (IMF, 2018c; Zimmerman, 2000). Such evolving process leads to dynamic efficiency gains (Carlsson, 2004) and is likely to influence price dynamics across the globe.

Information or knowledge is not new, but the form in which it is gathered, manipulated, stored, and *transferred* is a relatively recent phenomenon (Carlsson, 2004). We have italicized *transferred*, because a key element of the digitalization process is the emergence of the internet, which has increased the interconnectedness of the economy in manner that was unthinkable before it went live in the early 1990s.[19] Internet has exponentially increased the state space of information exchange, and therefore of innovation and the scope of change and transformation of the global economy. Echoing Carlsson (2004), when connections change, so does the structure of the system and with it, its dynamic properties. This interconnectivity is at the heart of what we consider digitalization today.

A. Current Measures of Digitalization

There are significant ongoing efforts to measure the digital economy (IMF, 2018c). In general, the goal has been to map aspects of the digital process into measures and indices of digitalization (Table 1). However, the scope and coverage to measure digitalization varies greatly. One approach has been to distinguish between the "digital sector" and the increasingly digitalized modern economy or "digital economy". The former covers core activities of digitalization, online platforms, platform enabled activities or e-commerce (IMF, 2018c; Goolsbee and Klenow, 2018).[20] The latter tends to include all activities that use digital data in the entire economy (IMF, 2018c). For example, the U.S. Bureau of Economic Analysis has developed a conceptual definition of the digital economy in terms of the internet and related information and communication technologies (ICT) that focuses on the digital enabling infrastructure, e-commerce, and the digital media (Barefoot et al., 2018).

Alternatively, there have been efforts to put forward comprehensive measures of the extent of digitalization at a country-level for a large group of countries. These include the *Network Readiness Index* by the World Economic Forum, the *Digital Economy and Society Index* by

[18] These three characteristics are referred in the literature as pervasiveness, improvement, and innovation spawning (Jovanovic and Rosseau, 2005).

[19] Varian (1996), MacKie-Mason and Varian (1994, 1996) discuss some basic facts of the Internet and related economic issues and impacts such as online pricing, market structure, etc.

[20] For instance, the McKinsey Global Institution and Brookings have constructed a digitalization index for industry/occupational level for the United States, while PWC has a similar industry level index for the EU countries.

Table 1. Summary of Selected Digitalization Indexes

Indicator	Description	Provider and Coverage	ICT Measurement Coverage 1/
Networked Readiness Index (NRI)	A composite indicator made up of four main categories 10 subcategories, and 53 individual indicators (ICT regulation, infrastructure, affordability, skills, usage, impacts etc.)	World Economic Forum Country level 139 countries, 2012–16	🟥🟨🟩🟦🟪⬜
Digital Economy and Society Index (DESI)	30 relevant indicators across five main dimensions: Connectivity, Human Capital, Internet usage, Digital Technology Integration, Digital Public Services	European Commission Country level 28 European countries, 2014–18	🟨🟦🟪
The Digitization Index	Based on 6 dimensions: affordability, reliability, capacity, access, usage and skills.	Katz el al. (2014) Country level 184 countries, 2004–11, selected countries 1995–11	🟥🟨🟩🟪
The Digitization Index (DiGiX)	DiGiX is structured around six principal dimensions: infrastructure, households' adoption, enterprises' adoption, costs, regulation and contents.	Cámara and Tuesta (2017) Country level 100 countries, year 2015	🟥🟨🟩🟪⬜
Digital Adoption Index (DAI)	Based on three sectoral sub-indices covering businesses, people, and governments (access, hardware, online services etc.)	World Bank Country level 171 countries, year 2016 only	🟥🟨🟦
MGI Industry Digitization Index	Metrics include: assets, usage, labor.	McKinsey Global Institute (2015) Sector level 22 US sectors, year 1997, 2005, 2013	🟥🟨🟪
Industry Digitization Index	Four dimensions of business: digital input, digital processing, digital output and infrastructure.	Friedrich et al. (2011) (Strategy&, PWC) Sector level European Union (27 countries), 2009-2012	🟥🟦
ICT Development Index (IDI)	Before 2009, it was the Digital Opportunity Index (DOI). It mainly focuses on ICT development (access, usage, skills)	International Telecommunication Union (ITU) Country level 176 countries, 2009–17	🟥🟨🟨🟦🟪
US Occupation-specific digital scores	used O*NET survey data to collect information about the knowledge, skills, tools and technology, education and training, work context, and work activities required for jobs.	Muro et al. (2017) (Brookings) Sector/occupation level 545 analyzed occupations, 23 industry groups, 2002–16	🟦🟪
China Internet-plus Index	The "Internet+" Index is published annually by Tencent Research Institute since 2015. It is constructed from four main aspects: digital economy, digital government, social network and digital entertainment.	Tencent Research Institute	🟨🟦

1/ Dimensions of digitalization:

🟥 Infrastructure 🟩 Affordability 🟪 Related Human Skills
🟨 Access and Usage 🟦 Integration Level/Impact ⬜ Regulatory Environment

Source: Staff summary from various sources.

the European Commission, the *Digital Adoption Index* by the World Bank, and the *ICT Development Index* for the International Telecommunication Union. These indexes aim at capturing distinct aspects of the process, including: (i) infrastructure; (ii) access and usage;

(iii) affordability; (iv) integration level and impact; (v) related human skills; and (vi) the regulatory environment (e.g., Katz et al. 2014, Camara and Tuesta, 2017). While comprehensive, a drawback of these indicators is that they tend to have limited country and/or regional coverage, small time spans, and often are only available at low-frequencies (e.g., annual).

B. A High-frequency Proxy for Digitalization

We propose in this paper a new proxy to gauge the impact of digitalization on inflation: the number of internet protocol (IP) addresses. An IP address is a numerical label assigned to each device—computer, cellphones, cameras, printers, and/or any other electronic device—connected to a computer network that use the Internet protocol for communication. It thus serves as an identification for every device connected to the Internet.[21] Since every device that connects to the internet needs to identify itself, the IP address captures the extent and penetration of available infrastructure in a country and, therefore, the extent of access and usage of connected devices. It thus provides a proxy for the degree of digital interconnectedness that is available for all countries in the world at a monthly frequency.

Our analysis relies on the most common current versions of IP, the Internet Protocol version 4 (IPv4) and version 6 (IPv6). Their formats are summarized in (Table 2).[22] IPv4 has been in place since the 1980s and is the most widely used in the world. However, with the rapid advance of the digitalization process the demand for IP addresses has exploded over time—including the number of devices connected to the internet (Figure 3). Anticipating that the global demand would rapidly outpace the supply of IPv4 addresses, a new internet protocol, the IPv6, was introduced and launched on June 6, 2012.[23] The IPv6 fulfills a similar role to

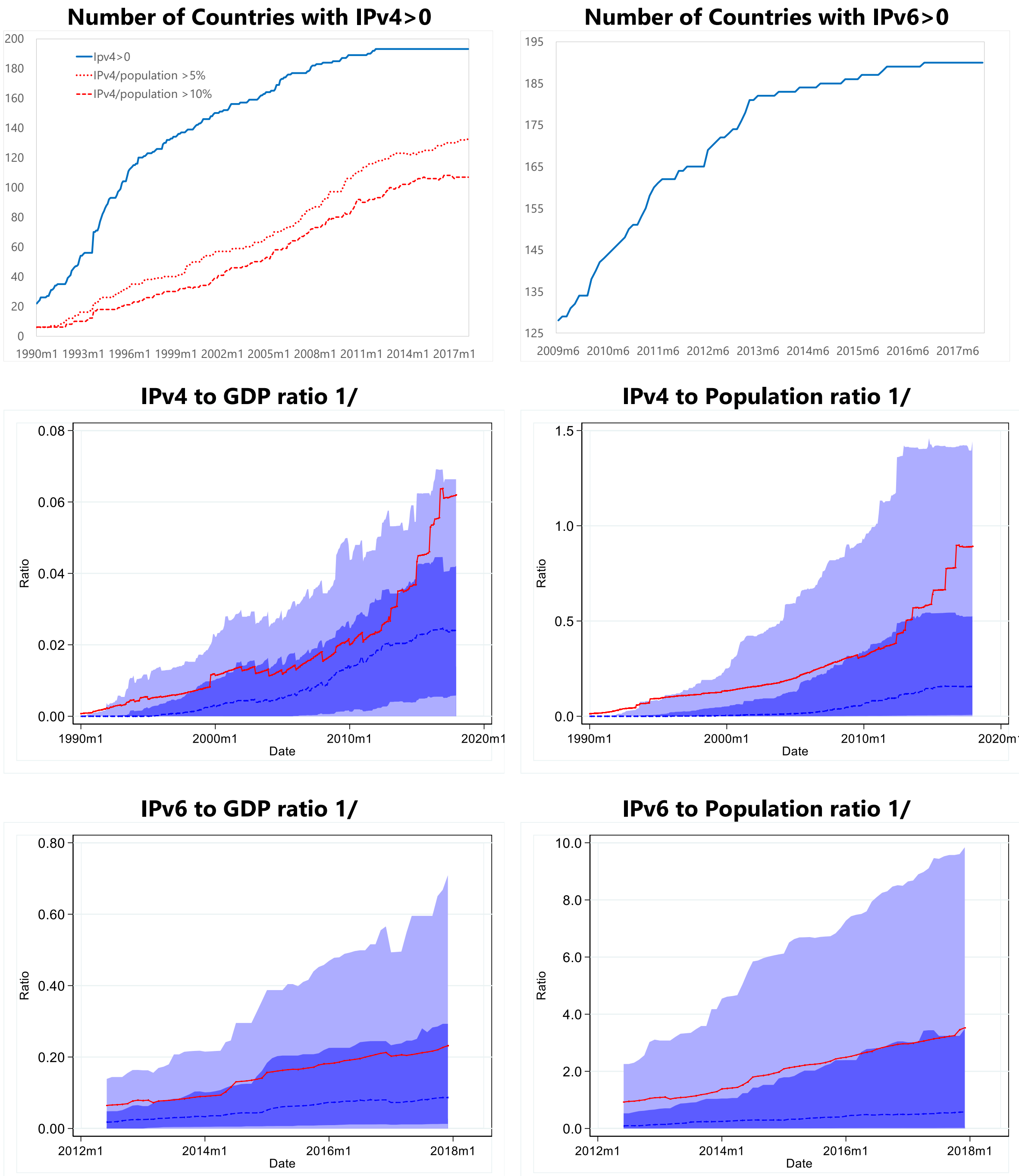
[21] The IP also identifies packages of data. Data transmitted on the internet are fragmented into small units, called IP packets (e.g., webpages, emails, and any other digital media). Thus, any IP packet contains data and two IP addresses, one for the sender and one for the receiver. Hence, the IP is a set of rules defining how devices communicate in the form of IP packets and using IP addresses. See https://en.wikipedia.org/wiki/IP_address.

[22] The IPv4 address uses dot-decimal notation with 32-bit (4 bytes) format. This is a format for numerical data consisting of a string of decimal numbers, each pair separated by a full stop (dot). For the IPv4 address, the 32 bits are divided into four octets written in decimal numbers (ranging from 0 to 255) and concatenated as a character string with full stop delimiters between each number. For example, the loopback interface address (i.e., the routing of electronic signals, digital data streams, or flows of items back to their source without intentional processing or modification, say, for testing the transmission or infrastructure) is usually assigned as 127.0.0.1. This consists of four octets: 01111111,00000000,00000000, and 00000001. The overall 32-bit number is represented in hexadecimal representation (i.e. base of 16) as 0x7F000001. This supports a total space of 4,294,967,296 or 2^32 addresses.

[23] IPv6 was developed between 1993 and 1998 and tested on June 8, 2011 by over 400 major web companies enabled and tested it on their main websites for 24 hours. See IPV6 launch at http://www.worldipv6launch.org/

Figure 3. Penetration of Digitalization

Number of Internet Protocol Addresses and Relative Ratios, Global Sample



Source: IP address dataset.
1/ Shades display the 10th and 90th (light blue) and 25th -75th (dark blue) inter-percentile range, respectively. The red line corresponds to the global mean.

the IPv4 but has a much larger address space.[24] Also, it provides a more efficient route aggregation and other special addressing features, but is not interoperable with IPv4, creating a parallel independent network. Data transmission between the two requires translator gateways. Since its launch, the participation and usage of IPv6 around the world has continued to grow.

Table 2. Internet Protocol Formats

	IPv4	IPv6
Length	Length: 32bits long (4 bytes)	128 bits long (16 bytes)
Format	4 group of numbers	Hexadecimal strings
	xxx.xxx.xxx.xxx, where 0<=xxx<=255	xxxx : xxxx : xxxx : xxxx : xxxx : xxxx : xxxx : xxxx **Network Prefix** (Describes the network location) — **Interface ID** (Provides unique identifying number)
Example	*192.0.2.53*	*2001:0db8:582:ae33::29*

Source: IBM knowledge center and author summary

The data that we use in this paper on the total number of IPv4 addresses are provided by the Asia-Pacific Network Information Centre (APNIC). It is available for 193 countries and regions between 1990 and 2018. These addresses are allocated by the Regional Internet Registry to service providers or private or public entities. The IPv6 is obtained from the same source, has similar country coverage, and is available since 2009. The proposed indicator captures the number of the 48 prefixes (since the number of individual 128-bit IPv6 addresses is too large), which is proportional to the total number of addresses. As shown in Figure 3, the deployment process of IPv6 is consistent with the IPv6 prefixes allocation data.[25]

While IP addresses have advantages as a proxy for digitalization, there are some caveats and other operational issues to consider. For example, its allocation is highly but not perfectly correlated with the usage of addresses.[26] Also, a zero in the data cannot be interpreted as zero digitalization level. This highlights the intrinsic difficulties of constructing reliable data on internet traffic, especially if we want to aggregate them by countries.[27] Nonetheless, the IP proxy offers many advantages, including its global coverage, high frequency, and public availability. Moreover, it is an effective proxy for digitalization as indicated, for example, by its correlation with the World Economic Forum's Network Readiness Index (Figure 4).

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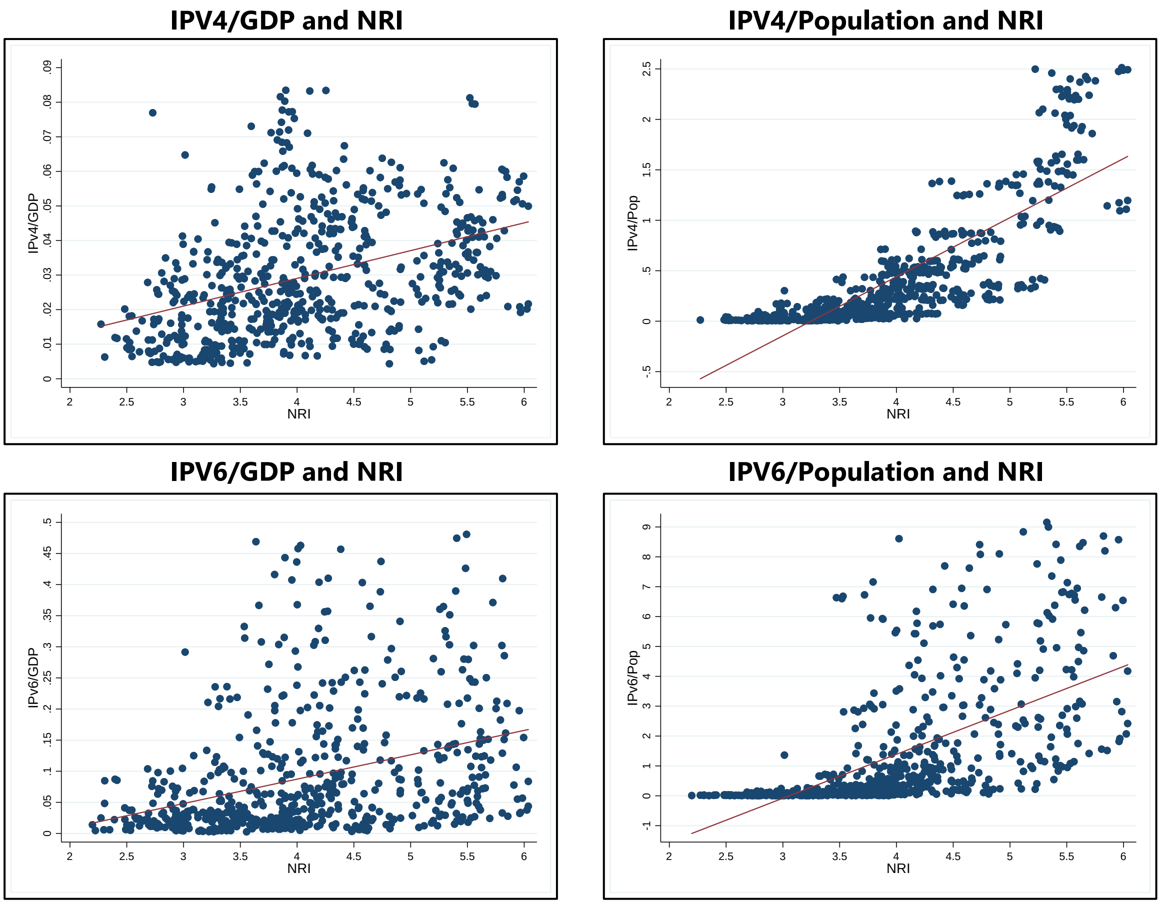
[24] The space is 2^{128} or approximately 340 undecillion addresses—10^28 times larger than the IPv4 addresses space. The IPv6 address has a 128 bit long (16 bytes) format containing eight groups of four hexadecimal digits.

[25] See Annex II for country-specific data on IP addresses.

[26] The allocation of an IP address does not necessarily imply that they are being used. Nonetheless, according to APIC, "there is a reasonable correlation between the country of allocation and the country of use". Another issue is that the allocated addresses may not have a 1:1 relationship with connected devices, since the widespread use of "network address translators", particularly in IPv4, allows an IP address to be shared across multiple devices.

[27] See *Data guzzlers* in the Economist. https://www.economist.com/graphic-detail/2011/06/01/data-guzzlers

Figure 4. Correlation of IP Addresses and the Network Readiness Index (NRI) 2012–16



Source: IP address dataset, World Economic Forum.

V. Data and Econometric Analysis

We now examine whether digitalization influences inflation dynamics in a sample of 36 advanced and emerging market economies. The analysis relies on the longest sample possible (January 1990-December 2017) at a monthly frequency. Using high frequency data allows to explore possible structural breaks (e.g., associated with the introduction of IPv6) using 60-month rolling-regressions. The sample of countries employed in the analysis is thus mainly determined by the availability of various global or country level macroeconomic indicators at a monthly frequency—e.g., appropriate measures of economic activity.[28]

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[28] The sample includes the following economies: Austria, Belgium, Brazil, Bulgaria, Canada, Chile, Colombia, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hong Kong SAR, Hungary,

To conduct the analysis, we start by constructing a monthly digitalization index by country, $D_{i,t}$. Specifically, we calculate the weighted average of the growth rate of IPv4 ($g_{i,t}^{IPv4}$) and IPv6 ($g_{i,t}^{IPv6}$), with the weights equal to the country-specific penetration of IPv4 or IPv6 relative to their global penetration in per-capita terms, specifically:[29]

$$D_{i,t} = \alpha_{i,t}^{IPv4} \cdot g_{i,t}^{IPv4} + \alpha_{i,t}^{IPv6} \cdot g_{i,t}^{IPv6} \qquad \text{Eq. (8)}$$

where

$$\alpha_{i,t}^{IPv4} = \frac{\frac{IPv4_{i,t}}{pop_{i,t}} \Big/ \frac{\sum_i IPv4_{i,t}}{\sum_i pop_{i,t}}}{\left[\frac{IPv4_{i,t}}{pop_{i,t}} \Big/ \frac{\sum_i IPv4_{i,t}}{\sum_i pop_{i,t}} + \frac{IPv6_{i,t}}{pop_{i,t}} \Big/ \frac{\sum_i IPv6_{i,t}}{\sum_i pop_{i,t}}\right]}$$

and,

$$\alpha_{i,t}^{IPv6} = 1 - \alpha_{i,t}^{IPv4}$$

The data for monthly inflation, unemployment, norminal effective exchange rate and bilateral exchange rates (vis-à-vis the U.S. dollar) are from the International Monetary Fund's *International Financial Statistics* (IFS). The one-year-ahead inflation expectations and the annual output gap data are from the World Economic Outlook (WEO) database. Country-specific monthly energy and food inflation are calculated using the *World Bank Commodity Price Index*. China's PPI data come from *Haver Analytics Ltd.* database. Global value chains (GVCs) integration is measured by the foreign value added divided by exports, as reported by the OECD database.

As described in Section IV, digitalization is proxied by the IP address allocation dataset obtained from *Regional Internet Registries* (RIRs). The absolute penetration of digitalization in our sample is captured by the log of the number of IP addresses (Annex II). As shown, economies such as the U.S. or Japan have the most digitalized economies, while Croatia, Slovakia, and Uruguay have the lowest.[30] Summary statistics for all variables are reported in Annex I, and a plot of our digitalization index is presented in Annex II.

Ireland, Israel, Italy, Japan, Latvia, Malaysia, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Spain, Sweden, Switzerland, United Kingdom, United States, and Uruguay.

[29] Measuring digitalization in per capita terms allows to capture its degree of penetration in each country.

[30] The relative degree of penetration varies depending on the reference measure used (e.g., population, U.S. dollar or PPP GDP). However, trends broadly resemble those displayed in Annex II.

A. Does Digitalization Influence Inflation in the Short Run?

We build on the framework developed in Section III to assess whether digitalization can influence inflation in the short-run and to test for the importance of various transmission channels through which this might occur. Formally, our empirical model is depicted as follows:

$$\pi_{i,t} = \delta_1^b \pi_{i,t-1} + \delta_2^f E_t \pi_{i,t+1} + \delta_3^g Y_{i,t}^{gap} + \beta_1^{IP} \cdot D_{i,t-1} + \beta_2^{IP} \cdot D_{i,t} + \beta_3^{IP} E_t \pi_{i,t+1} \cdot D_{i,t} + \beta_4^{IP} Y_t^{gap} \cdot D_{i,t} + \theta_j^z X_{j,i,t-1} + \alpha_i + d_t + \epsilon_{i,t} \quad \text{Eq. (9)}$$

where the inflation rate, $\pi_{i,t}$, is a function of inflation expectations—we assume a backward, δ_1^b, and a forward looking component, δ_2^f— and a measure of economic slack, $Y_{i,t}^{gap}$ with its impact captured by the parameter δ_3^g. We also include other control variables, $X_{j,i,t}$, to capture possible cost shocks, $X_{j,i,t-1}$, associated with commodity prices (e.g., energy and food inflation), or the nominal effective exchange rate, $NEER_{i,t}$, as captured by θ_j^z for $z = neer, ener, food$. The former control enters with a lag to avoid endogeneity issues. Country and time fixed-effects are indicated by α_i and d_t, respectively.

To capture the various channels through which digitalization affects inflation, our digitalization index, $D_{i,t}$, enters the model in **growth rates** influencing: (i) price dynamics, say, by reducing costs via productivity improvements or increased competition, either with a lag β_1^{IP} or contemporaneously β_2^{IP}; (ii) the formation of inflation expectations, β_3^{IP}; or (iii) the price response to domestic demand pressures; that is, we examine whether it has altered the slope of the Phillips curve, β_4^{IP}. In general, we expect digitalization to reduce inflation via the cost-productivity channel (negative sign of β_1^{IP} and β_2^{IP}), to flatten the Phillips curve (positive sign of β_4^{IP}) and to make price formation more forward-looking (positive sign of β_3^{IP}). Finally, the subscript *i* denotes countries, *t* time, and *j* the additional specific control variables.

The unemployment gap is calculated using the Hodrick–Prescott filter.[31] Eq. (9) is estimated using monthly data. The model is estimated using two-way fixed-effects, i.e., time (d_t) and country (α_i).

[31] The unemployment gap is calculated as the ratio of the difference between unemployment and a HP filter series with λ=129,600 and the filtered series.

B. Econometric Results

We report panel results with two-way fixed-effects for the full sample of 1990–2017 in Table 3.[32] The table displays the results for a traditional Phillips curve (Column 1) and then adds in a sequential manner various components that capture the potential channels through which digitalization can affect inflation. These are the cost productivity (Column 2), the slope of the Phillips curve (Column 3), and the expectation (Column 4) channels.

Estimates show that the standard components of the NKPC tend to have the expected signs (Column 1). Lagged inflation as captured by $\boldsymbol{\delta_1^b}$ is highly persistent, positive, and statistically significant across all our specifications. Also, the forward-looking component of inflation, $\boldsymbol{\delta_2^f}$, is positive and statistically significant.[33] As expected, the coefficients for the unemployment gap ($\boldsymbol{\delta_3^g}$) have the right negative sign and are significant in each specification. The nominal effective exchange rates (NEER) have negative and statistically significant effects, i.e., the depreciation of the domestic currency, captured by a lower value of NEER, is associated with an increase in domestic inflation rates. Finally, energy price inflation has the correct positive sign and is significant while food inflation has a significant negative coefficient.[34]

Results suggests that digitalization has on average a negative impact on inflation.[35] This effect operates mainly through the cost-productivity channel, as captured by the negative sign and statistical significance of the lagged coefficient of the digitalization index ($\boldsymbol{\beta_1^{IP}}$) in each specification (columns 2, 3 and 4). However, the overall impact of digitalization on inflation operating through the cost-productivity channel appears to be small.[36] On average a one-percentage increase in the digitalization index reduces inflation by 0.006 percent. We thus estimate that with the observed penetration of digitalization, average annual inflation in our

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[32] For the same specifications using alternative estimates using OLS, time effects, and country FE as well as standardized variables see Annex III.

[33] It is also worth noting that the sum of the coefficients is close to 1 under all specifications which suggest that inflation expectations are indeed formed by both a backward and a forward-looking component.

[34] Although the negative sign of food price inflation is counter-intuitive, it appears to reflect that time fixed-effects captures global food price developments. Indeed, once the time fixed-effect is excluded from the regression, the sign of the coefficient of food prices switches to positive (see Table A2 and A3 in Annex III).

[35] The results are qualitatively robust independently of whether we use the growth rates of the digitalization index or the growth rates of the number of IPv4 or IPv6. The former has the advantage that it allows a more parsimonious analysis for the full sample—as opposed to using each IP address separately in the regressions. The latter, albeit possible, requires using the growth rates of the number of IPv4 and IPv6 addresses separately in each regression. We conducted this analysis, and we also split the sample to run the regression with IPv4 only and IPv6, separately, delivering qualitatively similar results. This analysis—not reported— confirms that results are not driven by the weighting scheme discussed in Eq. (8).

[36] The analysis does not allow further disentangling relevant questions regarding the transmission channel. For example, determining whether the cost channel operates mainly through producers or retailers (see Basker, 2007, or Igan and Suzuki, 2012).

sample declined by about 0.05 percent since mid-2012. These estimate suggest a non-negigible cumulative impact on the price level of about 0.5 percent between mid-2012 and end-2017.

Table 3. Panel Regressions for Inflation (January 1990–December 2017)

Dependent Variable: Inflation

		(1)	(2)	(3)	(4)
Lagged inflation	δ_1^b	0.866***	0.866***	0.866***	0.866***
		(0.038)	(0.038)	(0.038)	(0.038)
Inflation expectations	δ_2^f	0.167***	0.167***	0.167***	0.167***
		(0.047)	(0.047)	(0.047)	(0.050)
Unemployment gap	δ_3^g	-0.364**	-0.365**	-0.366**	-0.366*
		(0.175)	(0.174)	(0.177)	(0.184)
Other controls	θ_1^{neer}	-0.002*	-0.002*	-0.002*	-0.002*
		(0.001)	(0.001)	(0.001)	(0.001)
	θ_2^{ener}	0.441***	0.441***	0.441***	0.441***
		(0.159)	(0.159)	(0.159)	(0.152)
	θ_2^{food}	-0.347*	-0.347*	-0.347*	-0.347**
		(0.175)	(0.175)	(0.176)	(0.168)
Digitalization Cost-productivity channel	β_1^{IP}		-0.006*	-0.006*	-0.006*
			(0.003)	(0.003)	(0.003)
	β_2^{IP}		-0.002	-0.002	-0.002
			(0.003)	(0.003)	(0.005)
Digitalization and the Slope of the Phillips Curve	β_4^{IP}			0.001	0.001
				(0.018)	(0.019)
Digitalization expectation channel	β_3^{IP}				-0.000
					(0.002)
N		9019	9019	9019	9019
R^2		0.983	0.983	0.983	0.983
adj. R^2		0.983	0.983	0.983	0.983

Clustered standard errors in parentheses

* p < 0.10, ** p < 0.05, *** p < 0.01

We do not find any evidence that digitalization has flattened the slope of the Phillips curve during the entire sample as the coefficient, β_4^{IP}, is not statistically significant in Table 3. However, this might be due to the fact that digitalization started playing a more important role in recent periods.

Finally, our results show no evidence that digitalization affects inflation through the expectation channel of price formation. The corresponding estimates (β_3^{IP}) are not statistically significant and have a positive sign.

C. Rolling Regression Analysis

The digitalization of the global economy has been a very dynamic process, so the relationship between inflation and digitalization is likely to have changed over time. To test how this process may have affected the strength of each transmission channel, we estimate the benchmark model using rolling-regressions with a 60-month window starting in January 2009.

Our analysis confirms that digitalization has affected inflation through the cost-productivity channel and, to a lesser extent, by slightly flatenning the slope of the Phillips curve, particularly since 2012.[37] The estimates also show that the impact of the digitalization index operating through the cost-productivity channel is negative during most of the sample (Figure 5, top panel). Although the negative coefficient lacks statistical significance in the early part of the sample, the contemporanaeous and the lagged effect of the index become statistically significant in early-2011 and late-2012, respectively. This is clear evidence that the cost-productivity impact of digitalization has gained importance in recent years. In line with the overall results discussed in the previous sub-section, there is no evidence that digitalization affects inflation through the expectation channel of price formation, apart from a brief period starting late-2011 (Figure 5, bottom panel).

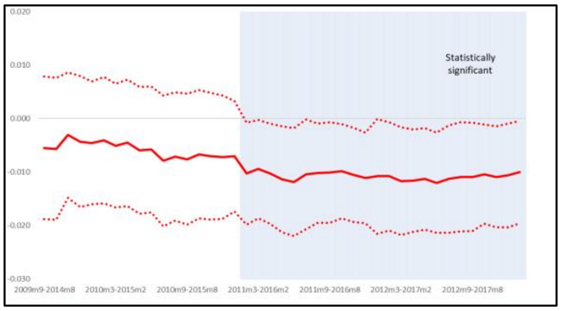
The results also suggest that the digitalization process has altered the slope of the Phillips curve (Figure 5, center panels). The unemployment gap coefficient is negative as expected, and has a declining trend since mid-2010, becoming statististically significant only after late-2011. The interaction term between the unemployment gap and the digitalization index also becomes significant after early-2011, with an increasing positive coefficient. This suggests that the response of inflation to the unemployment gap has weakened with digitalization. In other words, digitalization has on average flattened the Phillips curve over time. The flattening of the Phillips curve is in line with some findings in the literature (e.g., IMF, 2013).

[37] The analysis reported here is based on the preferred alternate model specification reported in Table 3.

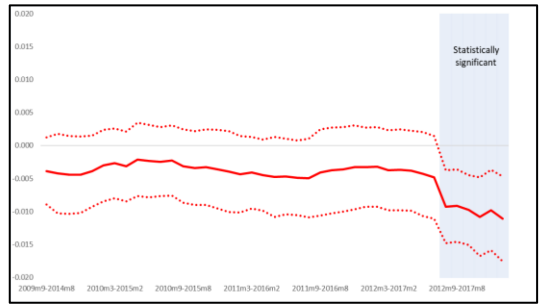
Figure 5. Rolling Regression Results

Cost-Productivity Channel

Contemporaneous (β_2^{IP})

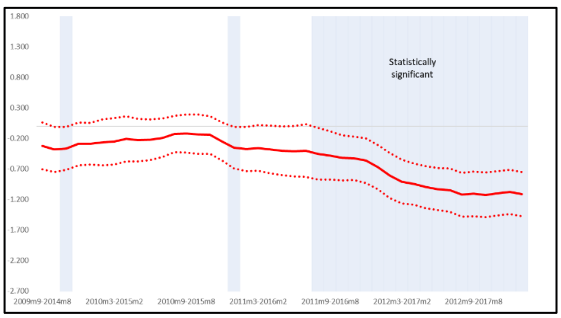


Lagged (β_1^{IP})

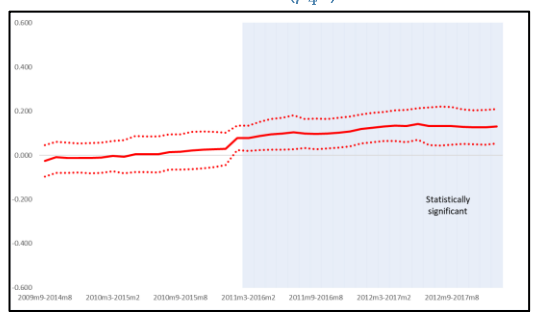


Slope of the Phillips Curve

Unemployment gap (δ_3^{g})

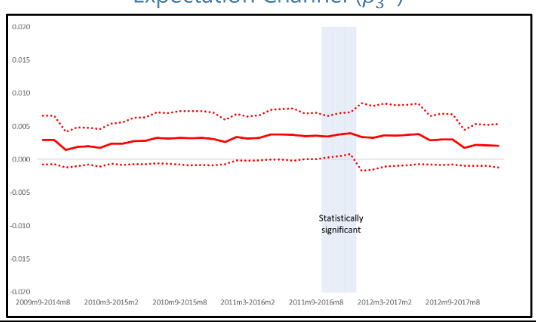


Interaction of unemployment gap and digitalization index (β_4^{IP})



Expectation Channel

Expectation Channel (β_3^{IP})



D. Is Digitalization a Key Global Driver of Trend Inflation?

We now examine whether digitalization is a structural driver of global inflation. To address this question, we use principal component analysis to obtain the main underlying driver of inflation and then use cointegration analysis to determine the explanatory role of our digitalization proxy.

Formally, we decompose inflation for the pool of countries in our sample as:

$$\underset{(1\times p)}{\Pi_t} = \underset{(1\times p)}{f_t}\underset{(p\times q)}{\Lambda'} + \underset{(1\times p)}{\varepsilon_t}$$

where Π is the de-meaned standarized vector of observed inflation; Λ the $p \times q$ factor loading matrix; f the matrix of factors, and ε the vector of errors with diagonal covariance matrix equal to the uniqueness matrix Ψ. In this framework, the correlation matrix Π can be decomposed through principal components as:

$$\Sigma = \Lambda I \Lambda' + \Psi$$

where we have assumed orthogonality between f_t and $\varepsilon_t$and normality in the error term.

E. Global Drivers of Inflation

The principal component analysis indicates that on average over two thirds (68.9 percent) of the inflation variation in our sample can be explained by the first three principal components

Figure 6. Share of Inflation Variation Explained by Principal Components

(In percent)

Source: staff calculations.

of inflation (Figure 6).[38] Moreover, we find that the share of inflation variation explained by these three principal components has increased over time. Their explanatory power peaked during the post-GFC period, explaning more than three fourths (79.1 percent) of the inflation

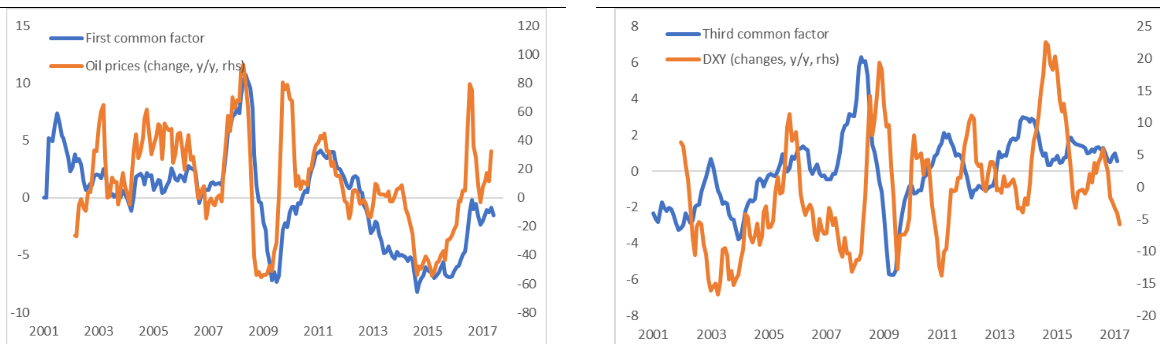
[38] Our focus on the first three principal components is justified because: (i) they explain a sufficiently large share of inflation's variation; (ii) the share of inflation variation explained by the fourth principal component is small; and finally, (iii) the first three principal components were identified.

variation. However, this behavior is mostly due the increasing contribution of the first principal component.

Our analysis also shows that these three principal components are largely associated with global factors. Specifically, the first and the third principal components are correlated with global cyclical factors, while the second principal component is mostly related to global structural factors. Indeed, the first principal component is highly correlated with oil price changes (the correlation coefficient is 0.6). That is, headline inflation is largely driven by energy prices (Figure 7), left-hand panel). The third principal component shows a high level of negative comovement with the U.S. dollar index, particularly since the global financial crisis, as the correlation has increased to about -0.4 (Figure 7), right-hand panel).[39] The intuition here is that this reflects the dollar's dominant role as a numeraire currency for global trade. As a result, changes in the dollar valuation are passed-through to domestic prices.[40]

Figure 7. First and Third Principal Components of Inflation vis-à-vis Oil Prices and the Dollar DXY Index

Cyclical Factor: Oil Prices | **Cyclical Factor: Dollar Index**



Source: staff calculations

The second common factor, reported in Figure 8, explains about 12 percent of the variation in domestic inflation.[41] Its dynamics resembles the global trend in domestic inflation. That is, a general secular disinflation— resembling the great moderation—, followed by recent stability (see Box 1 for a detailed discusison). There are a number of competing explanations for this. For example, the integration of China into global markets served as a positive supply shock to the global economy, possibly exerting a downward pressure on prices. Similarly, the increasing integration of emerging markets into global value chains could have led to a

[39] The U.S. dollar index (DXY) shows the value of the US$ relative to a basket of currencies.

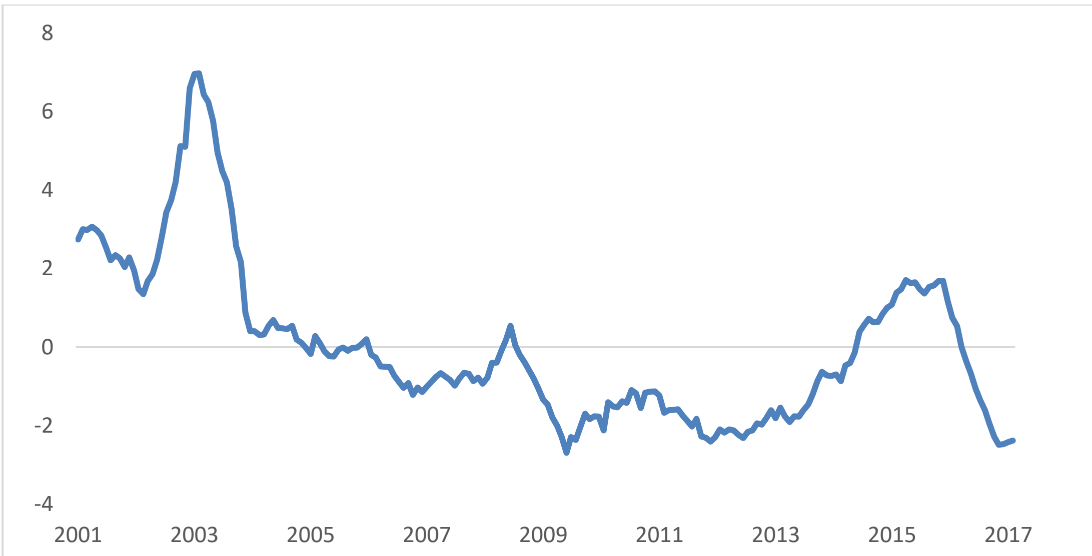
[40] However, the strength of this principal component may have weakened due to the gradual move away from currency pegs to the dollar (IMF, 2018b).

[41] It explains around 20 and 15 percent before and after the GFC, respectively.

decline in tradable goods inflation. Moreover, a number of emerging markets adopted inflation targeting frameworks during this period that likely raised the credibility of domestic policy and produced better-anchored inflation expectations. Finally, the ongoing digitalization process may have contributed to the secular decline in inflation.

Figure 8. Second Principal Component

(In percent)



Source: staff calculations.

VI. Is Digitalization Driving the Global Component of Inflation?

Having established that inflation dynamics can be summarized by the first three principal components, we now proceed to examine which factors drives the second principal component. The goal is to determine whether our digitalization proxy is a key driver of this component. To this end, we assess whether the inflation's second principal component is co-integrated with various proxies for global variables in our sample of 36 countries. Specifically, we consider (i) a proxy to capture the increasing role of China in the global economy, as captured by China's PPI, PPI_{usd}, which is expressed in U.S. dollar terms; (iii) a measure of global value chains (GVC) as captured by an index; and (iii) our proxy for digitalization. The GVC index from OECD is only available at annual frequency, hence we use the same values for the twelve months within a year. The digitalization proxy for each country is calculated using the same weights as in equation (9). Since our goal is to disentangle the role of structural variables, we calculate the weighted average of the level of digitalization in per-capita terms rather than on growth rates as done in the previous sub-section:

$$D_{i,t}^{l} = \alpha_{i,t}^{IPv4} \frac{IPv4_{i,t}}{pop_{i,t}} + \alpha_{i,t}^{IPv6} \frac{IPv6_{i,t}}{pop_{i,t}}$$

Our baseline results indicate the presence of a two co-integration relationships where both digitalization and GVC indexes show negative relationship with inflation (Table 5).[42] Given the possibility of different regimes before and after the GFC, we also perform cointegration tests for these two subsamples, before and after the global financial crises. The analysis shows the the presence of two cointegration vectors for the baseline and the sub-sample of 2009-14 (Table 5).

Table 4. Johansen Cointegration Test

	Rank	Eigenvalue	Trace Test	5% Critical Value of Trace Statistic
Baseline	0		67.49	47.21
	1	0.18	34.05	29.68
	2	0.12	12.37	15.41
	3	0.05	4.37	3.76
Sub-sample 2009-2014	0		111.94	47.21
	1	0.69	37.27	29.68
	2	0.31	13.40	15.41
	3	0.16	2.63	3.76
Emerging Markets	0		61.79	47.21
	1	0.19	27.31	29.68
	2	0.09	11.91	15.41
	3	0.05	3.12	3.76

The cointegration vector suggests that our digitalization proxy and the GVC indices are negatively correlated with the inflation factor (Table 6).[43] We also conduct robustness checks using a wider sample of 36 emerging market economies. Our analysis thus suggests that the second principal component of inflation is negatively associated with the GVC index and our digitalization proxy. We do not find China's PPI to be a significant explanatory variable in the sample's examined.

Overall our results confirm that inflation is largely driven by global factors. Some factors influence the cyclical component of inflation (energy prices and changes in the dollar valuation), while others influence the structural component of inflation: the digitalization proxy and global value chain index. That is, a greater integration of production processes and a deepening of the digitalization process are correlated with lower inflation in the long run. Specifically, a one percentage point increase in digitalization proxy would be associated with a 1.9 percentage point decline in the second principal component of inflation which explains 12 percent of the sample countries' inflation variation in the long run.

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[42] The Johansen cointegration tests are used with 3 lags as determined by various information criteria.

[43] The cointegration vectors are identified by putting zero coefficient restrictions on the PPI_{usd} and digitalization proxy for the first and second cointegration vectors.

Table 5. Cointegration Analysis
(Principal Components of Inflation vis-à-vis Various Competing Theories)

Country Sample	Baseline	Sub-sample 2009-2014	Emerging Markets
Number of cointegration vectors (β)	2	2	1
Cointegration vector			
▪ Digitalization proxy	-1.904***	-5.626***	-22.432***
▪ Global Value Chains (GVC)	-2.159***	-2.264***	-6.462***
▪ China PPI (USD)			0.073
▪ Constant	51.556	64.022	119.279
Lags	4	3	2
Normality Tests			
Jarque-Bera	25000	1519.17	81000
Skewness	976.005	172.12	2978.82
Kurtosis	25000	1347.05	78000

Note: Standard errors in parenthesis. ***, **, * indicate significance at 1,5, 10 percent, respectively.

VII. Conclusions

Given that the digitalization process is transforming the global economy, its macroeconomic implications need to be better understood. This paper aims at filling a gap in the literature by examining whether the digitalization process affects inflation dynamics across the world. Addressing this question is challenging since the digitalization of the economy is a dynamic process. Moreover, there is no agreed definition and no unique measurement for it. Based on the observation that all digital equipment connected to the internet require an IP address, we proposed using the number of IP addresses per country as a proxy for gauging the extent of digitalization (i.e., the degree of penetration, use, and the resulting interconnectedness associated with the digitalization process). This indicator is available at a monthly frequency for all countries in the world since the early 1990s.

Using our proposed digitalization proxy for a sample of 36 economies, our analysis has two main takeaways. Our results show that digitalization is a key determinant of the global trend or structural component of inflation. Also, digitalization has contributed to reducing short-term inflation, particularly since 2012. We also show that digitalization mainly affects inflation through a direct cost/mark-up channel—associated with the impact that digitalization has on costs through improved productivity or through increased competition—and to a lesser extent an indirect cost channel. This channel mainly captures the impact of digitalization on price-setting behaviors, in this manner influencing the slope of the Philips curve over the last few years. Our analysis finds no conclusive evidence suggesting that digitalization affects inflation through the inflation expectations channel.

We recognize that the impact of digitalization may transcend the effects usually captured by current standard measurements of inflation. However, given the rapid penetration and the influence of the digital economy, it is increasingly important for policymakers and economic agents to understand its macroeconomic impact, including on inflation. Given its structural feature, it is difficult for central bankers to take immediate policy actions. Nonetheless, our results suggest that to the extent that the digitalization process affects trend inflation and contributes to bring inflation down, central bankers across the world will increasingly have to monitor the impact of digitalization on price dynamics and whether this has implications for established relationships (e.g., with output gaps). As such and if necessary, central banks will have to recalibrate their policy response to the reality of the new digital world.

Annex I. Summary Statistics

Table A1. Summary Statistics

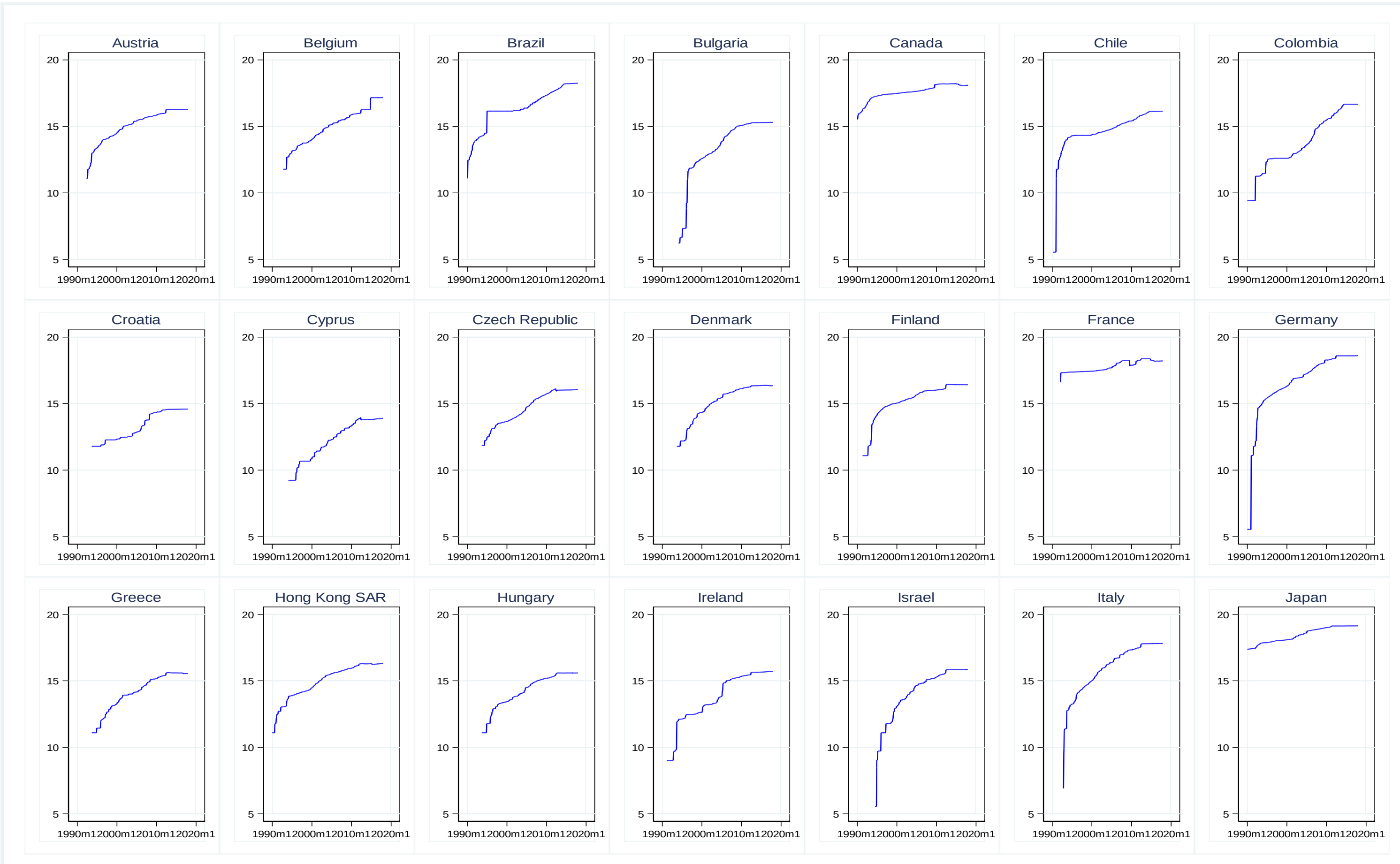
(Monthly Sample, January 1990–December 2017)

	Obs.	Mean	S.D.	Min	P5	P25	P50	P75	P95	Max
Digitalization Index	9019	1.26	2.74	-16.91	0.00	0.02	0.31	1.32	5.82	29.25
Inflation	9019	3.05	4.63	-6.54	-0.59	1.06	2.16	3.60	9.02	78.66
Unemployment gap	9019	0.00	0.11	-0.48	-0.19	-0.06	0.00	0.06	0.16	0.51
Inflation expectation	9019	2.99	3.47	-2.62	0.78	1.70	2.28	3.10	7.46	123.33
NEER	9019	100.80	56.37	53.71	77.52	93.42	98.40	101.93	119.75	1635.65
Energy inflation	9019	0.65	7.07	-28.36	-11.35	-3.35	0.90	4.76	11.36	134.30
Food inflation	9019	0.31	3.73	-22.10	-5.02	-1.99	0.16	2.58	5.84	114.50

Annex II. Digitalization Indicators Across Countries

Figure A1. Penetration of Digitalization by Country

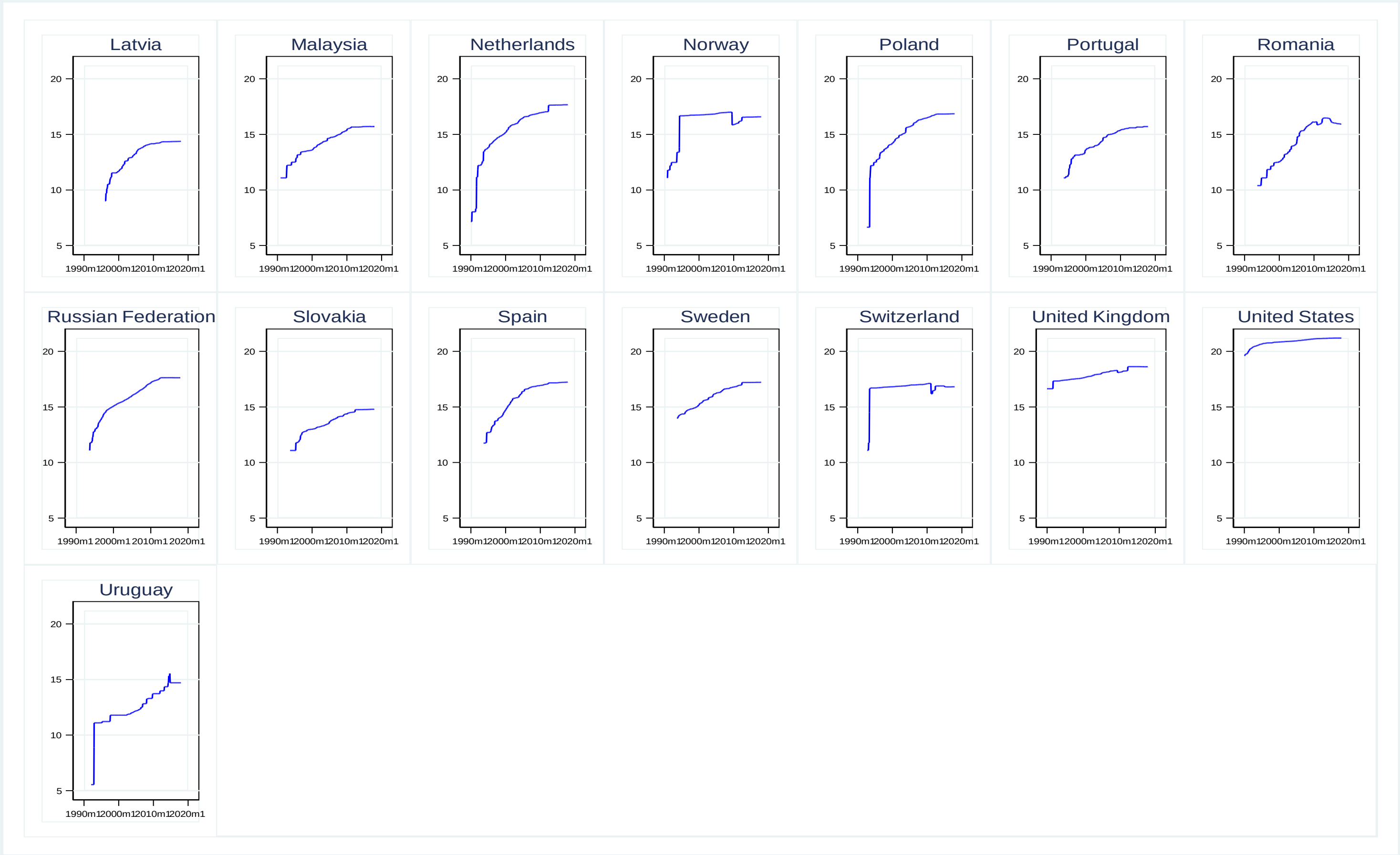
(Number of IPv4 Addresses (Log Scale))



Source: Author's calculations based on IP data set.

Figure A1. Penetration of Digitalization by Country (cont.)

(Number of IPv4 Addresses (Log Scale))



Source: Author's calculations based on IP data set.

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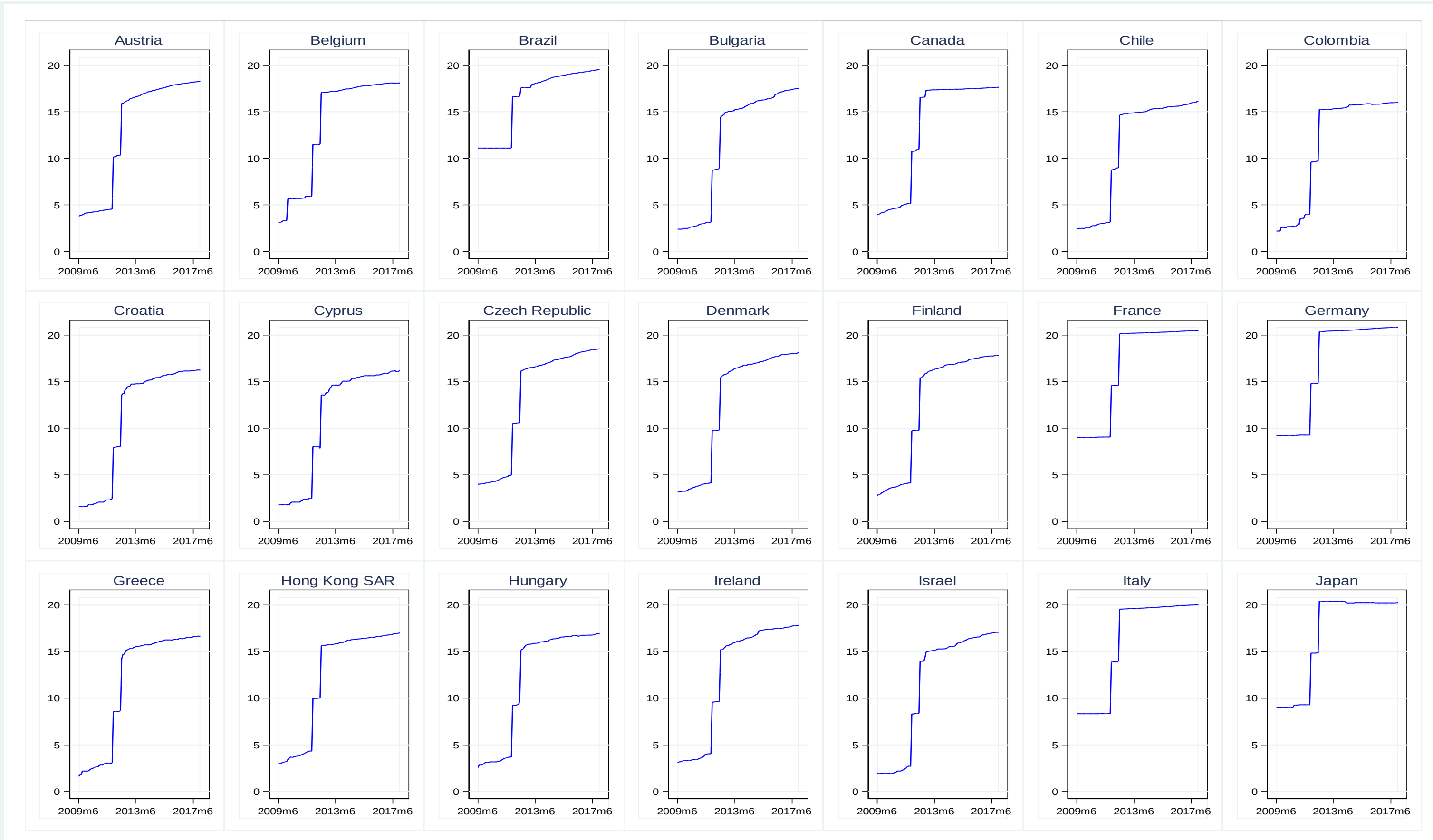
Figure A2. Penetration of Digitalization by Country

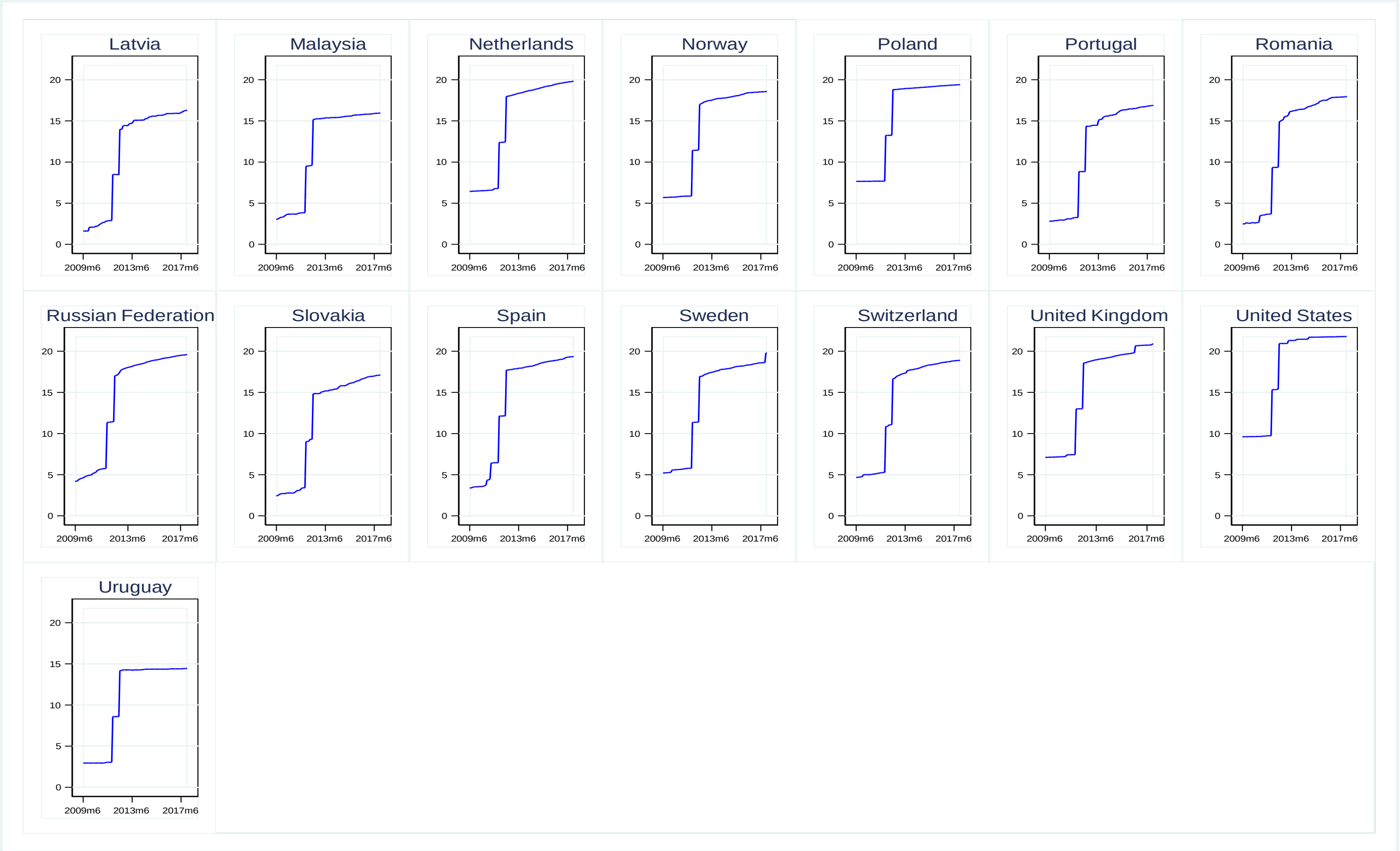
(Number of IPv6 Addresses (Log Scale))



Source: Author's calculations based on IP data set.

Figure A2. Penetration of Digitalization by Country (cont.)

(Number of IPv6 Addresses (Log Scale))



Source: Author's calculations based on IP data set.

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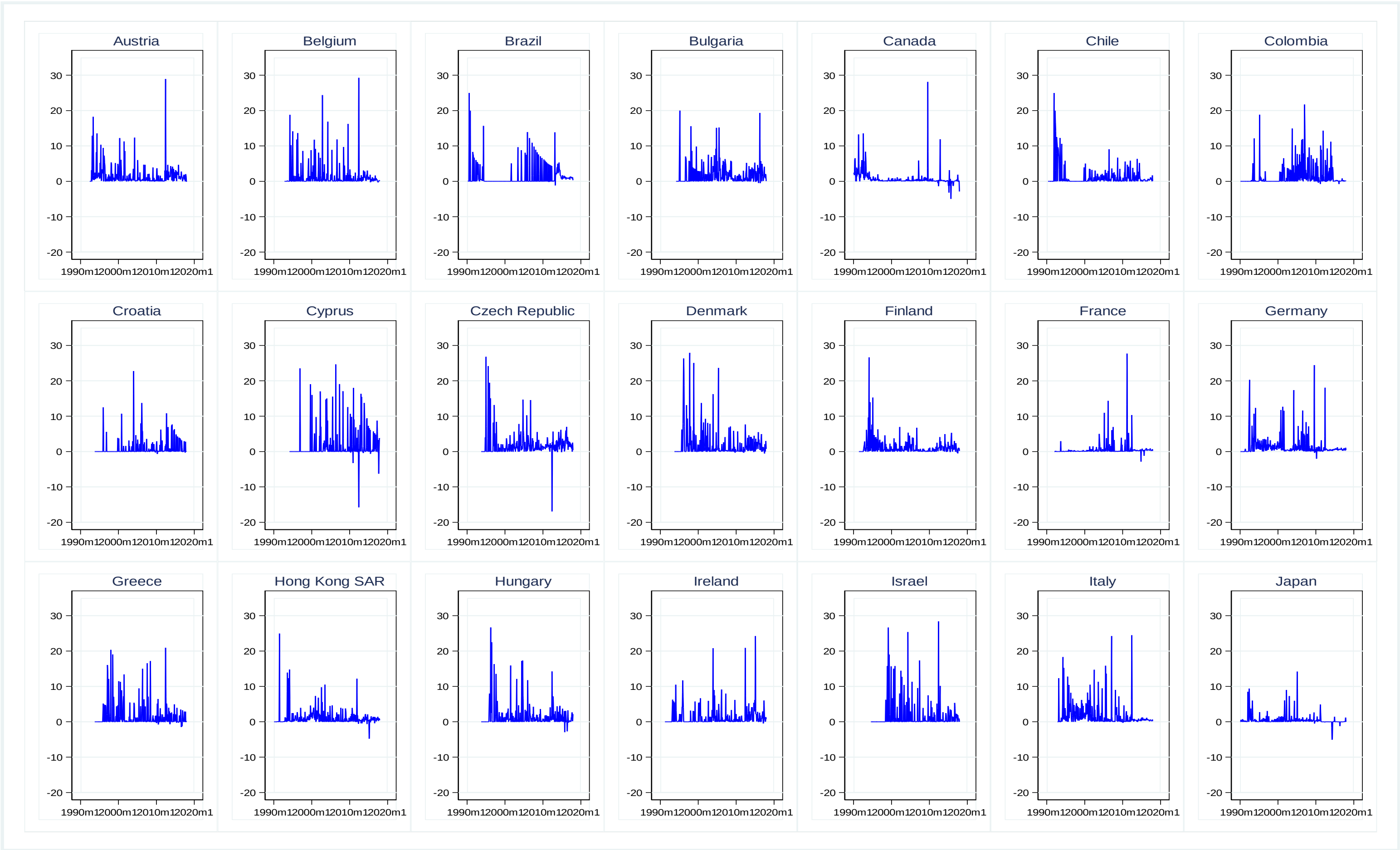
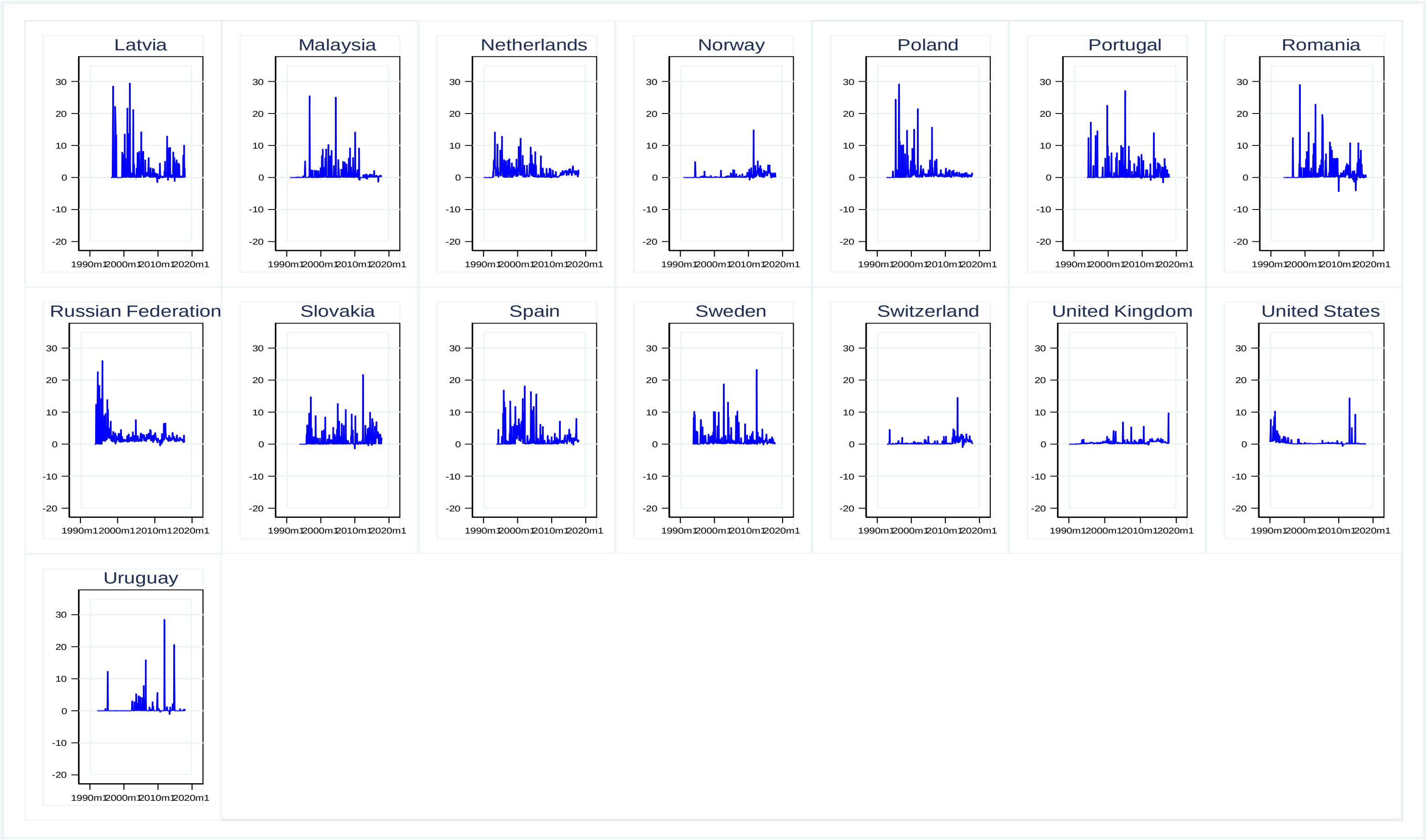
Figure A3. Digitalization Index



Source: Author's calculations based on IP data set. For calculations see text.

Figure A3. Digitalization Index (cont.)



Source: Author's calculations based on IP data set. For calculations see text.

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Annex III. Panel Regressions for Inflation, Benchmark, and Alternative Specifications

Table A2: Panel Regressions for Inflation, 1990.1 to 2017.12

(Digitalization Index)

		Benchmark Specification				Alternative Specification			
		OLS Inflation	**Month FE Inflation**	**Country FE Inflation**	**Both FE Inflation**	**OLS Inflation**	**Month FE Inflation**	**Country FE Inflation**	**Both FE Inflation**
Lagged inflation	δ_1^b	0.846***	0.871***	0.843***	0.866***	0.846***	0.871***	0.842***	0.866***
		(0.051)	(0.038)	(0.050)	(0.038)	(0.052)	(0.039)	(0.050)	(0.038)
Inflation expectations	δ_2^f	0.203***	0.156***	0.212***	0.167***	0.202***	0.156***	0.211***	0.167***
		(0.071)	(0.050)	(0.069)	(0.050)	(0.068)	(0.048)	(0.066)	(0.047)
Unemployment gap	δ_3^g	-0.618***	-0.354*	-0.632***	-0.366*	-0.622***	-0.354*	-0.638***	-0.366**
		(0.153)	(0.185)	(0.152)	(0.184)	(0.156)	(0.178)	(0.156)	(0.177)
Digitalization Cost-productivity channel	β_1^{IP}	-0.008**	-0.006*	-0.008**	-0.006*	-0.008**	-0.006*	-0.008**	-0.006*
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
	β_2^{IP}	-0.002	-0.002	-0.001	-0.002	-0.005*	-0.002	-0.005*	-0.002
		(0.007)	(0.004)	(0.007)	(0.005)	(0.003)	(0.003)	(0.003)	(0.003)
Digitalization expectation channel	β_3^{IP}	-0.001	0.000	-0.001	-0.000				
		(0.002)	(0.002)	(0.002)	(0.002)				
Digitalization and the Slope of the Phillips Curve	β_4^{IP}	0.007	0.002	0.007	0.001	0.011	0.002	0.011	0.001
		(0.025)	(0.019)	(0.024)	(0.019)	(0.023)	(0.018)	(0.022)	(0.018)
Other controls	θ_1^{neer}	-0.002	-0.002	-0.002*	-0.002*	-0.002	-0.002	-0.002*	-0.002*
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
	θ_2^{ener}	0.015***	0.484***	0.014***	0.441***	0.015***	0.483***	0.014***	0.441***
		(0.002)	(0.148)	(0.002)	(0.152)	(0.002)	(0.153)	(0.002)	(0.159)
	θ_2^{food}	0.027**	-0.387**	0.027**	-0.347**	0.027**	-0.386**	0.027**	-0.347*
		(0.011)	(0.164)	(0.011)	(0.168)	(0.011)	(0.169)	(0.011)	(0.176)
N		9019	9019	9019	9019	9019	9019	9019	9019
R^2		0.980	0.983	0.980	0.983	0.980	0.983	0.980	0.983
adj. R^2		0.980	0.982	0.980	0.983	0.980	0.982	0.980	0.983

Clustered standard errors in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Panel Regressions for Inflation, 1990.1 to 2017.12

(Digitalization index – Standardized Coefficients)

		Benchmark Specification				Alternative Specification			
		OLS Inflation	Month FE Inflation	Country FE Inflation	Both FE Inflation	OLS Inflation	Month FE Inflation	Country FE Inflation	Both FE Inflation
Lagged inflation	δ_1^b	0.846***	0.871***	0.843***	0.866***	0.846***	0.871***	0.842***	0.866***
		(0.051)	(0.038)	(0.050)	(0.038)	(0.052)	(0.039)	(0.050)	(0.038)
Inflation expectations	δ_2^f	0.121***	0.093***	0.127***	0.100***	0.120***	0.093***	0.126***	0.100***
		(0.042)	(0.030)	(0.041)	(0.030)	(0.040)	(0.029)	(0.039)	(0.028)
Unemployment gap	δ_3^g	-0.011***	-0.006*	-0.012***	-0.007*	-0.011***	-0.006*	-0.012***	-0.007**
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Digitalization Cost-productivity channel	β_1^{IP}	-0.004**	-0.003*	-0.004**	-0.003*	-0.004**	-0.003*	-0.004**	-0.003*
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
	β_2^{IP}	-0.001	-0.001	-0.001	-0.001	-0.002*	-0.001	-0.002*	-0.001
		(0.003)	(0.002)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Digitalization expectation channel	β_3^{IP}	-0.002	0.000	-0.003	-0.000				
		(0.007)	(0.005)	(0.007)	(0.005)				
Digitalization and the Slope of the Phillips Curve	β_4^{IP}	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Other controls	θ_1^{neer}	-0.023	-0.019	-0.024*	-0.021*	-0.022	-0.019	-0.024*	-0.021*
		(0.014)	(0.012)	(0.014)	(0.012)	(0.013)	(0.012)	(0.013)	(0.011)
	θ_2^{ener}	0.018***	0.589***	0.017***	0.538***	0.018***	0.589***	0.017***	0.538***
		(0.002)	(0.181)	(0.002)	(0.185)	(0.002)	(0.187)	(0.002)	(0.194)
	θ_2^{food}	0.017**	-0.247**	0.017**	-0.222**	0.017**	-0.247**	0.017**	-0.222*
		(0.007)	(0.105)	(0.007)	(0.107)	(0.007)	(0.108)	(0.007)	(0.112)
N		9019	9019	9019	9019	9019	9019	9019	9019
R^2		0.980	0.983	0.980	0.983	0.980	0.983	0.980	0.983
adj. R^2		0.980	0.982	0.980	0.983	0.980	0.982	0.980	0.983

Clustered standard errors in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

References

Abdih, Y., L. Lin, and A-C. Paret, 2018, "Understanding Euro Area Inflation Dynamics: Why So Low for So Long?", IMF Working Paper 18/188.

Auer, R., C. Borio, and A. Filardo, 2017, "The globalisation of inflation: the growing importance of global value chains", BIS Working Papers No. 602.

Barefoot, K., D. Curtis, W. Jolliff, J.R. Nicholson, and R. Omohundro, 2018, "Defining and Measuring the Digital Economy", Bureau of Economic Analysis, U.S. Department of Commerce.

Basker, E., 2007, "The Causes and Consequences of Wal-Mart's Growth", Journal of Economic Perspectives – Vol 21, No 3, pp 177-198.

Bernanke, B., 2010, "Globalization and monetary policy", Remarks at the Fourth Economic Summit, Stanford Institute for Economic Policy Research, Stanford, California, 2 March 2007

Bianchi, F., and A. Civelli, 2015, "Globalization and Inflation: Evidence from a Time Varying VAR", Review of Economic Dynamics, vol. 18(2), pp. 406-433.

Borio, C., and A. Filardo, 2007, "Globalisation and inflation: New cross-country evidence on the global determinants of domestic inflation", BIS Working Papers No 227

Camara, N., and D. Tuesta, 2017, "DiGiX: The Digitization Index", BBVA Working Paper No 17/03, February 2017.

Carlsson, B., 2004, "The digital economy: what is new and what is not?," Structural change and economic dynamics, Vol. 15, pp. 245-264.

Carney, M., 2017, "[De]Globalisation and inflation – speech by Mark Carney", 2017 IMF Michel Camdessus Central Banking Lecture, 18 September 2017

Cavallo, A., 2017, "Are Online and Offline Prices Similar? Evidence from Multi-Channel Retailers", American Economic Review, Vol. 107(1): 283-303

Cavallo, A., 2018a, "More Amazon Effects: Online Competition and Pricing Behaviors", Paper prepared for the 2018 Jackson Hole Economic Policy Symposium, September 7, 2018.

Cavallo, A., 2018b, "Scraped Data and Sticky Prices", The Review of Economics and Statistics, MIT Press, Vol 100(1), pp. 105-119

Cavallo, A., B. Neiman, and R. Rigobon, 2014, "Currency Unions, Product Introductions, and the Real Exchange Rate", Quarterly Journal of Economics, Vol. 129(2).

Cavallo, A., B. Neiman, and R. Rigobon, 2015, “The Price Impact of Joining a Currency Union: Evidence from Latvia”, IMF Economic Review 63(2), pp. 281-297

Cavallo, A., and R. Rigobon, 2016, “The Billion Prices Project: Using Online Prices for Measurement and Research”, Journal of Economic Perspectives, Vol. 30(2), pp. 151-78.

Cavallo, A., and R. Rigobon, 2011, “The distribution of the size of price changes”, NBER Working Paper 16760, February 2011.

Charbonneau, K., A. Evans, S. Sarker, and L. Suchanek, 2017, “Digitalization and Inflation: A Review of the Literature”, Staff Analytical Note 2017-20, Bank of Canada.

Ciccarelli, M., and B. Mojon, 2010, “Global Inflation”, The Review of Economics and Statistics, Vol 92, Issue 3, pp 524-535

Coffinet, J. and S. Perillaud, 2017, “Effects of the Internet on inflation: an overview of the literature and empirical analyses”, Banque de France, Paper presented at the 2017 IMF Statistical Forum.

Coibon, O., and Y. Gorodnichenko, 2015, “Is the Phillips Curve Alive and Well After All? Inflation Expectations and the Missing Disinflation”, American Economic Journal: Macroeconomics Vol 7, No 1, pp 197-232

Friedrich., R., M. LeMerle, F. Grone, and A. Koster, 2011, “Measuring Industry Digitization: Leaders and Laggards in the Digital Economy”, Booz & Co., London.

Goldfarb, A., and C. Tucker, 2019, “Digital economics,” Journal of Economic Literature, 57(1), pp. 3-43.

Goolsbee, A.D., and P.J. Klenow, 2018, “Internet Rising, Prices Falling: Measuring Inflation in a World of E-Commerce”, NBER Working Paper No. 24649.

Gorodnichenko, Y., V. Sheremirov, and O. Talavera, 2018, “Price Setting in Online Markets: Does IT Click?”, Journal of the European Economic Association, Vol 16, Issue 6, pp 1764-1811

Gupta, S., M. Keen, A. Shah, and G. Verdier (Eds), 2017, “Digital Revolution in Public Finance”, International Monetary Fund, Washington D.C.

He, D., R. Leckow, V. Haksar, T. Mancini-Griffoli, N. Jenkinson, K. Kashima, T. Khiaonarong, C. Rochon and H. Toupe, 2017, “Fintech and financial services: initial considerations”, IMF Staff Discussion Notes SDN/17/05, June, Washington D.C.

Igan, D., and J. Suzuki, 2012, “The “Wal-Mart effect” in central and eastern Europe”, Journal of Comparative Economics 40 (2012) 194-210.

International Monetary Fund, 2013, "The Dog That Didn't Bark: Has Inflation Been Muzzled or Was it Just Sleeping?", Chapter 3, World Economic Outlook, April. Washington D.C.

International Monetary Fund, 2018a, "Challenges for monetary policy in emerging economies as global financial conditions normalize", Chapter 3, World Economic Outlook, October. Washington D.C.

International Monetary Fund, 2018b, "Low Inflation in Asia: How Long Will It Last?", Chapter 2, Regional Economic Outlook, April 2018. Washington D.C.

International Monetary Fund, 2018c, "Measuring the digital economy", April, Washington D.C.

Jovanovic, B. and P. Rousseau, 2005, "General Purpose Technologies", in P. Aghion and S. Durlauf (EDs) Handbook of Economic Growth, Vol 1B, Elsevier.

Kamber, G., and B. Wong, 2018, "Global Factors and Trend Inflation", Reserve Bank of New Zealand Discussion Paper Series 2018/01

Katz, R.L., P. Koutroumpis, and F.M. Callorda, 2014, "Using a digitization index to measure the economic and social impact of digital agendas", Info, Vol. 16, No. 1, pp. 32-44.

Khor, H., J. Guajardo, and S. J. Peiris, 2018, " Evolution of monetary policy frameworks," In Ana Corbacho and Shanaka Peris (Eds.) *The ASEAN way: sustaining growth and stability*, International Monetary Fund, Washington D.C.

MacKie-Mason, J.K., & H.R. Varian, 1994, "Economic FAQs about the internet", Journal of Economic Perspectives, 8(3), 75-96.

MacKie-Mason, J.K., & H.R. Varian, 1996, "Some Economics of the Internet", Networks, Infrastructure and the New Task for Regulation, W. Sichel, ed., Ann Arbor: University of Michigan Press, 1996. Available at SSRN: https://ssrn.com/abstract=980788

McKinsey Global Institute, 2015, "Digital America: A Tale of the Haves and Have-Mores", December 2015.

Muro, M., S. Liu, J. Whiton, and S. Kulkarni, 2017, "Digitalization and the American Workforce", Brookings, November 2017.

Mühleisen, M., 2018, "The long and short of the digital revolution", in *Finance and Development*, Vol. 55, No. 2, June 2018.

Rogoff, K., 2007, "Impact of Globalization on Monetary Policy", In The New Economic Geography: Effects and Policy Implications, 265-305. Kansas City: Federal Reserve Bank of Kansas City.

Rudd, J., and K. Whelan, 2007, "Modeling Inflation Dynamics: A Critical Review of Recent Research", Journal of Money, Credit and Banking Vol 39, Supplement 1: Conference on "Quantitative Evidence on Price Determination", September 29 and 30, 2005, Co-sponsored by the JMCB and the Federal Reserve Board (Feb., 2007), pp 155-170

Varian, H. R., 1996, "Economic issues facing the Internet", Consortium for Research on Telecommunications Policy.

Wickens, M., 2011, "Macroeconomic Theory: A General Equilibrium Approach", Princeton University Press, Second Edition.

Yi, M. H., and C. Choi, 2005, "The effect of internet on inflation: panel data evidence," Journal of Policy Modelling, Vol. 27, Issue 7, October, pp. 885-889.

Zimmerman, H-D., 2000, "Understanding the Digital Economy: Challenges for New Business Models, AMCIS 2000 Proceedings, Paper 402