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The link between EU households' digitalization and growth factors. What does data (not) reveal?

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ABSTRACT

Households supply the workforce for the modern economy, increasingly based on information and communication technology (IT). The access of households to e-devices and e-channels has been continuously growing in the last two decades. The aim of the study is to reflect these theoretical concepts with data-based, econometric causality analysis. Specifically, this study investigates whether the digitalization of households is a factor in their macroeconomic and behavioural indicators. In other words, does households' access to digital devices and channels determine rates of employment, productivity (TFP), level of savings, disposable income, per capita GDP or the growth ratio of GDP, and even such institutional indicators as political stability? The methodology employed is panel Granger causality analysis and Dumitrescu-Hurlin test, and the regional scope is the EU. Causality is tested between the households' digitalization and their macroeconomic, consumer behaviour or institutional indicators using panel Granger causality tests.

KEYWORDS

digitalization, causality, households, EU

JEL CODES

C23, D12, D13, F55, J24, O14, O43

1. INTRODUCTION

The absorption of technology is determined by capability originating from intellectual capital. The developmental effect of households' digitalization appears several times as an intuitive

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opinion and materializes as a technological or social policy in the distribution of e-devices and internet access financed by public funds partially or exclusively. Some empirical studies have included few, very general Internet access indicators as a necessary growth factor. The current study aims to reflect the intuitive theory about the developmental importance of household digitalization with a detailed database on EU households' digital behaviour.

The following question are the drivers of the hypothesis testing in this study: Does the digitalization of households appear in macroeconomic indicators related to human capital? For example, does households' access to digital devices and channels determine rates of employment, productivity (TFP), level of savings, disposable income, per capita GDP or the growth ratio of GDP, or even such institutional indicators as political stability?

The methodology of this study is based on panel Granger causality and Dumitrescu-Hurlin type Granger causality analysis, which covers EU countries. The causality is tested between households' digitalization and the macroeconomic or institutional indicators. The expected conclusion is that the digitalization has had an impact on the specific economic, consumer and institutional processes or factors which form the environment of domestic production. The Granger tests were executed in EViews software on Eurostat and World Bank data applied for the period between 1995 and 2020 from 28 EU countries. The research question is the following: What is the direction of causality between households' digitalization and macroeconomic or institutional factors? The hypothesis is that causality can be measured regarding households' digitalization and macroeconomic or institutional factors.

2. LITERATURE REVIEW ON THE ROLE OF HOUSEHOLDS IN THE DIGITAL ECONOMY

The literature about the relations between digitalization and human capital confirms the legitimacy of analyzing the digital capabilities of households providing the workforce for industry. Several studies can be cited to support the importance of households' digital capabilities in the process of economic growth based on digitalization. Castaldo et al. (2018) proved that broad band connection has a positive impact on economic growth in the OECD countries. This assumption was confirmed by Fernández-Portillo et al. (2020) who found correlation between growth and the spread of IT with partial least square method using the Eurostat Digital Economy and Society Indicators (DESI) database.

Adolph et al. (2014) pointed out that it was recognized early on that digitalization is not merely a technological process, but also a socio-economic phenomenon. Hüther (2016) emphasized the importance of new skills and capabilities, besides regulation. Bertani et al. (2021) included households in their complex agent-based model as an active player in the financial, labour, goods and housing markets, not only as customers, but also as suppliers of labour to manufacturers in the digitalization process. Khera et al. (2021) used cross-country OLS regression on 52 developing and emerging countries to prove successfully that digitalization has a positive effect on economic growth. Their analysis included indirectly the 'population who has access to Internet' as a direct and significant variable of a composed digital usage index which was found to determine the real GDP growth rate. However, it was true merely for the longer period of 2011–2018, but both determinants became statistically insignificant for the shorter 2014–2018 time series. The latter result might mean that after a while, the basic indicators of digital inclusion might lose its capability to differentiate among countries.

Pradhan et al. (2018) included the share of total population using the Internet and broad band network into the dynamic OLS and fully modified OLS tests on a panel of G20 countries. They confirmed that there is long-run causality from the two IT factors to per capita GDP growth. Myovella et al. (2020) concluded from the analysis of Sub-Saharan African panel data from 2006 to 2016 that Internet users' share of the total population and broad band subscription matter in economic growth. Their OLS and Fixed Effect model confirmed this, however their GMM model did not result in significant coefficients. With the same methodology, Habibi and Zabardast (2020) could not achieve the same statistical significance on their database from 2000 to 2017. In the context of OECD countries, Internet users' share is significant at 5% only in their GMM model, and at 10% in their OLS and Fixed Effect model. Their same analysis about Middle East countries showed that the share of Internet users was not significant. Kadochnikova (2020) surveyed the regional ß-convergence of GDP per capita among Russian regions in the context of households' digitalization with a spatial correlation model in OLS and dynamic Spatial Autoregressive and Structural Equation model forms. Her results were mostly not statistically significant, negative, or close to zero in case of 'Number of active users of broadband Internet connection per 100 of the population, people' and 'Share of households having access to the Internet'. These results would not support the assumption about the positive impact of digitalization on economic growth.

Another aspect of the analysis is that households supply human capital to production. Mahmood and Mubarik (2020) examined, among other factors, the role of intellectual capital (namely human capital, structural capital and relational capital) in innovation. They analysed 217 Pakistani manufacturing SMEs using partial least squares structural equation modelling (PLS-SEM). Intellectual capital – which includes human capital, such as skills and capabilities – was proved to be determining the balance between innovation and exploitation activities. Wang et al. (2021) tested the effect of IT investments on intellectual capital related to fintech in banking, as a transformation in the financial sector, in the period from 2008 to 2018, considering 715 observations. Their results indicated a significant impact of IT and intangible asset investment on banking efficiency (in the case of conventional banks, especially small ones).

The status of households or the private sector has been analysed using the Granger-causality method in several aspects.[1] Similarly to the current methodology, the research with Granger causality methodology whose topic was closest to the current study was conducted by Kirikkaleli et al. (2018). They searched for correlations between electricity consumption, Internet demand and economic growth. Their paper applied Panel cointegration, Fully Modified Ordinary Least Squares, Dynamic Ordinary Least Squares and Dumitrescu-Hurlin causality tests to data from 35 OECD countries in the period 1993–2014. The majority of the multiple regression models indicated a positive linkage between electricity, Internet demand and economic growth. Their tests confirmed two-directional causality between electricity consumption and Internet demand and one-directional causality originating from economic growth to electricity consumption.

[1]Kónya (2004) investigated the relationship between savings and economic growth. Puente-Ajovín and Sanso-Navarro (2015) examined the correlation between private debt and economic growth, Kapounek and Lacina (2011) analysed perceptions of inflation and its anticipation, and Pomenkova and Kapounek (2009) discussed the causality of interest rates and prices.

Müller et al. (2020) surveyed information sharing via digital channels directed towards customers in terms of building social capital by digital skills and inclusion – for example interactions, vision, trust or human resource – in the framework of PLS-SEM methodology. Their conclusions about causality were that: "*a higher positive impact on production data* […] *can be observed for trust and benefit sharing. Further, digitally exchanging production data has a higher positive impact on efficiency and new business. Trust, shared vision, and the quality of the existing IT link have a higher positive impact on the willingness to exchange process data* […]."

Lula et al. (2019) analysed the demand for employee competencies on the labour market in Poland in the context of the digital economy. Based on competency schemas developed in the field of psychology, they investigated the competences demanded in the job offers. Their model supported the view that an IT competence mix in the workforce, supplied by households, is a fundamental factor in automation and robotization. Skobelev and Borovik (2017) suggested the concept which covers the digitalization of society beyond industry. The super smart society and the Internet of Everything – as they describe – essentially demand high levels of IT competence on the part of society, including households. Afonasova et al. (2019) emphasize the economic and social risks involved in the process of digitalization that can undermine the development of efficiency during IT-based development processes. They conducted a statistical analysis of Internet and broadband penetration – among other factors – in a comparative analysis between Russia and the EU. All of these studies demonstrate the complexity of the linkage between economic growth and digital economy. Halmai and Vásáry (2010) found that there has been an erosion of European growth potential and TFP, while Benczes and Szent-Iványi (2017) raised concerns about the limits of European growth potential within the existing and applied, current technologies, highlighting that the opportunities of 21st century digitalization are a must for the EU, in which households' digital readiness will be one of the crucial factors.

3. METHODOLOGY AND QUALITY OF DATA

3.1. Methodology

The existence of a link between households' digitalization and growth factors are empirically investigated by panel Granger causality tests. Granger causality[2] is a statistical concept of causality that is based on prediction. According to Granger causality, if a signal x "Granger-causes" a signal y, then past values of x should contain information that helps predict y, above and beyond the information contained in past values of y alone. In our case, x represents variables measuring the degree of digitalization of households (e.g. internet use, e-commerce) while y comprises data on labour market indicators, GDP, productivity and governmental institutional indices.[3]

In practice, Granger causality is computed by running bivariate regressions that in a panel data context take the following general form:

[2] See more: Granger (1969), Lopez-Weber (2017) and Freeman (1983).

[3] See Fidrmuc and Siddiquiy (2015) about the linkage between institutional quality and efficiency of market players.

$$y_{i,t} = \alpha_{0,i} + \alpha_{1,i} y_{i,\ t-1} + \ldots + \alpha_{k,i} y_{i,\ t-k} + \beta_{1,i} x_{i,\ t-1} + \beta_{k,i} x_{i,\ t-k} + \varepsilon_{i,t}$$

$$x_{i,t} = \gamma_{0,i} + \gamma_{1,i} x_{i,\ t-1} + \ldots + \gamma_{k,i} y_{i,\ t-k} + \delta_{1,i} y_{i,\ t-1} + \delta_{k,i} y_{i,\ t-k} + \varepsilon_{i,t}$$

where t denotes the time period dimension of the panel, and i denotes the cross-sectional dimension.

The pair of null-hypothesis of the Granger test are that x does not Granger Cause y (in the first equation $\beta_{l,i} = 0 \ \ \forall l, i$), and y does not Granger cause x (in the second equation $\delta_{l,i} = 0 \ \ \forall l, \ i$).

The different forms of panel causality tests differ on the assumptions made about the homogeneity of the coefficients across cross-sections. In this paper two different types of assumption were used.

1. In the first approach, the panel data were treated as one large stacked set of data, and then we performed the Granger Causality test in the standard way, with the exception of not letting data from one cross-section enter the lagged values of data from the next cross-section. This method assumes that all coefficients are the same across all cross-sections, i.e.:

$$\alpha_{0,i} = \alpha_{0,j}, \ \alpha_{1,i} = \alpha_{1,j}, \ \ldots \alpha_{k,i} = \alpha_{k,j} \quad \forall i, \ j$$

$$\beta_{1,i} = \beta_{1,j}, \ \ldots \beta_{k,i} = \beta_{k,j} \quad \forall i, \ j$$

$$\gamma_{0,i} = \gamma_{0,j}, \ \ \gamma_{1,i} = \gamma_{1,j}, \ \ldots \gamma_{k,i} = \gamma_{k,j} \quad \forall i, \ j$$

$$\delta_{1,i} = \delta_{1,j}, \ \ldots \delta_{k,i} = \delta_{k,j} \quad \forall i, \ j$$

2. The second approach, adopted by Dumitrescu-Hurlin (2012), makes an extreme opposite assumption, allowing all coefficients to be different across cross-sections:

$$\alpha_{0,i} \neq \alpha_{0,j}, \ \alpha_{1,i} \neq \alpha_{1,j}, \ \ldots \alpha_{k,i} \neq \alpha_{k,j} \quad \forall i, \ j$$

$$\beta_{1,i} \neq \beta_{1,j}, \ \ldots \beta_{k,i} \neq \beta_{k,j} \quad \forall i, \ j$$

$$\gamma_{0,i} \neq \gamma_{0,j}, \ \ \gamma_{1,i} \neq \gamma_{1,j}, \ \ldots \gamma_{k,i} \neq \gamma_{k,j} \quad \forall i, \ j$$

$$\delta_{1,i} \neq \delta_{1,j}, \ \ldots \delta_{k,i} \neq \delta_{k,j} \quad \forall i, \ j$$

This test is calculated by simply running standard Granger Causality regressions for each cross-section individually. The next step is to take the average of the test statistics. Dumitrescu-Hurlin showed that the standardized version of this statistic, appropriately weighted in unbalanced panels, follows a standard normal distribution.

With respect to the relatively large number of investigated variables (6 indicator measuring household's digitalization and 20 indicators for growth) which require numerous, $6 \times 20 \times 2 = 240$, tests, the appearance of a Type I error (i.e. a false positive) is highly likely using standard significance levels (e.g. using 5% significance level one can expect $240 \times 0.05 = 12$ false positive test results). In order to minimize this issue and to ensure the robustness of the results the following test strategy was applied.

Under the test assuming homogeneity of the coefficients across cross-sections, we carried out tests using three regressions, each one including 1, 2 and 3 lags, respectively. Maximum 3 lags were chosen due to the relatively short time dimension of the panel data. For each pair of variables, we consider result to be significant if at least two tests out of three regressions with different lags proved to be significant at a 5% level at least. According to our Monte-Carlo experiment, this strategy reduces the probability of false positive results by approximately 75%. It means that the probability of the appearance of Type I error diminishes to roughly 1.25% only (e.g. one can expect $240 \times 0.0125\% = 3$ false positive results). At the same time, this strategy ensures robustness as well across models with different lags.

Due to the large number of parameters to be estimated in Dumitrescu-Hurlin approach, the short time dimension of the panel data enabled using 1 lag only when we allowed all coefficients to be different across cross-sections. However, the results of the Dumitrescu-Hurlin type Granger test can serve as a crosscheck of our first test strategy where the homogeneity of the coefficients across cross-sections was assumed.

As testing for Granger causality requires the data to be stationary. First, the data are investigated with four types of panel unit root test: (1) Levin, Lin and Chu *t*-test, (2) Im, Pesaran and Shin W-statistic test, (3) ADF and Fisher Chi-square test, and (4) PP – Fisher Chi-square test. Again, the variety of applied unit root tests can deliver robust conclusions on whether the data is stationary. When certain data proved to be non-stationary, stationarity was obtained by differentiation in line with the recommendation of Hyndman-Athanasopoulos (2018).

3.2. Data

The tests were conducted on time series panel data from 28 EU countries and their time series between 1995 and 2020. For some of the countries the first five to nine years or the last year of the data are missing, but this lack of data is compensated for by the econometric software. (See the number of observations and other descriptive statistics in Table 1.)

The digital variables are as follows:

- E_COM: share of e-commerce users;
- FREQUENT_USE: percentage of households who regularly use the Internet (i.e. at least once a week);
- INT_ACCESS: level of Internet access of households. Percentage of households who have Internet access at home;
- INT_USE_3M: internet use by individuals, percentage of individuals aged 16 to 74, last Internet use within 3 months;
- HO_USUAL: employed persons working usually from home as a percentage of total employment, age 15–64;
- HO_STIMES: employed persons working sometimes from home as a percentage of total employment, age 15–64.

The labour market variables are as follows:

- PART_RATE: active population ratio, percentage, age 20–64;
- EMP_RATE: employment ratio, ratio, percentage, age 20–64;
- UNEMP_RATE _20-64: unemployment ratio, percentage, age 20–64;
- IT_EMPL_SHARE: share of IT in employment. Employment ratio by age and economic activity, Information and communication, age 15–64, percentage.

Table 1. Descriptive information about data used for analysis

Description	Variable name	Mean	Std. dev.	Min.	Max.	Obs.	Data source
Labour market							
Participation rate (year 20–64, %)	PART_RATE	75.4	5.3	60.3	87.3	682	Eurostat
Employment rate (year 20–64, %)	EMPL_RATE	69.2	6.2	51.7	82.4	682	Eurostat
Unemployment rate (year 20–64, %)	UNEMPL_RATE	8.3	4.3	1.9	27.3	682	Eurostat
Share of IT in employment (%)	IT_EMPL_SHARE	3.1	0.8	1.3	6.0	363	Eurostat
Economic performance							
GDP growth (%)	GDP_G	2.4	3.7	–14.8	25.2	705	Eurostat
Per capita GDP (Euro)	GDPPC_EURO	22,642	16,347	1,180	102,200	720	Eurostat
Per capita GDP (Purchasing power parity)	GDPPC_PPS	23,319	11,612	4,640	82,800	693	Eurostat
Labour productivity per hour worked (EU2020 = 100)	PROD	93.5	35.0	33.0	192.3	420	Eurostat
Total factor productivity (HP filtered)	TFP	–6.8	0.9	–8.1	–3.7	728	Eurostat
Total factor productivity (Production function)	TFPPF	–6.8	0.9	–8.1	–3.7	725	Eurostat
Total factor productivity growth (HP filtered, %)	TFP_G	1.1	2.6	–13.7	12.1	715	Eurostat
Total factor productivity growth (Production function, %)	TFPPF_G	1.2	1.2	–3.3	6.4	712	Eurostat
R & D output							
Patent applications (per 1 million person)	PATENT	86.3	97.4	0.8	350.4	336	Eurostat
High-tech patent applications (per 1 million person)	PATENT_HT	18.0	24.7	0.1	131.9	328	Eurostat
Governance indicator							
Control of corruption	CORRCTRL	1.0	0.8	–0.6	2.5	588	World Bank

(continued)

Table 1. Continued

Description	Variable name	Mean	Std. dev.	Min.	Max.	Obs.	Data source
Government effectiveness	GOVEFF	1.1	0.6	–0.6	2.4	588	World Bank
Political stability and absence of violence	POLSTAB	0.8	0.4	–0.5	1.8	588	World Bank
Regulatory quality	REGQUAL	1.2	0.5	–0.2	2.1	588	World Bank
Rule of law	RULEOFLAW	1.1	0.6	–0.6	2.1	588	World Bank
Voice and accountability	VOICE	1.1	0.3	–0.3	1.8	588	World Bank
Indicators for households' digitalization							
E-commerce users (%)	E_COM	34.9	19.4	2.0	80.0	308	Eurostat
Internet use (at least once a week, %)	FREQUENT_USE	74.5	14.1	31.0	97.0	335	Eurostat
Internet access of households (%)	INT_ACCESS	78.2	13.4	30.0	98.0	335	Eurostat
Internet use (within last 3 months, %)	INT_USE_3M	77.3	13.7	33.0	99.0	335	Eurostat
Employed persons working from home (usually, %)	HO_USUAL	5.3	3.7	0.2	25.1	650	Eurostat
Employed persons working from home (sometimes, %)	HO_STIMES	7.2	6.2	0.1	31.3	628	Eurostat

Note: Eurostat = Digital Economy and Society Indicators, World Bank = Worldwide Governance Indicators.
Source: authors.

The output variables are as follows:

- GDP_G: gross domestic product, change, percentage, year-on-year;
- GDPPC_CUR_PRICE_EUR: gross domestic product per capita, current prices, euro per capita;
- GDPPC_CUR_PRICE_PPS: gross domestic product per capita, current prices, purchasing power standards per capita.

The productivity and technology variables are as follows:

- PROD: labour productivity per person employed and hour worked (EU27_2020 = 100), nominal labour productivity per hour worked;
- TFP: total factor productivity (Solow residual, HP filtered);
- TFP_G: growth of total factor productivity (Solow residual, HP filtered, percentage);
- TFPPF: total factor productivity derived from the production function;
- TFPPF_G: growth of total factor productivity derived from the production function (%);
- PATENT: patent applications to the European patent office by priority year, per million inhabitants;
- PATENT_HT: high-tech patent applications to the European patent office by priority year, per million inhabitants.

The institutional variables are from the Worldwide Governance Indicators as follows:

- CORRCTRL: control of corruption;
- GOVEF: government effectiveness (quality of public services, civil service, policy formulation and implementation)
- POLSTAB: political stability and absence of violence/terrorism;
- REGQUAL: regulatory quality;
- RULEOFLAW: rule of law
- VOICE: voice and accountability

4. RESULTS

First, to secure the stationarity of the data, unit root tests were executed in four ways: Levin-Lin-Chu *t*-statistic, Im-Pesharan-Shin *W*-statistic, ADF – Fisher Chi-square and PP – Fisher Chi-square tests. Without differentiation, five variables contained unit root, where there was at least one version of the unit root tests which would have been statistically significantly stationary at 1% and one more version which confirms it: PART_RATE, IT_EMP_SHARE, PROD, E_COM, HO_USUAL. In their case, differentiation had to be applied. The others were significantly stationary. Table 2 contains the results of unit root tests, also for the first differentials of the originally non-stationary variables, to show that the differentiated data does not contain unit roots.

The Granger causality test analysed the linkage between digitalization and specific variables in two directions. First, the impact of digitalization on the other factors can be seen, as demonstrated in Table 3. Table 5 helps to visualise the directions. Conclusion on the existence of causality is established in the following way: if it meets the strict significance criterion set in the

Table 2. Results of the unit root tests

Variable	*P*-value			
	Levin, Lin & Chu t	Im, Pesaran & Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-suqare
	Level, individual intercept included			
PART_RATE	0.0536*	0.9699	0.4934	0.0971*
EMPL_RATE	0.0011***	0.0087***	0.0047***	0.9020
UNEMPL_RATE	0.0000***	0.0000***	0.0000***	0.5967
IT_EMPL_SHARE	0.8370	0.9999	0.9843	0.9988
GDP_G	0.0000***	0.0000***	0.0000***	0.0000***
GDPPC_EURO	0.0000***	0.0000***	0.0000***	0.0000***
GDPPC_PPS	0.0000***	0.0021***	0.0103**	0.0000***
PROD	0.0112**	0.8912	0.9073	0.8727
TFP	0.0000***	0.0000***	0.0000***	0.0000***
TFPPF	0.0000***	0.0000***	0.0000***	0.0000***
TFP_G	0.0000***	0.0000***	0.0000***	0.0000***
TFPPF_G	0.0000***	0.0000***	0.0001***	0.8068
PATENT	0.0001***	0.0260**	0.0092***	0.0000***
PATENT_HT	0.0000***	0.0434**	0.0344**	0.0043***
CORRCTRL	0.0058***	0.1173	0.0917*	0.5674
GOVEFF	0.0000***	0.0000***	0.0000***	0.0189**
POLSTAB	0.0000***	0.0000***	0.0000***	0.0000***
REGQUAL	0.0565*	0.0363**	0.0527*	0.0841*
RULEOFLAW	0.0004***	0.0080***	0.0024***	0.0001***
VOICE	0.0007***	0.0000***	0.0000***	0.0049***
E_COM	0.9805	1.0000	1.0000	0.9953
FREQUENT_USE	0.0000***	0.6293	0.1887	0.0000***
INT_ACCESS	0.0000***	0.0002***	0.0001***	0.0000***
INT_USE_3M	0.0000***	0.2575	0.1077	0.0000***
HO_USUAL	1.0000	1.0000	0.9809	0.9785
HO_STIMES	0.0000***	0.0231**	0.0000***	0.1673
	First difference, individual intercept included			
PART_RATE	0.0000***	0.0000***	0.0000***	0.0000***

(continued)

Table 2. Continued

Variable	*P*-value			
	Levin, Lin & Chu t	Im, Pesaran & Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-suqare
IT_EMPL_SHARE	0.0000***	0.0000***	0.0000***	0.0000***
PROD	0.0000***	0.0000***	0.0000***	0.0000***
E_COM	0.0000***	0.0000***	0.0000***	0.0000***
HO_USUAL	1.0000	0.0000***	0.0000***	0.0000***

Source: Eurostat, World Bank, authors calculations.
Remarks: *, **, *** denotes 10%, 5% and 1% significance level respectively.

methodological part, i.e. 1% significance in one of the model version or 5% significance at least in case of two lags or two model versions. (It must be emphasized that causality involves better predictability of caused indicators than causing indicators.)

A very strong predictive relationship can be observed from the three Internet use indicators (FREQUENT_USE, INT_ACCESS, INT_USE_3M). At 0.1% level of statistical significance, they are absolutely the causes of the main labour market indicators (EMPL_RATE, UNEMPL_-RATE), confirmed by both model versions, while, the causality to the sound regulation (REGQUAL), the rule of law, the PPP-based GDP per capita and TFP indicators, derived from productivity function, was indicated by one of the causality models. Furthermore, they affect GDPPC_EURO, TFP_G at 1% level of significance and TFP at merely 5%, but in all lagged case.

Habitual working from home (HO_USUAL) indicates causality to technological licenses (PATENT, PATENT_HT) at 1% level of significance and to IT employment share at 0.1%, in both case with 2 lags, which are one-way impacts. The habitual home office practice has a two-way causality with per capita GDP determined in euro. The working from home occasionally (HO_STIMES) is proved to be rather an effect of labour market, income, productivity and technology or governance indicators because of the following test results. In some case, HO_STIMES indicates causality to EMPL_RATE, UNEMPL_RATE, GDPPC_EURO and REGQUAL merely at 5%, but in case of more than one lag. Most of them resulted in counter causality – except UNEMPL_RATE at 5% or stronger significance. In case of PATENT_HT, HO_STIMES is significant at 1%, but the counter causality is stronger at 0.1% level of significance.

The counter causality analysis included in Table 4 indicates the impact on digitalization detected and Table 5 demonstrates this visually. First of all, it must be established, that the working from home indicators are determined by the included labour market, macroeconomic and institutional indicators. In case of two-directional causality, the macroeconomic variables as cause mostly have higher level of statistical significance. The HO_STIMES is caused by the two GDP per capita indicators, the two patent variables, GOVEFF, RULEOFLAW and VOICE at very strict, 0.1% level of statistical significance by EMPL_RATE, POLSTAB and REGQUAL at 1%. Besides, at 5%, HO_STIMES is dependent on TFP (2^{nd} lag), TFPPF (2^{nd} lag), TFP_G in one-directional causality. This means that occasional working from home is a result of a highly

Table 3. Results of Panel Granger (PAN) causality test with common coefficients and Dumitrescu-Hurlin type Granger (D-H) causality with individual coefficients (1st, 2nd, 3rd lag), H0: No causality from household digitalization variables (columns) to the specific macroeconomic variables (rows), *P*-values

	E_COM		FREQUENT_USE		INT_ACCESS		INT_USE_3M		HO_USUAL		HO_STIMES	
	PAN	D-H	PAN	D-H	PAN	D-H	PAN	D-H	PAN	D-H	PAN	D-H
PART_RATE	0.543	0.267	0.772	0.830	0.929	0.973	0.704	0.597	0.115	0.380	0.090*	
lag 2			0.380		0.391		0.563				0.260	
lag 3			0.026**		0.022**		0.017**				0.568	
EMPL_RATE	0.416	0.310	0.000 †	0.000 †	0.000 †	0.000***	0.000 †	0.000 †	0.188	0.754	0.298	
lag 2			0.017**		0.045**		0.007***				0.031**	
lag 3			0.205		0.327		0.113				0.037**	
UNEMPL_RATE	0.558	0.376	0.000 †	0.000 †	0.000 †	0.000***	0.000 †	0.000 †	0.189	0.777	0.047**	
lag 2			0.061*		0.071*		0.009***				0.011**	
lag 3			0.032**		0.089*		0.006***				0.020**	
IT_EMPL_SHARE	0.021**	0.880	0.605	0.130	0.667	0.246	0.682	0.138	0.584	0.140	0.861	
lag 2	0.288				0.630		0.856		0.691	0.000 †		
GDP_G	0.970	0.452	0.529	0.864	0.458	0.615	0.687	0.873	0.260	0.059*	0.441	
lag 2			0.065*		0.030**					0.992		
lag 3			0.051*		0.073*							
GDPPC_EURO	0.538	0.008***	0.004***	0.060*	0.005***	0.512	0.002***	0.002***	0.261	0.003***	0.017**	
lag 2			0.115		0.070*		0.353			0.094*	0.039**	
lag 3			0.086*		0.056*		0.096*				0.045**	
GDPPC_PPS	0.493	0.965	0.001 †	0.072*	0.000 †	0.015**	0.001 †	0.001 †	0.649	0.014**	0.263	
lag 2			0.093*		0.002***		0.030**			0.013**	0.264	
lag 3			0.399		0.090*		0.093*				0.166	
PROD	0.539	0.421	0.400	0.952	0.672	0.875	0.468	0.916	0.786	0.807	0.144	
TFP	0.565	0.999	0.021**	0.574	0.035**	0.469	0.040**	0.592	0.506	0.591	0.336	
lag 2			0.012**		0.045**		0.030**					
lag 3			0.010**		0.034**		0.017**					
TFPPF	0.775	0.160	0.955	0.000 †	0.133	0. 000 †	1.000	0.000 †	0.096*	0.589	0.011**	
lag 2					0.699		0.691		0.509	0.037**	0.941	
TFP_G	0.357	0.955	0.006***	0.028**	0.007***	0.152	0.012**	0.117	0.843	0.949	0.480	
lag 2			0.010**		0.040**		0.026**					
lag 3			0.008***		0.024**		0.013**					
TFPPF_G	0.180	0.378	0.864	0.000 †	0.822	0.000 †	0.921	0.000 †	0.592	0.252	0.710	
PATENT	0.523		0.955	0.172	0.761	0.198	0.872	0.292	0.795	0.843	0.062*	
lag 2									0.002***		0.783	
lag 3									0.003***		0.503	
PATENT_HT	0.767		0.388		0.529		0.346		0.147		0.694	
lag 2									0.007***		0.715	
lag 3									0.015**		0.009***	
CORRCTRL	0.322	0.259	0.656	0.692	0.608	0.822	0.698	0.551	0.706	0.944	0.582	
GOVEFF	0.938	0.413	0.466	0.011**	0.732	0.084*	0.409	0.002***	0.532	0.232	0.159	
POLSTAB	0.053*	0.388	0.397	0.363	0.596	0.328	0.394	0.275	0.091*	0.488	0.153	
lag 2	0.122				0.219				0.381			
lag 3	0.233				0.055*				0.032**			
REGQUAL	0.942	0.442	0.000 †	0.158	0.000 †	0.021**	0.000 †	0.104	0.868	0.825	0.002***	
lag 2			0.000 †		0.000 †		0.000 †				0.006***	
lag 3			0.022**		0.003***		0.026**				0.037**	
RULEOFLAW	0.301	0.695	0.257	0.000 †	0.273	0.000 †	0.158	0.000 †	0.473	0.936	0.241	
VOICE	0.147	0.946	0.129	0.051*	0.084*	0.081*	0.081*	0.127	0.164	0.004***	0.554	

Notes: significance:† at 0.1% *** at 1%, ** at 5%, * at 10%. For each variable in the rows, the 1st line is lag 1, 2nd line is lag 2, 3rd line is lag 3.
Shaded blocks: Causality, H0 is rejected at 5% significance. If lag 1, lag 2 and lag 3 did not indicate any significance in the full row, lags 2 and 3 are not displayed.
Source: authors.

Table 4. Results of Panel Granger (PAN, common coefficients) and Dumitrescu-Hurlin type Granger (D-H, individual coefficients) causality, (1st, 2nd, 3rd lag), H0: No causality from the specific macroeconomic variables (row) to household digitalization variables (columns), *P*-values

		E_COM		FREQUENT_USE		INT_ACCESS		INT_USE_3M		HO_USUAL		HO_STIMES	
		PAN	D-H	PAN	D-H	PAN	D-H	PAN	D-H	PAN	D-H	PAN	D-H
PART_RATE		0.767	0.143	0.835	0.570	0.940	0.544	0.840	0.828	0.321	0.251	0.630	
EMPL_RATE		0.618	0.086*	0.335	0.277	0.818	0.216	0.386	0.808	0.001 †	0.000 †	0.004***	
	lag 2					0.209				0.001 †	0.000 †	0.005***	
	lag 3					0.100*				0.005***		0.011**	
UNEMPL_RATE		0.734	0.132	0.767	0.897	0.484	0.260	0.897	0.551	0.029**	0.000 †	0.149	
	lag 2									0.063*	0.147		
IT_EMPL_SHARE		0.138	0.911	0.270	0.474	0.235	0.978	0.473	0.607	0.105	0.594	0.716	
	lag 2	0.013**		0.079*							0.000 †	0.083*	
	lag 3	0.005***		0.052*								0.236	
GDP_G		0.717	0.714	0.629	0.630	0.112	0.500	0.704	0.911	0.566	0.180	0.082*	
	lag 2					0.069*						0.168	
GDPPC_EURO		0.764	0.433	0.068*	0.000 †	0.695	0.027**	0.039**	0.010***	0.000 †	0.000 †	0.000 †	
	lag 2			0.121				0.103		0.001 †	0.000 †	0.000 †	
	lag 3			0.406				0.571		0.003***		0.000 †	
GDPPC_PPS		0.871	0.443	0.038**	0.006***	0.233	0.002***	0.022**	0.011**	0.065*	0.198	0.000 †	
	lag 2			0.065*		0.096*		0.086*		0.061*	0.000 †	0.000 †	
	lag 3			0.225		0.237		0.425		0.183		0.000 †	
PROD		0.988	0.827	0.440	0.997	0.299	0.613	0.399	0.712	0.492	0.520	0.290	
	lag 2							0.573		0.549		0.055*	
	lag 3							0.245		0.090*		0.070*	
TFP		0.904	0.495	0.774	0.000 †	0.498	0.000 †	0.656	0.027**	0.775	0.000 †	0.058*	
	lag 2			0.084*		0.084*					0.000 †	0.012**	
	lag 3			0.339		0.487						0.015**	
TFPPF		0.889	0.056*	0.789	0.000 †	0.527	0.055*	0.666	0.000 †	0.752	0.000 †	0.056*	
	lag 2									0.161	0.000 †	0.018**	
	lag 3									0.004***		0.017**	
TFP_G		0.232	0.749	0.890	0.339	0.147	0.065*	0.913	0.176	0.175	0.510	0.010**	
	lag 2			0.080*		0.087*						0.046**	
	lag 3			0.318		0.330						0.018**	
TFPPF_G		0.177	0.751	0.441	0.987	0.288	0.187	0.495	0.996	0.053*	0.279	0.010**	
	lag 2									0.001 †		0.058*	
	lag 3									0.001 †		0.095*	
PATENT		0.997		0.388	0.505	0.192	0.195	0.522	0.978	0.192	0.038**	0.000 †	
	lag 2											0.000 †	
	lag 3											0.001 †	
PATENT_HT		0.725		0.355		0.210		0.307		0.624		0.000 †	
	lag 2									0.657		0.002***	
	lag 3									0.075*		0.001 †	
CORRCTRL		0.210	0.945	0.686	0.857	0.761	0.799	0.943	0.643	0.108	0.419	0.258	
	lag 2	0.234								0.073*		0.394	
	lag 3	0.047**								0.286		0.227	
GOVEFF		0.897	0.337	0.045**	0.663	0.502	0.822	0.020**	0.301	0.140	0.312	0.000 †	
	lag 2			0.538				0.107		0.168		0.000 †	
	lag 3			0.794				0.870		0.202		0.023**	
POLSTAB		0.754	0.624	0.799	0.293	0.423	0.440	0.943	0.535	0.693	0.594	0.010***	
	lag 2							0.598				0.019**	
	lag 3							0.241				0.106	
REGQUAL		0.918	0.870	0.062*	0.549	0.243	0.378	0.029**	0.339	0.167	0.657	0.007***	
	lag 2			0.251				0.041**		0.066*	0.374	0.011**	
	lag 3			0.717				0.554		0.197		0.070*	
RULEOFLAW		0.945	0.513	0.044**	0.532	0.438	0.808	0.026**	0.134	0.273	0.114	0.000 †	
	lag 2			0.080*				0.007***			0.007***	0.001 †	
	lag 3			0.342				0.209				0.002***	
VOICE		0.873	0.923	0.107	0.828	0.569	0.694	0.046**	0.037**	0.169	0.345	0.000 †	
	lag 2							0.055*		0.034**		0.001 †	
	lag 3							0.366		0.068*		0.000 †	

Notes: significance: † at 0.1% *** at 1%, ** at 5%, * at 10%. For each variable in the rows, the 1st line is lag 1, 2nd line is lag 2, 3rd line is lag 3.

Shaded blocks: Causality, H0 is rejected at 5% significance. If lag 1, lag 2 and lag 3 did not indicate any significance in the full row, lags 2 and 3 are not displayed.

Source: authors.

Table 5. Panel Granger causality test results

	E_COM	FREQUENT_USE	INT_ACCESS	INT_USE_3M	HO_USUAL	HO_STIMES
PART_RATE						
EMPL_RATE		← (grey)	← (grey)	← (grey)	↑ (grey)	↑ ←
UNEMPL_RATE		← (grey)	← (grey)	← (grey)	↑ (grey)	←
IT_EMPL_SHARE	↑				←	
GDP_G						
GDPPC_EURO	←	↑ ←	←	↑ (grey) ← (grey)	↑ (grey) ←	↑ ←
GDPPC_PPS		↑ ←	↑ ← (grey)	← (grey)	↑ ←	↑
PROD						
TFP		↑ ←	↑ ←	←	↑	
TFPPF		↑ ←	←	↑ ←	↑	
TFP_G		←	←	←		↑
TFPPF_G		←	←	←	↑	
PATENT					←	↑
PATENT_HT					←	↑ ←
CORRCTRL						
GOVEFF				←		↑
POLSTAB						↑
REGQUAL		←	← (grey)	↑ ←		↑ ←
RULEOFLAW		←	←	↑ ←		↑
VOICE				↑ (grey)	←	↑

Notes: ← indicates that the variable in the column representing households' digitalization Granger causes the macroeconomic variable in the row. ↑ indicates that the macroeconomic variable in the row Granger causes the variable in the column representing households' digitalization. Causality is confirmed with 1% statistical significance level or at least two lags with 5% significance level. Arrows with grey shadow mean that both panel Granger causality test and Dumitrescu-Hurlin test confirmed the causality.
Source: authors.

developed economic environment instead of being a factor of growth, employment, technology and good governance. The habitual working from home is clearly determined by EMPL_RATE, UNEMPL_RATE, GDPPC_EUR, TFP, TFPPF and TFPPF_G (2^{nd} lag) at 0.1% level of statistical significance.

The determination of households' shopping from webshops (E_COM) is out of the causality in both directions. It is not a cause at all, and it is an effect merely of IT employment with 3 lags, at 1% significance. Some of the institutional indicators demonstrate an impact on INT_USE_3M (RULEOFLAW, REGQUAL, VOICE) at 1% or 5% significance with more than one lag. The causality tests of governance indices suggest that better governance can result in higher levels of working from home and greater availability of the Internet.

The following policy conclusions can be drawn. First, with regards to Internet use and access, strong and unambiguous causality can be observed to employment and unemployment, moreover to per capita GDP and total factor productivity. It seems that sound regulation and rule of law depends strongly, too, on the access and use of IT channels and devices. The Internet might provide ways of following current trends, participating in training and creating or finding new segments of industries and professions.

Habitual working from home develops the capability to create (high-tech) patents. This might mean that R&D services based on IT are more flexible regarding the place of working. Besides, citizens' political freedom and participation appears to be stronger with higher home office activity. This institutional linkage demands further analysis. Occasional working from home is fundamentally an output indicator of economic activity and good governance which demonstrates the economic, technological and institutional efficiency. According to the World Bank definition, it means that working from home is much more prevalent where there is better *quality of public services and the civil service*, a higher *degree of civil service independence from political pressures*, fairer *quality of policy formulation and implementation,* credible *government commitment,* lower *likelihood of political instability and/or politically motivated violence (including terrorism), confidence in and abiding by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts,* finally, *freedom of expression, freedom of association, and a free media*.

The share of e-commerce users was shown to be irrelevant to the linkages. The counter causality from IT employment to e-commerce shopping is more deterministic. This could be interpreted in the following: higher incidence of the IT sector results in more e-commerce opportunities and available devices.

5. DISCUSSION AND CONCLUSION

The results are particularly in line with the previous studies referred to in the literature review. They support the conclusion of Pradhan et al. (2018), Myovella et al. (2020), Khera et al. (2021) and particularly Habibi and Zabardast (2020) related to OECD countries, who demonstrated that incidence of Internet use in the population increases growth potential. The current results of tests on Internet access and frequency of its use resulted in determining causality to the labour market, growth and technology/productivity indicators. Thus, the current test results falsify the statistical insignificance of penetration indices of Internet use in the population in the context of economic growth and convergence concluded by Habibi and Zabardast (2020) from the time series of Middle Eastern countries and Kadochnikova (2020) about Russian regions.

Hüther (2016), Bertani et al. (2021), Mahmood and Mubarik (2020), Lula et al. (2019) and Horváth and Szabó (2019) concluded that households play an important role in industrial production via digitalization as labour suppliers and product or service buyers. They discussed labour skills and capabilities which can determine the process of the industrial revolution based on digitalization and automation, as the quality of human capital originates in households. The current study confirmed this approach with the detection of causality from Internet use and Internet access to employment and unemployment, and from these latter variables to 'usual home office'. Moreover, Internet use indicators demonstrated a deterministic linkage towards GDP per capita and TFP indicators. However, as buyers, households' role was not confirmed by testing the e-commerce variable.

The analysis was built on the panel Granger causality test with common coefficients and the Dumitrescu-Hurlin type Granger causality test with individual coefficients which detected linkages between households' digitalization indicators and other specific economic indicators including the labour market, GDP, productivity and technology, and, finally, governmental institutional variables. Data was collected from Eurostat and the Worldwide Governance Indicators of the World Bank.

The new result of the study is that it reflected the developmental importance of household digitalization using a detailed database on EU households' digital behaviour. Moreover, it indicated the existence of a relationship between digitalization and macroeconomic development. The main novel conclusions about the importance of households' digitalization in employment, growth, productivity and public policy are as follows. First, the analysis included more sophisticated digital variables than earlier studies, which ensured that the causality tests were successful. Second, access and use of the Internet have an impact on employment and unemployment, per capita GDP, total factor productivity and public regulation quality. Level of habitual working from home affects thew creation of technological patents, and probably productivity. In contrast, the test results indicated the dependence of occasional ('sometimes') working from home on certain specific variables of the labour market, GDP, productivity and technology, or public governance. Accordingly, this digitalization variable of households can be used as an output indicator of development, employment and good governance (government efficiency, political stability, regulation quality, rule of law and freedom of voice). Finally, the presence of higher numbers of e-commerce users might be in related to IT employment, but does not link to any other factors included in the current study.

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