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Reshaping financial systems: The role of ICT in the diffusion of financial innovations – Recent evidence from European countries

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ABSTRACT

Exchange-traded funds (ETFs) are among the fastest-growing types of innovative financial products. The emergence and spread of these instruments have been facilitated by the digital revolution. Information and communication technology (ICT) is profoundly reshaping the global economic landscape, laying solid foundations for unrestricted and unbounded flows of information and knowledge, eliminating information asymmetries, and furthering the rapid diffusion of financial innovations worldwide. This work contributes to the literature by exploring the linkages between variations in ICT penetration and the development and expansion of financial innovation on stock exchanges in ten European countries: France, Germany, Hungary, Italy, Norway, Poland, Spain, Switzerland, Turkey, and the United Kingdom. The analysis covers the period from 2004 to 2019, and uses panel and country-specific regression models to verify the relationship hypothesized between increasing ICT penetration and the development of exchange-traded funds. Our findings indicate that ICT spreads evenly in all the countries, laying solid foundations for the development of innovative financial products. We also find that ICT positively influences the diffusion of ETFs, regardless of the other possible determinants considered; however, despite the high level of ICT adoption in most of the economies analyzed, ETF market development has not been universal, with substantial between-country differences.

1. Introduction

Information and communication technology (ICT) has transformed the global landscape profoundly, altered the structure of economies radically, and brought new types of organizational and social networks into being (Lechman, 2017; Lechman and Marszk, 2019). The unprecedentedly rapid, worldwide diffusion of ICT has coincided with dynamic changes across financial systems, with the introduction and spread of innovative financial services, institutions, and instruments (Lechman and Marszk, 2015) that contribute to global financial diversity.

One of the most prominent financial innovations in recent decades is exchange-traded funds (ETFs), part of the more general category of exchange-traded products. The history of ETFs in most parts of the world is rather brief—the pioneering funds were introduced in the United States in the late 1980s and, in Europe, in the early 2000s (Deville, 2008). Despite the development of ETF markets on a global scale, the United States has remained the world's largest market for these investment funds (according to ETFGI, as of early 2020, the US market accounted for some 70% of total global assets held by ETFs). The growth dynamics of the ETF markets differ substantially by country (whether measured by assets or turnover), even within Europe (for a detailed analysis, see Marszk and Lechman (2019a, 2019b, 2020)). The differences reflect a number of factors, one of which is differences in ICT penetration rates. The factors in the development of ETFs, particularly when compared with other instruments offering similar investment exposure, have been relatively neglected by researchers, with a few exceptions that include Lechman and Marszk (2015, 2019) and Madhavan (2016). This is a significant research failing, especially considering the growing importance of ETFs and their possible impact on global, regional, and local financial systems. This has already been recognized by some supervisory institutions (Financial Stability Board, 2011; IMF, 2011; Ramaswamy, 2011); for a discussion of the regulatory challenges linked to ETFs, see Amenc et al. (2012) or Aggarwal and Schofield (2014). It has also been confirmed in a number of empirical studies with a particular focus on such issues as financial contagion (Ben-David et al., 2011; Madhavan, 2012; Bai et al., 2015; Aldridge, 2016; Bhattacharya and O'Hara, 2016; Converse et al., 2018; Palin et al., 2019; Thomaidou and Kenourgios, 2020) and financial market volatility

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(Lin and Chiang, 2005; Jr and J, 2010; Curcio et al., 2012; Krause and Tse, 2013; Krause et al., 2014; Ivanov and Lenkey, 2018; Chang et al., 2019; Zhu, Luo and Jin, 2019).

In its most common form, an ETF is a passive investment vehicle, somewhat resembling index mutual funds, with the aim of matching (tracking) the performance of some benchmark, usually a stock market index (Elton et al., 2019). However, there are differences, notably in the fund unit creation and redemption process (in the case of ETFs, this takes place on both the primary and the secondary markets), with resulting differences in cost, liquidity, and tracking abilities (Kostovetsky, 2003; Agapova, 2011; Ben-David et al., 2017; Elton et al., 2019; Stankevičienė and Petronienė, 2019). There is a vast body of literature on the comparative advantages and disadvantages of ETFs versus mutual funds (Poterba and Shoven, 2002; Athma and Kumar, 2011; Rompotis, 2011; Blitz and Huij, 2012; Schizas, 2014; Chen et al., 2018; Farinella and Kubicki, 2018; Lettau and Madhavan, 2018; Afonso and Cardoso, 2019; Marszk and Lechman, 2019a). The present study adopts a different perspective, however, and focuses on the financial market position of ETFs in relation to stock index derivatives and applies the concept of an equity index arbitrage complex (Gastineau, 2010).

The study's contribution is twofold. First, it adds to the discussion on the determinants of ETFs by analyzing the role of ICT in their diffusion. Although some similar work has been done (Lechman and Marszk, 2015, 2019), this study augments past evidence and adds to our knowledge by using different metrics and the most recent data with regard to the relevant issues. Second, this is the first study to examine the determinants of the development of ETFs in Europe by comparison with stock index derivatives rather than mutual or other investment funds. Third, this is also the first study to extensively examine various, non-ICT, determinants of the development of ETF markets in Europe in terms of their market share. In summary, we selected 15 different variables that may potentially impact the process of ETF market development, which include not only ICT variables, but also many other financial and socioeconomic factors.

The main idea is to provide empirical evidence on the relationship between ICT penetration and the diffusion of innovative financial instruments—in this case, ETFs. More specifically, the aim is to

- examine key trends in access to ICT as a prerequisite for development and diffusion of ETFs in Europe and
- verify, for the countries selected, the hypothesis that increasing ICT penetration impacts the development of the ETF market (i.e., the diffusion of these instruments), considering other possible determinants of this process.

Our sample consists of ten European countries: France, Germany, Hungary, Italy, Norway, Poland, Spain, Turkey and, to a limited extent, Switzerland and the UK. The time covered is 2004 to 2019. Thus, to verify the quantitative correlations, we use ICT and ETF data for the period 2004–2019.

The paper comprises five sections. Section 2 presents the theoretical background and explains some issues associated with ETFs: basic features, how they compare with stock index derivatives, and the relationship between ETFs and ICT. Section 3 outlines the methodological framework and presents the data sources. Section 4, presenting the empirical results, has three parts: an overview of ICT diffusion in the countries selected, preliminary descriptive evidence on ETF market development, and an evaluation of the relationship between ETFs and ICT. Section 5 closes with our general conclusions.

2. ETFs and ICT: conceptual and theoretical background

2.1. ETFs, stock index futures, and stock index options: the equity index arbitrage complex

Globally, the largest category of ETFs, whether gauged by number, assets, or turnover, is passive equity funds that track the returns of various equity indexes; other types (e.g., fixed income or commodity ETFs) are less common. Most passive equity ETFs directly track (replicate) the returns of the stock market indexes selected, mostly either blue-chip or broad market indexes (Blitz and Huij, 2012; Rompotis, 2020). To guarantee the efficacy of the tracking mechanism (that is, to minimize tracking difference and error), the prices of the ETF shares need to be kept close to the fund's net asset value (which is related to the prices of the assets tracked) (Gastineau, 2001; Aber et al., 2009). A key mechanism, here, is trading on the primary ETF market, where the creation and redemption of the shares takes place (Marshall et al., 2018). These are transactions between the fund's sponsor and authorized participants, and may consist in the delivery of the underlying assets in exchange for the units of the ETF, cash settlement, or a combination of the two (Fassas, 2014; Naumenko and Chystiakova, 2015; Rompotis, 2016). These operations form part of the arbitrage mechanism on the ETF market (Dolvin, 2010; Hilliard, 2014). The other portion of the ETF market is the secondary segment, that is, trading on various venues (including stock exchanges) that involve turnover in the shares of the ETFs (Box et al., 2019). This dual market, in many cases involving an in-kind creation and redemption mechanism (Osterhoff and Kaserer, 2016; Fulkerson et al., 2017), is one of the key innovative attributes of ETFs (Marszk and Lechman, 2019a, 2019b, 2020).

Our analysis applies the concept of "equity index arbitrage complex," as in the framework suggested by Gastineau (2010). This can be understood as a set of financial instruments based on a common equity index which constitutes their principal underlying asset. The equity index arbitrage complex consists of three categories of domestic financial instruments, depending on the relation of their basic parameters to the underlying assets. First, securities that relate directly to the index, that is, combinations of the stocks of the index (labelled "traditional," such as baskets of stocks or ETFs). Second, derivatives with a direct and proportional relationship to the index ("symmetric" derivatives, such as equity index futures, equity index ETF futures, and equity index swaps). Third, derivatives that relate indirectly and non-proportionally to the index, owing to embedded or stand-alone option features ("non-symmetric" or "convex" derivatives, such as equity index options, equity index ETF options, or related structured notes). There are two basic reasons for the inclusion of certain instruments in the complex. The first and most straightforward is that, in all cases, the underlying assets are equity indexes; therefore, they are all, to some extent, substitutes. The second reason is the relationship of arbitrage between the instruments within the complex. According to Gastineau (2010), their prices are interlinked through arbitrage: differences from the stock index should be limited by the trades of arbitrageurs profiting from any such inconsistencies.

The study considers domestic instruments exclusively, owing to the lack of sufficient data on foreign-listed funds linked to stock indexes in a particular country. Further, given the limited data available on the instruments traded off-exchange, the focus is on the three major types of listed securities within each of the aforementioned sets (except baskets of stocks): ETFs, equity index futures, and equity index options.

We now turn to a discussion of the key similarities and differences between these elements of the equity index arbitrage complex. For simplicity, we omit equity index options (which, in any case, are relatively less popular instruments on the exchanges than futures). However, as noted by Thomsett (2016), most of the issues raised regarding the equity index futures also apply to options.

The main common (or similar) attributes of equity index ETFs and equity index futures can be identified according to five criteria (Goltz and Schröder, 2011; Madhavan et al., 2014; Arnold and Lesné, 2015; Marszk and Lechman, 2020):

1. underlying assets: equity indexes,
2. trading: through stock exchanges and like venues,
3. counterparty risk: limited by various mechanisms,

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4 liquidity: high, mostly due to exchange listing and trading, as well as actions of authorized market participants, and
5 pricing: continuous intra-day, determined by market participants' trades.

There are also several differences between them. We list these below, beginning with the relative strengths of ETFs, followed by a similar discussion of the relative advantages of equity index futures. This discussion is based on Gastineau (2010), Goltz and Schröder (2011), Madhavan et al. (2014), Arnold and Lesné (2015), BlackRock (2015), CME Group (2016), Madhavan et al. (2016), Thomsett (2016), Liu and Tse (2017), Wang et al. (2018), Arunanondchai et al. (2019), Chang et al. (2019), Marszk et al. (2019), Marszk and Lechman (2020).

One of the most basic differences concerns maturity structure. EFT shares have no preset maturity (they are open-ended), whereas futures, by definition, have a fixed, predetermined maturity, usually one or three months. Therefore, maintaining a long-term investment in futures exposes holders to roll-over costs, among other things. In addition, as Madhavan et al. (2014) observe, these costs result in greater mispricing of futures than of ETFs. The next major difference involves the diversity of the instruments available: the product range of equity index ETFs is much broader than that of the comparable category of futures, as it embraces various types of indexes, including some of the less popular ones (although, in many less developed ETF markets, the product range is strictly limited and comparable to that of derivatives, that is, they track mostly blue-chip stock indexes). Another advantage of ETFs is easier position management, which is much less complicated than that for derivatives, especially for most ETFs with exposure to foreign indexes.

In some other areas, futures hold a comparative advantage. Three aspects are worth noting: First, investing in an equity index via futures requires less capital than via ETFs, as it requires only an initial margin deposit (some proportion of the full notional value) and possible subsequent topping-up, whereas an ETF requires full upfront payment. Second, as a consequence, futures are suitable for obtaining and maintaining leveraged exposure; for ETFs, this is limited mostly to leveraged and leveraged-inverse funds. Third, taking a short position on indexes is easier with futures, as there may be restrictions on the short selling of EFT shares (a partial solution, here, is offered by inverse and inverse-leveraged ETFs).

Finally, in some cases, there is no clear-cut advantage for either ETFs or futures. This refers, above all, to the cost of the investment: either one may have a comparative advantage, depending on application, time period, and other factors. Madhavan (2016) lists four potential applications of both ETFs and futures: (1) long-term strategic risk allocation, (2) excess cash investments, (3) hedging, and (4) rapid shift of exposure.

Generally, considering all the foregoing aspects, ETFs would seem to be more efficient for long-term risk management (see Gastineau, 2010), whereas futures are more suitable for short-term parallel applications. However, in the case of US investors, the length of the holding period becomes less important for leveraged or short positions, as index futures are more beneficial (CME Group, 2016). On the contrary, as has been observed by Madhavan et al. (2014), Arnold and Lesné (2015), and Lettau and Madhavan (2018), owing to the stricter regulations imposed on derivatives following the global financial crisis of 2008, ETFs have become more cost-effective for institutional investors. Another related reason is the high level of competition among ETF providers, as well as economies of scale, which means that the costs of investment in ETFs, especially in equity index ETFs (the closest substitutes for index futures and options), have fallen significantly (by an average of 40% between 2008 and 2014, for the largest ETFs (Arnold and Lesné, 2015)).

2.2. ICT as a factor in the development of ETF markets

Before the global digital revolution, stock market transactions were performed through face-to-face transactions: buyers and sellers met physically in a stock exchange building to transact. The requirement of physical presence in a stock exchange constituted a significant barrier for traders, thus limiting total turnover of transactions and geographic coverage of traders. Black noted that "… a stock exchange can be embodied in a network of computers, and the costs of trading can be sharply reduced, without introducing any additional instability in stock prices." (Black, 1971, p. 87). In the 1980s, the New York Stock Exchange (NYSE) implemented an electronic system that allowed submission of orders directly to the trading floor; in subsequent years, the NYSE extensively automatized its trading systems as digital technologies developed. Similar changes, that is, introduction of electronic trading systems, took place in Nasdaq. Stoll (2006) notes that, "[The] Nasdaq Stock Market owes its very existence to computer and communications technology" (Stoll, 2006, p.159). Today, there is general agreement among scholars that digital technologies are the first driver of global financial markets, and that stock market transactions and the emergence of innovative instruments are driven by the economy-wide presence of ICT (Kennedy, 2017; Kyle and Lee, 2017).

Among the array of factors determining the functioning of ETF markets, ICT has been posited as contributing notably to strengthening financial systems, financial development (see, for example, Wurgler (2000), Yartey (2008), Comin and Nanda (2019), and Kim (2019)), and the introduction of various ICT-based innovative financial products. Stigler (1961) and Morck et al. (2000) point out that, in some ways, financial markets are "information markets"; hence, unbounded flows of information are essential to their functioning (Easley et al., 2016; Goldstein and Yang, 2017). Accordingly, ICT may reshape the operation of financial markets, facilitating unlimited information and data dissemination and decreasing the number of market failures, such as time delays and information asymmetries. Morck et al. (2000) also observe that ICT allows rapid flows of information. By affording physically separated actors the convenience of purchasing assets that are unavailable at their original location, these technologies further the decentralization and enhance the efficiency of financial markets (Bai et al., 2016). In this framework, hard infrastructure offering high-speed broadband is essential: broadband communication networks have greater information-carrying capacity, and expand financial market activities, such as trading (Lechman and Marszk, 2015). On the other hand, some authors contend that the overwhelming impact and pervasiveness of the new technologies may engender financial instability (Ilyina and Samaniego, 2011). Others, including Pozzi et al. (2013), Cvetanović et al. (2018) and Pantielieieva et al. (2018) have stressed the growing volatility of financial markets that may be caused by greater ICT penetration, and have held that digital gaps between countries may produce financial exclusion, thus rendering global financial systems less stable.

To date, empirical evidence on the impact of ICT access and use on financial development is quite fragmented and lacking in robustness. Shamim's (2007) pioneering study on empirical linkages between ICT penetration and financial markets in 61 economies in the period 1990–2002 found that ICT had a positive impact on financial development. Similar evidence for developing countries is provided by Claessens et al. (2002), who also suggest that the development of ICT infrastructure may further financial development in developing and emerging economies. In a study of African economies, Andrianaivo and Kpodar (2011) show that broader adoption of ICT enhances financial inclusion, with positive spillovers for financial development and economic growth. Sassi and Goaied (2013), in a study covering the Middle East and North Africa region, find that greater ICT penetration benefits financial development, and that—where this two-way relationship is important—it helps to stimulate economic growth.

ICT may affect financial markets and financial innovation (including ETFs) in various ways. The role of ICT in the development of ETF markets is observed on both demand and supply sides. As Lechman and Marszk (2015) note, because ETFs are listed and traded on stock exchanges, the development of these products depends largely on changes

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in capital markets, including those due to increasing ICT penetration. However, the spread of new technologies also affects the diffusion of financial innovations at large (Sharpe, 1991); therefore, the impact of ICT is not limited to such instruments as ETFs, but is felt broadly throughout the financial system. Similar conclusions can be found in Berger and Nakata (2013), Diaz-Rainey et al. (2015), Beck et al. (2016), Zavolokina et al. (2016), and Drummer et al. (2017), to cite a few.

The demand-side factors relate to those features of ETFs that make them more beneficial and attractive to investors than other similar options, such as mutual funds (or, as in the present study, equity index futures and options). These advantages are magnified by a higher level of stock market development, which itself may be the result of greater ICT penetration. The development of electronic trading systems produces a profound transformation of stock exchange microstructures (Blennerhassett and Bowman, 1998; Hasbruck, 2007; Lagoarde-Segot, 2009; Nishimura, 2010; Dutta et al., 2017). A high degree of trading automation reduces transaction costs and thus fosters more efficient risk-sharing, along with improved liquidity and more efficient pricing mechanisms (Hendershott et al., 2011; Linton and Mahmoodzadeh, 2018; Leone and Kwabi, 2019; Thiagarajan et al., 2019; Heng et al., 2020). Electronic trading also accelerates the dissemination of information between different markets and participants (Weber, 2006; Nishimura, 2010), which is made possible and magnified by enhanced access to the Internet and greater network bandwidths.

The cost of investing in ETFs consists mostly of exchange trading costs; therefore, the development of electronic trading systems, which reduces these costs, increases the attractiveness of ETFs vis-à-vis mutual funds (Lechman and Marszk, 2015; Drummer, Feuerriegel and Neumann, 2017; Marszk et al., 2019). Another advantage is that tracking error may potentially be smaller than for index mutual funds, due to arbitrage, since it minimizes the deviations of the price of an ETF from those of the instruments tracked (Marshall et al., 2013; Chen et al., 2017). To minimize tracking error, arbitrage transactions need to be made almost instantaneously and with the lowest possible transaction costs, which depends on access to up-to-date market information on the prices of both the underlying securities and the ETF shares. Electronic trading systems and wide access to fast Internet connections enable market participants to act instantly, based on the latest market data (Borkovec et al., 2010; Madhavan, 2012; Kirilenko et al., 2017). Moreover, real time communication yields another benefit from ETFs by providing investors with a price that is determined continually by the interplay of stock exchange supply and demand, while enabling them to trade ETF shares at any moment during market hours (Hill et al., 2015).

The factors in the supply side of ETF markets relate to the possibility of developing new, increasingly more complex types of ETF. The supply-side impact of ICT penetration on ETF markets can be summarized in two main points:

- Transferring securities between institutions that trade in ETF shares requires advanced settlement systems to guarantee timeliness and correctness. Such systems are more cost-effective when the technology is constantly upgraded (Schmiedel et al., 2006; Serifsoy, 2007; Schaper, 2012; Li and Marinč, 2016, 2018); consequently, a fast broadband Internet connection is crucial. Failing such technology, ETF marketing is either impossible or too costly to compete with mutual funds;
- ICT facilitates immediate response to the latest data and enables transfers of funds between physically distant markets, which is particularly important for emerging-market ETFs, with their higher transaction costs and lower liquidity (Aggarwal et al., 2012; Blitz and Huij, 2012; MacDonald, 2017).

ICT is also central to the cross-listing of ETFs (Calamia et al., 2013; Panourgias, 2015; Alderighi, 2020). In a cross-listing, an ETF's shares may be traded on one stock exchange and the underlying (the assets tracked) on another. Consequently, to obtain the key advantages of ETFs (minimal tracking error and low cost), the trading and settlement systems on both exchanges must employ advanced technologies (widely implemented ICT). Market participants must also know up-to-date exchange rates and be able to carry out linked transactions to manage the exchange rate risk. Both of these requirements are met by technologically advanced forex markets.

In short, the development of ETFs and trade in them is impossible without electronic trading systems and access to ICT for market participants. The threshold level of ICT necessary simply for the initial introduction of an ETF on a local financial market does not appear to be particularly high (ETFs are traded on emerging markets such as Indonesia and India). Presumably, all the European countries studied here have already reached this level. However, the policy implications of the linkage between ETF diffusion and ICT penetration are not so straightforward. National rates of diffusion of new technologies and diffusion of financial innovations differ significantly; therefore, there is a need to examine the trajectories of the processes, not only their starting points. Moreover, ETF markets are not homogenous: ETF products may differ in replication method (physical versus synthetic), which means that the structure of an ETF market (and consequently its impact on the financial system) may also be affected by the degree of ICT penetration. The development of synthetic ETFs requires more advanced technology, in that these need a more complicated creation and settlement mechanism than physical ETFs (for details, see, e.g., Johnson et al. (2011), Kosev and Williams (2011), Naumenko and Chystiakova (2015), Rompotis (2016), Nwogugu (2018), and Liebi (2020)).

3. Methodology and data

Our research strategy combines a set of descriptive statistics that unveils the main characteristics of our data: a locally weighted polynomial smoother (LOWESS) adopted for non-parametric graphical approximation of the relationship between the variables and regression models, including panel regressions and dynamic panel models to verify the hypothesized impact of ICT on ETF market development.

Using a locally weighted polynomial smoother nonparametrically is a method employed to graphically fit the curve of a relationship between two variables. This method of analysis is useful and widely adopted, as it allows relaxation of the rigid assumptions of conventional parametric analysis and regressions; accordingly, no assumption is made concerning the form of the relations. A major advantage of the locally weighted polynomial smoothing method is that it is outlier-resistant, introducing no disturbances in results (Cleveland, 1979; Hastie and Loader, 1993; Fan and Gijbels, 1995).

To examine statistical associations between ICT penetration rates, selected determinants, and ETF development, we use regression analysis. First, to determine whether there is a quantitative relationship between a selected variable and ETF diffusion, we use panel analysis, complemented by an estimation of analogous country-wise regressions. We try a fixed effects regression, which yields:

$$\varphi_{iy} = \alpha_i + \gamma_1 x_{1iy} + \cdots + \gamma_n x_{niy} + \varepsilon_{iy}, \tag{1}$$

where i denotes the country and y the year. In our empirical analysis, φ_{iy} represents ETF shares in consecutive i-countries and y-years, while x_{niy} are various explanatory variables that, hypothetically, may explain changes in ETF shares in the examined financial markets, that is, ICT penetration rates and other selected determinants.

Eq. (1) may be extended by introducing country dummies:

$$\varphi_{iy} = \alpha_i + \gamma_1 x_{1iy} + \cdots + \gamma_n x_{niy} + \delta_2 C_2 + \cdots + \delta_n C_n + \varepsilon_{iy}. \tag{2}$$

In Eqs. (1) and (2), α_i denotes unobserved time-invariant effects, δ_n is the coefficient for binary-country regressors, C is the country dummy, and n the number of countries in the sample. For Eqs. (1) and (2) to satisfy the exogeneity assumption, we assume $E(\varepsilon_{iy}\ x_{iy}) = 0$, with x_{iy} the explanatory variables. To confirm the adequacy of the fixed effects

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regression, we perform a Hausman test (Maddala and Lahiri, 1992) to check the null hypothesis: where $H_0 : cov\ (\alpha_i,\ x_{iy}) = 0$, a random effects regression is asymptotically more efficient; otherwise, a fixed effects regression is more suitable.

Where the random effects model turns out to be more appropriate, we estimate:

$$\varphi_{iy} = \gamma_0 + \gamma_1 x_{1iy} + \cdots + \gamma_n x_{niy} + \alpha_i + \varepsilon_{iy}\ , \quad (3)$$

with notation as in Eqs. (1) and (2). By convention, random effects models assume that national variation is random and thus uncorrelated with the explanatory variables.

We also consider the dynamic panel regression approach (Arellano and Bond, 1991), specified as follows:

$$\boldsymbol{Y}_{iy} = \left(\boldsymbol{Y}_{iy-1}\right) + \boldsymbol{\beta}\left(\boldsymbol{x}_{iy}^{`}\right) + \boldsymbol{u}_{iy}, \quad (4)$$

where $\boldsymbol{Y}_{i,y-1}$ shows the lagged value of the dependent variable, ψ and $\boldsymbol{\beta}$ are the estimated coefficients, and the remaining notations are as in Eq. (2). For the model specified in Eq. (4), we assume $\boldsymbol{u}_{i,y} = \boldsymbol{\mu}_i + \boldsymbol{\nu}_{i,y}$, if $\boldsymbol{\mu}_i \sim \boldsymbol{IID}\ (0, \boldsymbol{\sigma}_{\boldsymbol{\mu}}^2)$ and $\boldsymbol{\nu}_{i,y} \sim \boldsymbol{IID}(0, \boldsymbol{\sigma}_{\boldsymbol{\nu}}^2)$ (Baltagi, 2008).

Finally, to trace country-specific characteristics with respect to the correlations analyzed, we estimate individual country regressions that take the general econometric form:

$$\theta_i = \omega_0 + \omega_{1,i} + \cdots + \omega_{mi} + \varepsilon_i, \quad (5)$$

where i denotes the country and m is the number of explanatory variables. In this case, we employ the standard OLS model.

Our research covers stock exchanges in two Central and Eastern European countries, namely Hungary and Poland, as well as another eight European countries with a relatively long history of ETF trading: France,[1] Germany, Italy, Norway, Spain, Switzerland, Turkey, and the UK. Some other European countries with ETF markets (such as Sweden) were omitted due to issues related to the availability of data on ETFs and the problems with attribution of funds to certain markets (issues associated with exchanges operating in more than one country). The sample period, 2004–2019, is selected based on data accessibility—this is the only period for which a balanced dataset is available for the majority of the sample countries. However, the history of local ETF markets in Hungary and Poland is shorter, and the period of analysis for them is accordingly considerably shorter than for the other countries. The datasets for Switzerland and the UK are also limited.

Our main data source for the turnover of equity index instruments is the World Federation of Exchanges database (WFE, 2020). Supplementary sources, used in the cases of missing or inconsistent observations, are the datasets and reports of local stock exchanges. For equity index instruments, the core indicator is the turnover of ETFs, stock index options, and stock index futures (in millions of US dollars, for international comparability). However, for the UK, the scope of the analysis is severely limited, owing to lack of reliable data on the turnover in derivatives on the local stock exchanges, due partly to organizational changes on the main exchange; consequently, for the UK, we only analyze the turnover of ETFs, not in proportion to the other instruments. A similar treatment applies to the case of Switzerland.

Our focus is on how ETFs stand in relation to stock index derivatives. Our primary indicator of ETF market development (i.e., the diffusion of ETFs) is the share of ETFs in the total turnover of equity index instruments (ETFshare). To extend the analysis, we also consider an "absolute" standalone indicator of ETF market development, that is, EFT turnover in dollars (ETFtotal).

For ICT, we use two types of data: the number of fixed broadband subscriptions (FBS) per 100 inhabitants, and Internet users (IU), as the "proportion of individuals who used the Internet from any location in the last three months." The data on Internet users were derived from estimates based on results from national households surveys; data on Internet users correspond to the proportion of individuals using the Internet. The estimated number should reflect the total population of the country or, at least, individuals aged 5 years and older that have access and can use the Internet network. In the event that the survey data are not available or the target population reflects a more limited age group, an estimate for the entire population is produced, which allows a computation of the Internet users in a country. The fixed broadband subscription rate shows the accessibility of the backbone infrastructure that allows use of the Internet network. Technically, fixed broadband infrastructure combines fixed (wired) broadband, satellite broadband, and terrestrial fixed wireless broadband.[2] The fixed broadband subscription rate refers to fixed subscriptions to high-speed access to the Internet *via* cable modem, DSL, fiber-to-the-home/building, or other fixed broadband subscriptions, satellite broadband, and terrestrial fixed wireless broadband; it includes both residential subscriptions and subscriptions for organizations. All the data on ICT access and use are from the World Telecommunication/ICT Indicators database (June 2020 Edition).

To account for the attributes of the analyzed countries that could affect the development of ETF markets, we introduced several explanatory variables other than diffusion of ICT in our model specifications. Additionally, we chose several control variables to test for the stability of our estimates, based on a review of the literature (Demirgüç-Kunt and Levine, 1999; Levine, 2002; Klapper et al., 2004; Khorana et al., 2005; Masciandaro, 2006; Müller and Weber, 2010; Lemeshko and Rejnuš, 2014; Lorizio and Gurrieri, 2014; Dragotă et al., 2016; Lettau and Madhavan, 2018) and data availability. Data sources include (in all cases the most recent editions of each database as of October 2020 were used):

- The IMF Financial Development Index Database—indexes of general financial development (FD), development of financial markets (FM) and development of financial institutions (FI).
- The Behavioral Finance and Financial Stability Global Crises Database and Systemic Banking Crises Database II (Laeven and Valencia, 2020), supplemented by the World Bank's Global Financial Development Database—financial crisis variable (Crisis) that represents occurrence of at least one category of financial crisis in a given year, that is, banking, currency, or sovereign debt; in some cases supplementary sources were used.
- The Heritage Foundation's database—indexes of economic freedom (EF), investment freedom (INF), and financial freedom (FF).
- Worldwide Governance Indicators—regulatory quality (RQ) and rule of law (RoL).
- The World Bank's Global Financial Development Database—bank deposits as a percentage of GDP (BD), mutual fund assets as a percentage of GDP (MFA), stock market capitalization as a percentage of GDP (SMC), and stock market total value traded as a percentage of GDP (SMTVT).
- World Development Indicators—taxes on income, profits, and capital gains as a percentage of revenue (Tax), GDP per capita in PPP constant 2017 international $ (GDP), sum of imports and exports of goods and services as a percentage of GDP as a measure of trade openness (Open), foreign direct investment, net inflows as a percentage of GDP (FDI), and gross fixed capital formation as a percentage of GDP (GFCF).

It should be noted that there are other factors that have been identified in previous studies as determinants of the development of

[1] For France, the data refer to the equity index instruments traded on the entire Euronext exchange.

[2] See – ITU definitions at www.itu.int

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Table 1
ICT summary statistics for the countries selected. 1990–2019. Annual data.

Country	# of obs.	Mean	Std. dev.	ICT penetration in 1990	ICT penetration in 2019
Internet Users [%]					
France	30	42.5	34.2	0.05	83.8
Germany	30	49.9	35.8	0.12	88.1
Hungary	30	36.7	32.2	0.00	80.3
Italy	29	31.2	24.5	0.01	74.4
Norway	30	61.8	38.1	0.71	98.0
Poland	30	34.9	30.3	0.00	84.5
Spain	30	39.9	33.2	0.01	90.7
Switzerland	29	53.7	35.2	0.59	93.2
Turkey	28	26.1	24.8	0.00	73.9
UK	30	52.4	37.7	0.08	94.8
Fixed Broadband Subscriptions [per 100 inhab.]					
France	22	24.9	17.2	0.02	45.7
Germany	20	25.3	14.5	0.32	41.9
Hungary	20	17.6	11.5	0.03	32.9
Italy	20	17.3	9.7	0.21	28.7
Norway	19	27.5	14.3	0.52	41.3
Poland	19	12.6	7.8	0.03	20.7
Spain	20	19.2	10.9	0.19	33.3
Switzerland	20	30.8	15.5	0.78	46.3
Turkey	19	8.4	5.6	0.02	17.1
UK	19	24.2	14.1	0.08	39.6

Note: for Fixed Broadband Subscriptions, the time series are available from 1998.
Source: Authors` calculations.

investment funds and similar entities, such as ETFs; they are not included in our analysis for various reasons, mostly due to data availability (in the case of, e.g., more detailed indicators of ICT adoption in the financial system) and completeness (e.g., data on access to financial services) issues and to avoid collinearity. There are also, however, some rather unique cases. For instance, despite the importance of the legal origin of the various attributes of the financial system (see, for example, La Porta et al. (2000)), we do not include a variable to distinguish between common and civil law countries. The reason lies in the composition of our sample, with only one country with a common law legal system, the UK. Moreover, due to insufficient data on the equity index instruments other than ETFs, this country is excluded from most of the analysis.

4. Empirical analysis

4.1. ICT development - descriptive and graphical evidence

To investigate changes in ICT access and use in the economies selected, we use the annual time series on fixed broadband networks between 1998 and 2019 and Internet user rates for the period 1990–2019. These gauges of the progress of ICT diffusion in the sample countries between 1990 and 2019 are presented in Table 1 (and graphically in Fig. 1). No significant national differences in ICT diffusion are observed. In terms of Internet users, every country shows rapid growth in the share of the population with an Internet connection. In 1990, under 1% had access to ICT (the highest ratios were in Norway, at 0.70%, and Switzerland, at 0.59%, while the lowest were in Hungary, Poland, Spain, Italy, and Turkey, at a near-negligible 0.003–0.01%). After almost three decades of exponential growth, all countries had IU ratios above 70% in 2019, with the best performers in this regard being Norway, the UK, and Switzerland, achieving 98%, 94.8%, and 94.2%, respectively. Similarly rapid growth characterized access to fixed broadband networks (i.e., population share with fixed broadband subscriptions), which grew at an annual average rate of 34% in Germany and as much as 48% in Hungary and Poland, to levels ranging from 20.7% in Poland to approximately 45–46% in France and Switzerland in 2019. In short, none of the countries examined was a significant outlier in terms of access to and use of ICT. Notably, regarding all examined European countries, we observe strong convergence tendencies with regard to ICT deployment between 1990 and 2019, as all the economies considered enjoyed rapid growth in ICT saturation rates.

The panel regression estimations (see Table 1A in the Appendix) suggest that the share of the population using the Internet may well be explained by the share with access to fixed broadband. The estimated coefficients are positive and statistically significant, implying that the proportion of Internet users can be considered as a key indicator of access to ICT. As explained in Section 3, “Internet users” refers to the

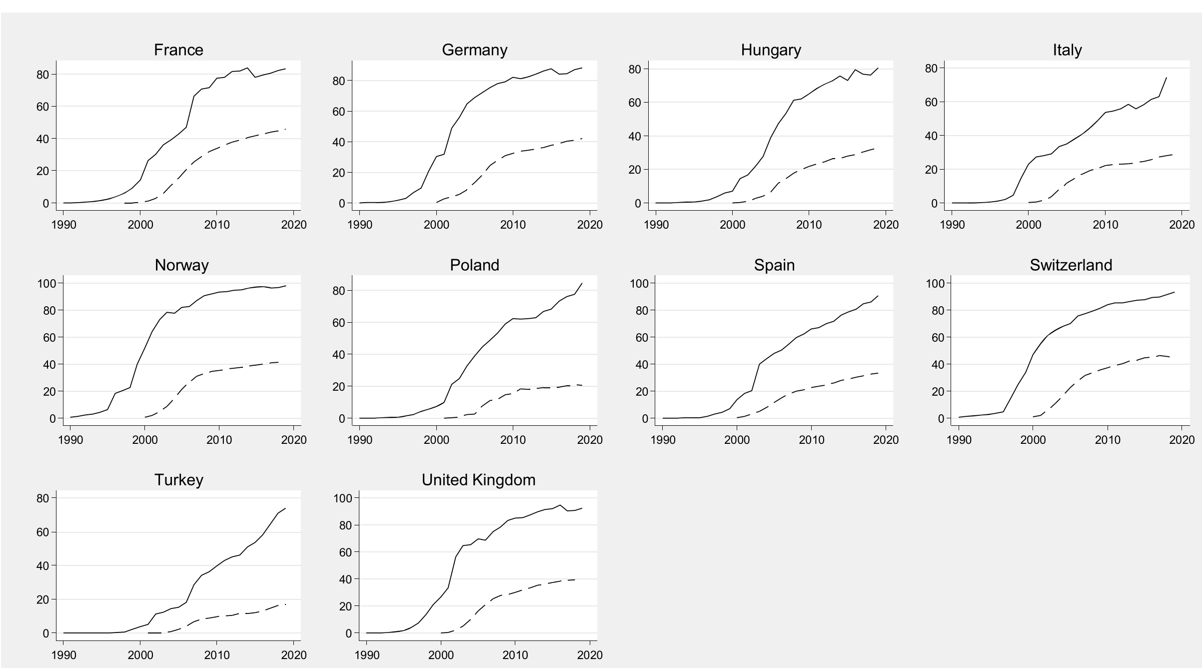

Fig. 1. ICT diffusion trajectories, 1998–2019. Note: Y-axis: the share of the population with access to ICT; X-axis – time. Solid line: Internet Users; dashed-line: Fixed Broadband subscriptions. Source: Authors` elaboration.

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Table 2
Summary statistics for ETFs. Annual data, 2004–2019.

	France Turnover of ETFs [mln USD]	ETF share of total stock index financial instruments [%]	**Germany** Turnover of ETFs [mln USD]	ETF share of total stock index financial instruments [%]	**Hungary** Turnover of ETFs [mln USD]	ETF share of total stock index financial instruments [%]
# of obs.	16	16	16	16	13	13
Min	17 840.4	0.30	45 158.1	0.33	0.66	0.08
Max	198 246.8	4.88	306 853.5	0.71	43.94	3.43
Mean	111 001.4	1.84	172 495.1	0.47	7.68	0.81
	Italy		**Norway**		**Poland**	
# of obs.	16	16	15	14	10	10
Min	4 826.2	0.59	29.1	3.43	28.9	0.02
Max	128 500.9	10.6	22 493.2	80.6	98.3	0.14
Mean	80 834.6	6.6	6 140.3	47.4	53.9	0.08
	Spain		**Switzerland**		**Turkey**	
# of obs.	14	14	16	–	15	8
Min	1 925.8	0.17	7 854.3	–	372.6	0.25
Max	13 929.5	1.41	128 787.8	–	14 217.4	6.6
Mean	6 373.4	0.67	71 812.7	–	4 218.9	1.62
	United Kingdom					
# of obs.	14	–				
Min	23 272.4	–				
Max	457 522.3	–				
Mean	204 249	–				

Source: Authors` calculations.

proportion of society that has access to digital technologies and thus can use the Internet network, while fixed broadband network constitutes the backbone infrastructure that is a prerequisite for the use of the Internet network. The fixed broadband network used as one of the core ICT indicators relates to the network density in a given country, and reflects the state of development of the ICT infrastructure. These two ICT metrics are broadly used to approximate digital inclusiveness, indicating people's access to information and digitally-based services. However, elementary metrics on ICT performance should be used wisely and carefully interpreted. Despite the simplicity of ICT indicators, their in-depth analysis clearly unveils areas in which countries are doing well as well as those areas where there is still room for improvement.[3]

Access to high-speed networks and network carrying capacity are essential elements for the development of more sophisticated and technology-based financial instruments, as well as for institutions and individuals, as they facilitate participation in digital financial markets. The remainder of this study sheds light on the traced relationships between ICT deployment and ETF market development across European economies.

4.2. *Development of ETF markets*

The second step of the investigation is an analysis of the development of ETF markets through selected summary statistics for the main national trends. Two measures are considered: monetary turnover of ETFs on the local stock exchanges and the percentage share of ETFs in the total turnover of stock index financial instruments (Table 2 and Fig. 2).

In the sample period, Hungary and Poland were the two largest ETF markets in the CEE region. Even there, however, ETF markets remained substantially underdeveloped (Table 2 and Fig. 2). In Hungary, ETFs were launched much earlier than in Poland (in 2007); however, turnover has remained substantially lower, with a mean annual value of $7.68 million, compared with $53.9 million in Poland. In Hungary, the greatest volume of turnover was recorded in the early years, with the all-time high of $43.94 million coming in 2007. In relative terms (i.e., ETFs' overall market share), however, the highest values, which can be termed outliers, were registered in 2015 and 2017 (see Fig. 2). In Poland too, the highest turnover was found in the early phase, less than a year after the introduction of ETFs in 2011 (it should be noted, however, that record-high levels of trading were observed in 2020, that is, the year following the time period of our sample). Trading volume soon declined, however, to a low of $68.9 million in 2012. In the following years, activity on the Polish ETF market was limited, and the highest recorded share of ETFs represented an extraordinary one-month spike in annual ETF trading at 0.14% in 2015, which was, in any case, one of the lowest values in the entire sample. One major reason for the extremely low turnover of ETFs in Hungary and Poland was the small number of these instruments available: Hungary had only one listed; in Poland, the number rose to six in December 2019, although most of these were launched in 2018 and 2019, with no perceptible growth in market activity. This lack of further development can be attributed to such factors as customers' lack of awareness and the limited size of the local financial markets (Marszk and Lechman, 2019a).

In the five other European countries—France, Germany, Italy, Switzerland, and the UK—ETFs were listed during the entire period; in two countries, Norway and Turkey, they were launched in 2005. In Spain, they were introduced in 2006. However, the analysis for the UK also starts in 2006, owing to lack of data. In Germany and France, ETF turnover increased in the period 2004–2011, and then declined substantially as a consequence of the eurozone debt crisis and falling stock market indexes. In the final years covered here, there was no significant trading rebound in Germany, and only a short-lived one in France. The pattern of ETF market growth in Spain was different: turnover was highly variable until 2011, held stable in 2012 and 2013, expanded in the period 2013–2015, and then contracted significantly. This trajectory can be attributed to both regional factors (eurozone crisis) and local factors. Even more magnified variability can be noted for Norway: its ETF market reached a record-high level in 2009, and the next years

[3] When interpreting basic metrics on ICT, it is important to emphasize that the relationship "*those who have access* > *users* > *subscribers*" is true. Usually the number of legal subscribers accounts for the smallest number of people, while the number of users exceeds the number of subscribers, and the number of those who have access to certain technology usually exceeds the number of users. "Subscribers" are legal owners of a given technology who are obliged to pay for it, while "users" are those who use a certain technological solution without necessarily paying for it.

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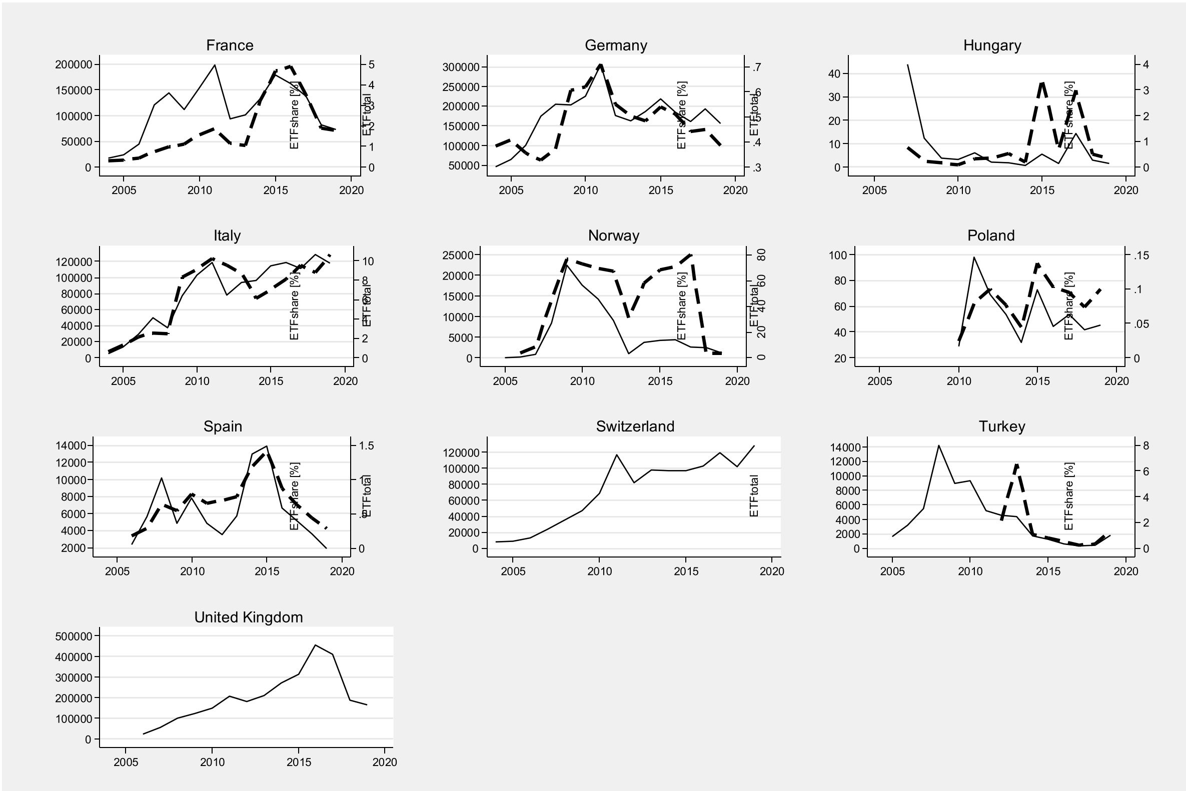

Fig. 2. Turnover of ETFs and share of ETFs of total turnover of index financial instruments, 2004–2019 (annual time series). Note: solid line (left-hand Y-axis): turnover of ETFs [mln USD]; dashed-line (right-hand Y-axis): ETF share of total stock index financial instruments [%]. For Switzerland and the UK, ETF share of total stock index financial instruments was not available. Source: Authors` elaboration.

marked its decline; interestingly, a highly similar trend is noted for the Turkish ETF market. In the cases of both Norway and Turkey, the one-time peaks in trading can be explained as related to the intensive stock trading amidst the turmoil in the global financial markets. In Italy, Switzerland, and, to a lesser extent, the UK, the growth of the ETF market was steadier. Trading in the UK peaked in 2016 and 2017; in Italy, ETF turnover remained broadly stable from 2015 on. In Switzerland, it remained steady in the period 2013–2016, with substantial growth occurring in the next three years, reaching maximum levels comparable to those of the Italian market. It is worth observing that, despite common factors and a high degree of European market integration (most of the examined countries are EU member states), the impact of such events as the global financial crisis and the eurozone debt crisis differed among the analyzed economies. For example, ETF turnover expanded in France after 2011, while it held stable in Germany.

There are also considerable differences between the European economies (other than Poland and Hungary, already discussed) in the share of ETFs in the total stock index financial instruments (Switzerland and the UK are excluded due to lack of data). In Germany, France, Turkey, and Spain, the market share of ETFs remained very low over the whole period. In Germany, although ETF turnover was relatively high, the market share was among the lowest in the sample (see Table 2); that is, the role of ETFs was marginal by comparison with the other elements of the equity index arbitrage complex. This also suggests potential problems in measuring and evaluating ETF market development (the diffusion of ETFs): conclusions may differ significantly depending on one's definition of this process (although, in most cases, they are rather similar). In Italy, the market share of ETFs increased up to 2010 and then stabilized; for the entire period, it averaged 6.6%, the second-highest in the entire sample, thus confirming its relatively great development, in which one possible factor was the integration of the Italian stock exchange with its British counterpart. The highest mean and maximum levels of the market share of ETFs in the examined sample were reached in Norway (the peak value exceeded 80%), yet they may mostly be attributed to the swings in the turnover of the competing stock index financial instruments. Nonetheless, Norway may be regarded as the regional leader in terms of the relative position of ETFs: they have grown substantially in a comparatively small market.

Additionally, we verified the correlation between market share and ETF turnover value: it was positive in all the countries.[4] The lowest correlation coefficient was calculated for Hungary (0.17); in all the other cases, it exceeded 0.5, with the highest values obtained for Italy, Spain, and Turkey. To some extent, analyses of turnover values and market shares should yield similar results (for a more detailed discussion, see Section 4.3 below); therefore, we can adopt market share as our main indicator. Moreover, this choice is substantiated by the fact that it allows for an examination of the changes in the position of ETFs in relation to the competing stock index instruments. The impact of ICT is assessed through both panel and country-specific approaches.

4.3. Relationships between diffusion of ETFs and ICT: empirical test

This section empirically verifies the association between changes in ICT penetration and ETF market development in our sample countries between 2004 and 2019. For a comprehensive in-depth insight and identification of associations (or lack thereof), we use both graphic visualization and panel analysis. First, we graphically analyze two relationships: that between the ETF share of total trade in index financial instruments and the ICT penetration rate (proxied by the fixed

[4] Detailed results available on request.

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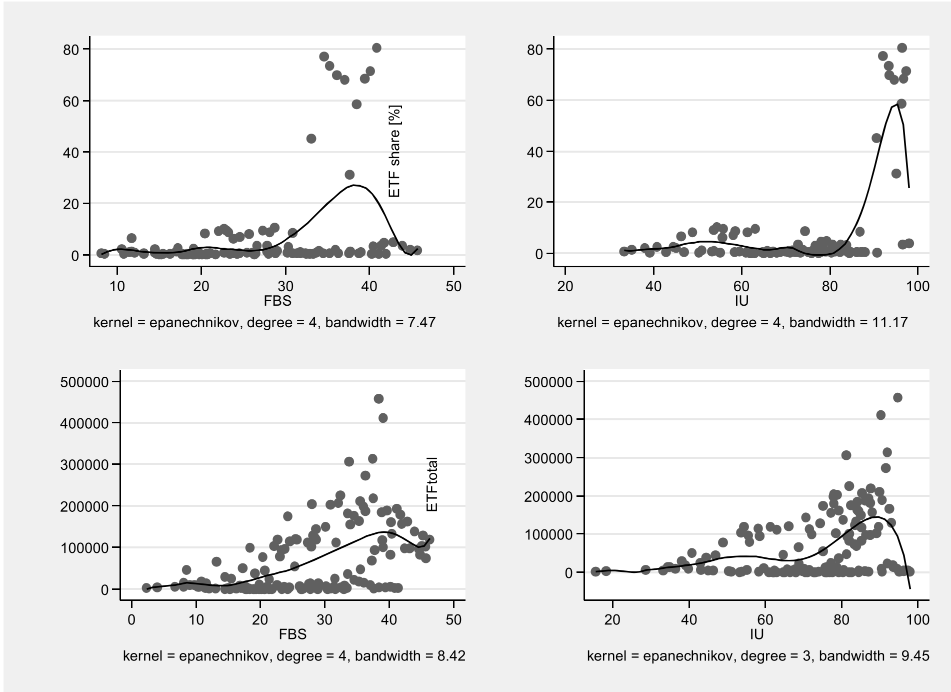

Fig. 3. Exchange-traded funds and ICT penetration rates, 2004–2019 (annual series). Note: nonparametric graphical approximation, bandwidth adjusted. Switzerland and the UK are excluded from the ETF share as no data was available for the period. ETFtotal is ETF turnover expressed in millions of USD. ETF share is the percentage of total turnover in stock index financial instruments. Source: Authors` elaboration.

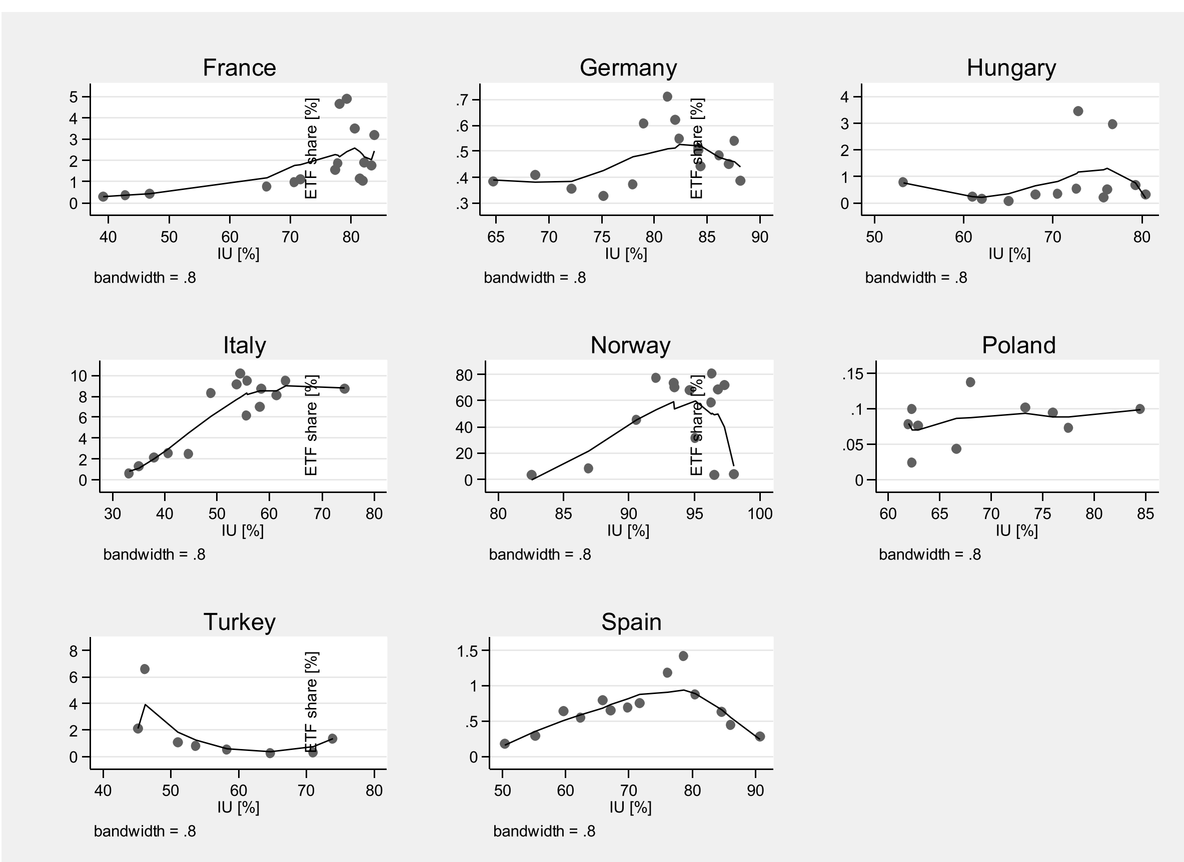

Fig. 4. ETF share in equity index instruments and Internet Users, 2004–2019 (annual series). Note: nonparametric graphical approximation; default bandwidth; X-axis: Internet user penetration rate (raw data); Y-axis: ETF share (raw data). Source: Authors` elaboration.

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Table 3

Panel regression estimates: ETF share and its determinants, 2004–2019 (annual series).

LnETFshare$_{(i,y)}$	**FE_1**	**FE_2**	**FE_3**	**FE_4**	**FE_5**	**FE_6**	**FE_7**	**FE_8**	**FE_9**	**FE_10**	**FE_11**	**FE_12**	**FE_13**	**FE_14**	**FE_15**	**FE_16**	**FE_17**	**FE_18**	**FE_19**	**FE_20**
LnIU$_{(i,y)}$	**2.41 [0.52]**	**2.57 [0.51]**	**2.97 [0.49]**	**2.75 [0.56]**	**3.3 [0.56]**	**1.99 [0.62]**	**2.45 [0.59]**	**2.75 [0.56]**	**3.23 [0.57]**	**1.7 [0.75]**	**1.98 [0.75]**	**1.89 [0.76]**	**2.52 [0.55]**	**2.9 [0.65]**	**3.52 [0.61]**	**2.1 [0.62]**	**3.5 [0.85]**	**2.52 [0.55]**	**2.24 [0.48]**	**3.1 [0.49]**
LnFD$_{(i,y)}$																				**-2.2 [1.1]**
LnFI$_{(i,y)}$															-2.5 [2.1]					
LnFM$_{(i,y)}$	**-1.9 [0.89]**						**-1.7 [0.91]**	-0.84 [1.2]												
Crisis$_{(i,y)}$																			-0.13 [0.18]	-0.06 [0.17]
LnEF$_{(i,y)}$		0.81 [3.62]															-2.3 [3.2]			
LnINF$_{(i,y)}$						**2.5 [0.95]**				**2.1 [0.96]**			**2.65 [0.83]**			**2.3 [0.96]**		2.6 [0.83]		
LnFF$_{(i,y)}$	0.55 [0.91]											1.1 [0.94]		-0.41 [0.96]						
LnRQ$_{(i,y)}$			**0.84 [0.22]**	**1.1 [0.28]**	**1.1 [0.29]**			**1.1 [0.28]**	**1.1 [0.29]**					**1.1 [3.1]**	**1.1 [0.29]**		**1.1 [0.31]**			**0.85 [0.22]**
LnRoL$_{(i,y)}$													0.43 [0.28]					**0.43 [0.28]**		
LnBD$_{(i,y)}$										0.91 [1.4]	1.6 [1.4]	1.2 [0.72]					0.38 [1.52]			
LnMFA$_{(i,y)}$	-0.31 [0.35]	-0.24 [0.39]													-0.08 [0.33]					
LnTax$_{(i,y)}$		**-1.4 [0.72]**	-1.1 [0.67]	-0.92 [0.75]				-0.91 [0.75]	**-1.2 [0.70]**	**-1.1 [0.75]**	**-1.35 [0.69]**	**-1.6 [0.72]**				1.02 [0.75]			**-1.3 [0.70]**	
LnSMC$_{(i,y)}$					-0.51 [0.43]	-0.36 [0.44]	-0.11 [0.46]		-0.23 [0.45]				-0.52 [0.39]		-0.36 [0.45]	-0.12 [0.47]		-0.52 [0.39]		
LnSMTVT$_{(i,y)}$				-0.36 [0.24]										**-0.52 [0.21]**						
R^2 [within]	0.35	0.34	0.36	0.42	0.39	0.35	0.33	0.42	0.42	0.39	0.35	0.36	0.51	0.41	0.41	0.37	0.41	0.51	0.25	0.36
Rho	0.92	0.92	0.91	0.93	0.91	0.88	0.91	0.92	0.92	0.92	0.91	0.92	0.93	0.92	0.91	0.91	0.89	0.93	0.89	0.90
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
[Prob >F]	[0.16]	[0.12]	[0.34]	[0.59]	[0.50]	[0.24]	[0.25]	[0.33]	[0.62]	[0.06]	[0.11]	[0.15]	[0.28]	[0.45]	[0.32]	[0.23]	[0.11]	[0.28]	[0.02]	[0.02]
# of countries	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
# of obs.	91	91	99	85	88	88	88	85	88	91	91	91	85	85	88	88	91	85	100	99

Note: constant included but not reported; standard errors in square brackets below coefficients; panel – strongly balanced; results statistically significant at the 5% level in bold; all values are logged; Switzerland and the UK are excluded; Hausman tests – not reported but available on request.

Source: Authors` estimations.

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Table 4
Panel regression estimates: ETF share and its determinants, with control variables, 2004–2019 (annual series).

$LnETFshare_{(i,y)}$	**FE_1C**	**FE_2C**	**FE_3C**	**FE_4C**	**FE_5C**	**FE_6C**	**FE_7C**	**FE_8C**	**FE_9C**	**FE_10C**	**FE_11C**	**FE_12C**	**FE_13C**	**FE_14C**	**FE_15C**	**FE_16C**	**FE_17C**	**FE_18C**	**FE_19C**	**FE_20C**
$LnIU_{(i,y)}$	**2.35**	**2.73**	**3.04**	**3.1**	**3.4**	**2.2**	**2.5**	**3.2**	**3.5**	**1.8**	0.76	0.54	**2.85**	**2.76**	**3.21**	**2.18**	**1.95**	**2.85**	**2.71**	**2.94**
	[0.66]	**[0.66]**	**[0.51]**	**[0.57]**	**[0.63]**	**[0.7]**	**[0.74]**	**[0.48]**	**[0.59]**	**[0.86]**	[0.83]	[0.77]	**[0.57]**	**[0.66]**	**[0.76]**	**[0.71]**	**[0.81]**	**[0.58]**	**[0.61]**	**[0.58]**
$LnFD_{(i,y)}$																				
$LnFI_{(i,y)}$															0.66					
															[2.4]					
$LnFM_{(i,y)}$	**-2.9**						**-2.2**	0.09									-1.5			
	[0.89]						**[0.98]**	[0.93]									[3.28]			
$Crisis_{(i,y)}$																			-0.26	-0.02
																			[0.19]	[0.19]
$LnEF_{(i,y)}$		-0.14										2.05								
		[3.9]										[0.93]								
$LnINF_{(i,y)}$						**2.6**				**2.1**			**2.88**			**2.6**		**2.9**		
						[0.91]				**[0.97]**			**[0.72]**			**[0.91]**		**[0.73]**		
$LnFF_{(i,y)}$	1.13													0.93						
	[1.05]													[1.03]						
$LnRQ_{(i,y)}$			**0.93**	**1.1**	**1.2**			**0.92**	**1.18**					**0.9**	**1.21**		**1.00**			**0.79**
			[0.18]	**[0.25]**	**[0.27]**			**[0.19]**	**[0.27]**					**[0.29]**	**[0.27]**		**[0.26]**			**[0.21]**
$LnRoL_{(i,y)}$													**0.75**					**0.75**		
													[0.25]					**[0.25]**		
$LnBD_{(i,y)}$										1.01	**4.24**	**3.8**					**3.2**			
										[1.43]	**[1.45]**	**[1.4]**					**[1.4]**			
$LnMFA_{(i,y)}$	-0.12	-0.22													-0.21					
	[0.38]	[0.44]													[0.35]					
$LnTax_{(i,y)}$		**-1.8**	-0.24	-0.18				-0.31	-0.31	**-1.3**	-0.41	-0.36				-0.02			-0.36	
		[0.84]	[0.67]	[0.80]				[0.82]	[0.80]	**[0.65]**	[0.83]	[0.73]				[0.81]			[0.76]	
$LnSMC_{(i,y)}$					-0.11	0.16	0.05		-0.001				-0.32		-0.13	0.18		-0.32		
					[0.43]	[0.45]	[0.52]		[0.45]				[0.38]		[0.45]	[0.48]		[0.38]		
$LnSMTVT_{(i,y)}$				-0.17										-0.23						
				[0.25]										[0.22]						
$LnGDP_{(i,y)}$	-2.47	-1.2	-2.6	-3.1	-2.8	**-4.3**	-3.2	-2.42	-2.3	-1.5		-5.8	0.34	**-4.3**	-2.4	**-4.3**	-2.6	0.34	-4.1	**-3.2**
	[1.95]	[2.2]	[1.5]	[1.7]	[1.6]	**[1.7]**	[2.3]	[1.5]	[1.8]	[1.9]		[1.8]	[1.6]	**[1.9]**	[1.89]	**[1.8]**	[1.7]	[1.6]	[1.6]	**[1.3]**
$LnOpen_{(i,y)}$		0.81	0.43	0.19	0.81	0.47	1.1			0.85	-0.13	1.5	-1.3	0.45	1.04	0.47	0.75	-1.3	-0.56	-0.01
		[1.61]	[1.2]	[1.2]	[1.3]	[1.4]	[1.7]			[1.53]	[1.34]	[1.3]	[1.2]	[1.25]	[1.46]	[1.4]	[1.2]	[0.12]	[1.43]	[1.4]
$LnFDI_{(i,y)}$			-0.04	-0.01	-0.01	-0.006		-0.03	-0.009		-0.02	0.04	0.02	0.001	-0.01	-0.01	0.01	0.02	-0.06	-0.03
			[0.06]	[0.07]	[0.07]	[0.08]		[0.06]	[0.07]		[0.08]	[0.07]	[0.06]	[0.07]	[0.07]	[0.08]	[0.07]	[0.06]	[0.08]	[0.07]
$LnGFCF_{(i,y)}$	-0.27	1.27					0.49	0.07	-0.12	1.2	-0.16									
	[1.09]	[1.2]					[1.1]	[0.91]	[0.96]	[1.2]	[0.97]									
R^2 [within]	0.37	0.36	0.51	0.52	0.51	0.44	0.35	0.51	0.51	0.39	0.41	0.50	0.62	0.52	0.52	0.44	0.56	0.62	0.36	0.41
Rho	0.94	0.94	0.95	0.96	0.91	0.95	0.95	0.95	0.94	0.94	0.92	0.97	0.95	0.97	0.95	0.95	0.96	0.96	0.95	0.94
# of countries	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
# of obs.	91	91	88	76	79	79	88	88	79	91	82	82	76	76	79	79	82	76	89	94

Note: constant included but not reported; standard errors in square brackets below coefficients; panel – strongly balanced; results statistically significant at the 5% level in bold; all values are logged; Switzerland and the UK are excluded; Hausman tests – not reported but available on request.
Source: Authors` estimations.

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broadband penetration rate, FBS, and number of Internet users, IU), and that between the value of ETF turnover and ICT penetration. The method employed is locally weighted scatter plot smoothing (LOWESS).

Fig. 3 portrays the relationship between ETF diffusion and ICT penetration in all the economies between 2004 and 2019; Fig. 4 depicts the relationship in each individual country. The positive association between ETF market development and ICT is relatively clear in Fig. 3 (for panel data on ETF turnover), while the empirical links for the individual countries in Fig. 4 are even more evident (with a few exceptions).

Our empirical research builds on the supposition widely acknowledged among scholars that ICT represents the main driver of electronic stock trading. As discussed in Section 2, growing ICT penetration, especially with regard to broadband networks offering high-speed Internet connection with high carrying capacity, constitutes a solid fundament for the emergence and further development of innovative, technology-based financial instruments, such as ETFs. Our sample countries are characterized by dynamic development and rapidly increasing penetration rates of information and communication technologies (see Table 1 and Fig. 1), which determine the introduction of ETFs into financial markets. Financial markets are a perfect example of global markets that operate through adoption and usage of digital technologies. The introduction of innovative, ICT-based financial instruments, such as ETFs, due to their nature, is directly determined and facilitated by economy-wide ICT adoption and usage, especially broadband networks (Berger and Nakata, 2013; Okwu, 2015; Asongu and Nwachukwu, 2019). Moreover, ICT affects many features of ETFs, for example, their cost-efficiency due to low distribution and accounting expenses (consequently, investors show a high propensity to buy ETF shares and to rebalance their portfolios at a low price). Due to access to high-speed network connections and adequate technologies, these financial instruments are priced continuously. Additionally, digital technologies allow for higher price transparency and new opportunities for financial gains for investors; timely transactions among geographically separated agents are also an important means through which ICT fosters ETF diffusion. Apparently, major ETF advantages are ICT-enhanced; due to the nature of ETFs, the ICT penetration process constitutes a major determinant of their development. Furthermore, rapidly increasing acceptance and usage of digital technologies lead to replacement of traditional face-to-face transactions by electronically driven ones, which boosts liquidity, order volumes, and number of transactions. The causality between digital technologies and the introduction of innovative technology-based financial instruments has been traced in previous studies, for example, Anderianaivo and Kpodar (2011), Sassi and Goaied (2013), Diaz-Rainey and Ibikunle (2015), Drummer et al. (2017), Lettau and Madhavan (2018), and Marszk et al. (2019).

Across the economies analyzed, increasing ICT penetration rates between 2004 and 2019 were accompanied by growth in the value of ETF turnover and increasing shares of ETFs in the total turnover of index financial instruments, a pattern discernible (Fig. 3) for both ICT indicators (FBS and IU). When IU penetration rates were below 60%, ETF trading was relatively less active; however, when access to and use of the Internet became more common (particularly for IU penetration rates above 70%), ETF trading increased; the correlation coefficient is 0.36. This indicates that broad Internet use is a key prerequisite for the expansion of the ETF market. These findings are consistent with the graph of the statistical relationship between FBS penetration rates and ETF turnover, whose correlation coefficient is the closest among the pairs of variables (0.50).

A slightly different picture emerges from the graphs of ETF shares in Fig. 3. The correlation coefficients between ETF shares and FBS and ETF shares and IU are 0.36 and 0.44, respectively, which suggest a marginally weaker association between ICT penetration and the relative weight of ETFs in the total turnover in equity index financial instruments. It is particularly discernible in the case of FBS penetration rates below 25% and IU below 80% (i.e., most of the observations).

Fig. 4 presents country-specific evidence of the statistical association between ICT penetration (proxied by IU) and the ETF share. In one country, France, the graph shows that, below a certain level of IU penetration, the ETF share remains relatively small; however, once IU reaches about 65%, the share begins to rise rapidly. This might suggest that a level of IU≅ 65% represents an ICT penetration threshold for a jump in financial innovation, whose diffusion depends on sophisticated new technologies. In France, with the coefficient of 0.58, there is a strong correlation between IU and the ETF share. In Italy, the relationship between ETF share and IU is the strongest: the ETF share began to rise significantly at a lower IU penetration rate of between 30% and 40%, while the correlation coefficient between these variables is 0.84, indicating a strong statistical relationship (relatively weak for IU above 60%). Similar results are found for Germany and Hungary: when IU passed 70% and 60%, respectively, the ETF share began to rise sharply. However, it should be noted that for Germany, Spain, and Hungary, this 'boost' in share is only relative; the share remains quite low for the entire period. For instance, in Germany between 2008 and 2009, the ETF share more than tripled, although the rise was still merely from 0.18% to 0.61%; to put it differently, the growth rate was 238%, although the share remained well below 1%. The cases of Spain and Hungary are similar, with correlation coefficients of 0.29 and 0.24, respectively. For Poland, ETFs were only introduced in 2010, leaving too few annual observations for any robust conclusions (however, the relationship may be preliminarily assessed as rather weak). As already noted in Section 4.2, in the cases of Norway and Turkey, the development of the local ETF markets has been volatile, which has affected the results presented in Fig. 4. In Norway, the relationship is positive for the lower levels of IU but becomes neutral or even negative for the higher ones. In the case of Turkey, it may be described as U-shaped and substantially different from any other economy analyzed. Moreover, Turkey is the only case in our empirical sample in which the correlation coefficient between IU and ETF share is negative (-0.55) in the analyzed period.

The quantitative relationship between ICT penetration and ETF market development is explored more thoroughly via panel analysis (for the results, see Tables 3 and 4). The dependent variable is the ETF share (of the total turnover in equity index financial instruments), $ETFshare_{(i,y)}$, where i indicates the country, and y the year. We utilized several explanatory and control variables (the data sources and abbreviations used are listed in Section 3), with analogous notations. Considering the aim of this study, the key independent variable is $IU_{(i,y)}$. We hypothesize that greater ICT penetration may foster ETF market development. As in the previous analyses, we use annual data for ETFs and ICT between 2004 and 2019. Given that $IU_{(i,y)}$ and $FBS_{(i,y)}$ are highly correlated (coefficient of 0.88), to avoid collinearity, we restrict the analysis to only one ICT explanatory variable, $IU_{(i,y)}$.

The remaining variables can be divided into a few categories of potential determinants of ETF market development (the abbreviations of the variables are provided in the brackets). First, we consider the overall level of financial development (FD) as well as the development of two key elements of financial systems: financial markets (FM) and institutions (FI). Next, we account for the occurrence of any type of financial crisis (Crisis). The third category of variables represents the selected aspects of a given country's institutional conditions, such as the quality of regulations (RQ) and the rule of law (RoL), as well as some aspects of economic freedom (EF, INF, and FF). In the fourth group, we include various financial variables: bank deposits (BD) used as a proxy for the development of the banking sector and financial literacy, assets of mutual funds (MFA), and two stock market variables showing the dimensions of its capitalization (SMC) and turnover (SMTVT). Finally, we employ a set of variables to control for differences in the macroeconomic conditions (GDP, Open, FDI, GFCF) and taxes (Tax). As a methodological remark—due to the high dynamics of the interactions between ETF markets and their environment (encapsulated by the aforementioned factors), we decided not to use lagged values of the

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explanatory and control variables—any changes should, without substantial delays, be reflected in the values of the turnover of the ETFs, either considered in isolation or in relation to the other equity index instruments.

Tables 3 and 4 summarize the panel regression for the correlation between ICT penetration and ETF market development in the eight countries examined between 2004 and 2019. In the first step, we use a panel regression model with a general form, as specified in Eq. (1), thus accounting for a possible grouping of observations among economies (see Table 3). The Hausman test[5] unequivocally suggests the use of the fixed effects specification in these cases; the returned p-values are lower than 0.05.[6] To verify the impact of the various explanatory variables, we estimated many panel models. We present the twenty most robust specifications (FE_1 – FE_20); the selection was subject to, among others, avoidance of multicollinearity. The most striking conclusion is the positive and statistically significant values of the $LnIU_{(i,y)}$ coefficients, regardless of the other variables included. It supports the supposition that ICT deployment has a strong and positive impact on $LnETFshare_{(i,y)}$. Among the other possible determinants, the estimates for the variables $LnINF_{(i,y)}$ and $LnRQ_{(i,y)}$ are positive and statistically significant in most of the specifications, thus implying a positive relationship with $LnETFshare_{(i,y)}$. It means that, apart from the adoption of ICT, the development of the ETF markets in Europe can, to some extent, be explained by certain conditions related to the quality of regulations and investment freedom. There are also some variables with statistically significant negative coefficients: $LnFD_{(i,y)}$, $LnFM_{(i,y)}$, and $LnTax_{(i,y)}$. However, the two determinants of financial development (overall and financial markets) appear only in three specifications and, therefore, these results, which seem rather counterintuitive, should be regarded with caution. However, in these models, the ICT coefficient is positive and significant, which could imply that the role of ICT was more profound. The tax variable seems more relevant, as it is significant in six out of the nine specifications in which it was included; it may be concluded that the tax levels (including taxes on capital gains) are inversely related to the development of the ETF market in the European economies, a result that seems rather intuitive.

Regarding the estimated goodness-of-fit (Table 3), in most cases the returned R^2 is rather average. Moreover, in each model, we controlled for time fixed effects, to check for any time-specific shocks (time-related effects). Our results suggest that the examined relationships are not affected by any time-specific effects, as no year dummy included in the analysis is statistically significant. The lowest R^2 is 0.25, reported for the specification FE_19. We observe R^2 at around 0.41–0.42 for five model specifications (FE_4, FE_9, FE_14, FE_15 and FE_19), while for two specifications, FE_13 and FE_18, we observe the highest model fit with R^2 at 0.51. These results suggest that the selected explanatory variables explain about 50% of the changes in the ETF share across the examined countries in the period 2004–2019. The results are considered satisfactory, and are a reminder of the significant amount of unexplainable variation inherent in this field of study, for example, risk preferences of investors, investors' predictions regarding future financial market developments, or, for instance, monetary policies and personal attitudes toward financial innovations, which are hard to capture in such models.

In the next step, we supplement our analysis by estimating panel regressions with the control variables to assess the stability of our previous estimates. The results are summarized in Table 4; again, we present the twenty most robust specifications, FE_1C – FE_20C. The results mostly confirm the conclusions formulated above. The positive relationship between ICT diffusion and the development of ETF markets is again unveiled by the positive and statistically significant coefficients in most of the specifications. Regarding the other variables, we identify again a possible positive contribution by both $LnINF_{(i,y)}$ and $LnRQ_{(i,y)}$. Additionally, these models uncover the potential positive impact of one more institutional variable, ($LnRoL_{(i,y)}$), and the sole significant variable associated with the development of a particular segment of the financial markets, ($LnBD_{(i,y)}$). Despite the hypothesized stronger relation of ETFs to equity markets (foremost due to the composition of the portfolios of ETFs), our results indicate a more pronounced role for bond markets; it may be explained by possible complementarity of these two types of instruments on the European markets; however, this issue requires further analysis. Regarding negative and statistically significant coefficients, we again identify $LnFM_{(i,y)}$ and $LnTax_{(i,y)}$ (the latter, however, in fewer specifications than previously). Moreover, among the control variables, the share of ETFs seems to be inversely related to the level of economic development proxied by GDP per capita ($LnGDP_{(i,y)}$). This result is not surprising as, in Section 4.2, we showed the between-country differences in the development of ETF markets: in some of the richer European countries, they have remained rather small in terms of share. All other control variables are insignificant. The estimated models with the control variables exhibit slightly higher goodness-of-fit measures compared to those summarized in Table 3. The lowest R^2, at 0.39, is reported for two models, FE_2C and FE_19C, while the highest score of 0.62 is reported for FE_13C and FE_18C. For the remaining models, we observe a goodness-of-fit of around 0.50. These results suggest that the inserted control variables do not detract from the statistical significance of the explanatory variables in the specifications in Table 3 and, instead, slightly "add" to the explanation of the ETF share changes in the sample countries.

To complete the picture, we employ dynamic panel regression models using a two-step system GMM estimator (Arellano and Bover, 1995; Blundell and Bond, 1998)—see Table 2A in the Appendix. We estimate ten specifications, DPD_1 – DPD_10, and introduce an additional explanatory variable, *LnETFshare_lag_1*, that is, one-year lag of the dependent variable. Instruments for differenced equations are used for all the specifications. In all of them, we find that the ETF share in the previous period, *LnETFshare_lag_1*, is positively associated with $LnETFshare_{(i,y)}$, thus indicating the highly endogenous and self-reinforcing character of the ETF diffusion. The IU coefficients are both positive and statistically significant in two out of the eight specifications in which they were included, thus providing some limited evidence that, even after accounting for the positive feedback between the levels of ETF market development in the subsequent periods, ICT affects $LnETFshare_{(i,y)}$ positively. Last, among the other explanatory variables included in the various DPD specifications, only $LnFD_{(i,y)}$, $LnFM_{(i,y)}$, $LnRQ_{(i,y)}$, and $LnBD_{(i,y)}$ are statistically significant; nonetheless, $LnFM_{(i,y)}$ (development of financial markets) and RQ (regulatory quality), exclusively, are statistically significant and positive in more than one specification. Interestingly, in contrast with the static models, the coefficient of $LnFM_{(i,y)}$ is positive, which could mean that, after considering the time effects of ETF diffusion, the development of financial markets becomes a factor that stimulates rather than hinders the development of ETF markets. The statistical significance of $LnRQ_{(i,y)}$ implies the importance of the regulatory environment for the development of ETF markets, already noted in the static models discussed above.

Finally, for deeper insight into the subject, we provide country-specific models (see Table 3A in the Appendix), although the small number of observations renders their reliability questionable, which is the reason that we focus on the panel regression models. We report estimates for eight countries, with Switzerland and the UK excluded. We employ standard OLS regressions, in which the dependent variable is the ETF market share (as in the panel regression analysis), while we consider as the explanatory variables those determinants that unveiled statistical significance in the panel regression analysis. Henceforth, we use four explanatory variables: IU, INF, RQ, and Tax. In four countries, France, Germany, Italy, and Norway, we confirm a positive and statistically significant association between ETF market development and ICT usage (proxied by IU). In all these four economies, the IU coefficients are high

[5] Hausman tests for specific models are not reported in the paper but are available on request.

[6] Models are estimated at the 5% level of statistical significance.

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and positive, indicating a relatively strong relationship between ETF market share and ICT usage. It should be noted that all four are relatively more developed than the four remaining economies; moreover, in all four, the levels of ICT diffusion were the highest in our sample, which shows that adoption of ICT affects the spread of ETFs more strongly in countries that are economically and technologically advanced. Furthermore, these countries can be characterized as having more developed financial systems, including financial markets. In the remaining four countries, Hungary, Poland, Spain, and Turkey, the above-mentioned relationships are statistically insignificant. Regarding the remaining variables, we also confirm a negative association between ETF market share and taxes in two specifications, Germany and Spain. Regulatory quality versus ETF market development yields a statistically significant positive association in Norway, whereas investment freedom is significantly positively associated with ETF market development in Spain.[7] However, these results appear to be highly country-specific, and therefore generalizations for the region should be avoided.

With regard to country-specific analysis, it will be noted that the number of observations is small. For instance, for Poland and Turkey, we have only 9–10 and 7–8 observations, respectively, which lead to considerable bias in our estimations. For Turkey, the estimations are additionally violated by abrupt fluctuations in ETF market share. In 2012 (the initial year for which ETF market share is available), it was at 2.1%, 6.5% in the next year, whereas it dropped to 1.06% in 2014, and even further, to 0.22%, in 2017. Moreover, in Turkey, similar rapid changes can be observed in terms of regulation quality: 0.05 in 2004, then peaking in the period 2012–2013 at 4.2, and then dropping radically until it was nearly zero in 2018 and 2019. In Hungary and Norway, similar instability with regard to ETF market shares is observed; the ETF development pattern is not stable, instead marked by erratic fluctuations between highs and lows. In Hungary, additionally, we observe relative instability in regulatory quality (generally falling over time) and taxes.

In general, the estimates support our hypothesis that increases in ICT deployment should increase the overall market share of ETFs in our sample countries between 2004 and 2019. The coefficients for $LnIU_{(i,y)}$ are positive, as expected, in most of the estimated models, and show relative stability, regardless of the model specified.

5. Conclusions

This study analyzes the emerging impact of new ICT on the development of financial innovations in stock exchanges in ten European countries: France, Germany, Hungary, Italy, Norway, Poland, Spain, Switzerland, Turkey, and the UK.

We first examined the general diffusion paths of ICT (proxied by fixed broadband networks and Internet user rates) in each country, between 1990 and 2019. Obviously, regardless of cross-country differences in the speed or curve of ICT diffusion, economic performance, or institutional framework, the new technologies spread rapidly in all the countries. This soaring universal popularity identifies ICT as an extremely successful technology that has not only revolutionized telecommunications markets, but also produced massive structural shifts in financial markets, permitting, for instance, a whole series of innovative financial instruments whose development depends utterly on sophisticated technological solutions.

We have also analyzed the development of ETF markets through descriptive statistics. In Hungary and Poland (two CEE countries), the ETF markets were very small and showed practically no development. In the more advanced European economies, the trajectory of the ETF market development varied considerably. In Spain and Germany, the share of ETFs in the overall equity index instrument market remained very low. In France and Italy, there was more significant development. In Norway and Turkey, the development of the ETF markets was highly volatile during our sample period. The analysis of the relative importance of the ETF market in Switzerland and the UK was limited by a lack of data on competing products; nonetheless both ETF markets showed steady growth.

Central to the study was the identification and examination of possible factors in the development of the ETF markets, in particular ICT (as discussed in the theoretical section). Both panel and country-specific regressions were used. First, we evaluated the correlations between ETF market development and ICT penetration. The panel model estimates indicated that fixed effects models were preferable. For the best fitted models, the regression coefficients (showing the impact of ICT on ETF markets) were positive and statistically significant. For the fixed effects estimates, the R^2 varied from 0.25 to 0.61 (see Tables 3 and 4), which might be interpreted to mean that, on average, around 43% of changes in the ETF market share were explained by changes in ICT deployment and other financial-market related variables if all estimated fixed effects models were considered. Regarding the other non-ICT variables, the fixed effects models showed the highest significance for growing ETF market share in four variables: financial markets development, investment freedom, regulatory quality and taxes on income, profits, and capital gains. The remaining variables were statistically insignificant in most cases. Dynamic panel models confirm only some of the fixed effects specification results. Including the 1-year lagged ETF share variable in the model generally captures a significant share of variability; however, we managed to confirm the statistical importance of three other explanatory variables: Internet users, financial markets development, and regulatory quality.

Further, our country-specific estimates, in four out of the eight examined countries, confirmed a positive and statistical significance of the Internet users variable on ETF market share development. In some cases, we also confirmed the importance of regulatory quality, investment freedom, and taxes on income, profits, and capital gains. However, it should be noted that, due to the very limited number of observations (especially in the cases of Poland and Turkey), the results are biased. Furthermore, the easily observable instability of ETF market share development (Hungary, Norway, Turkey) as well as that of other variables over time (e.g., regulatory quality in Turkey) mean that the results of the country-wise estimates must be treated only as additional evidence, while the panel regression results provide the more valid results.

The digital revolution and soaring deployment and use of the Internet worldwide has created solid foundations for the broad development of financial markets and the introduction of innovative financial instruments in which trading depends on ICT. Exchange-traded funds are a perfect example of such instruments, and, in the last two decades, they have been successfully introduced in a series of financial markets. However, it should be borne in mind that further development of financial instruments, ETFs for instance, may lead to growing financial market vulnerability: rapidly changing prices, price co-movements, and idiosyncratic as well as liquidity shocks that may spill over from one asset to others and generate financial market instability.

The study carries some potentially important implications for policymakers and market participants. First, it demonstrates a positive relationship between the diffusion of the new technologies and the development of ETF markets in a sample of European countries. Consequently, ICT should be seen as a potentially important factor for the diffusion of ETFs within the financial system (possibly by fostering greater adoption of ICT by market participants), or as an issue that must be considered, say, by financial companies in analyzing the prospects for a particular ETF market. A second key implication relates to the trend in the market share of ETFs in relation to the overall market in stock index options and futures. The increase in this share was confirmed for some of the sample countries, showing ETFs' increasing popularity vis-à-vis other types of investment funds and related types of derivatives. This may be relevant to the analysis of the competitive position of ETFs by

[7] The association between investment freedom and ETF market development is also demonstrated in Turkey; however, the coefficient is negative, which suggests possible invalidity.

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Table 1A
Panel regression results: Internet Users (IU) and Fixed Broadband Subscriptions (FBS), 1998–2019.

	$LnIU_{(i,y)}$ Pooled OLS	RE	RE(IV)	RE(IV)
$LnFBS_{(i,y)}$	.47 (0.018)[a]	.45 (0.017)[a]	.56 (0.00)[a]	.56 (0.13)[b]
Hausman test (prob>chi^2)	–	.48	–	–
R^2	0.81	.82 (overall)	.77 (overall)	.77 (overall)
Country-fixed effects	No	No	No	No
Instruments – lagged FBS	No	No	Yes	Yes
# of countries	10	10	10	10
# of observations	156	156	154	154

Note: constant included but not reported. [a] Below coefficients are standard errors at the 5% level of significance. [b] bootstrap SE (1000 replications).
Source: Authors` estimations.

financial institutions. Further, given the possible arbitrage between these instruments, they need to be viewed in the context of financial stability, as was shown by the "flash crash" on the US financial markets.

The limitations of the analysis and the restricted scope of the study leave several issues for future research. We have considered a sample of countries from Europe—similar in-kind analysis can be conducted for other regions, such as North or Latin America. Moreover, future studies could cover additional determinants, such as more detailed indicators of development for other financial market segments. Another potentially rewarding avenue of inquiry is comparative research on the diffusion of ETFs from various perspectives, that is, in relation not only to stock index derivatives, but also the other kinds of investment funds. Finally, ETF diffusion and its underlying factors could be analyzed to determine the key differences between certain specific types of ETFs in terms of exposure (e.g., blue-chip or broad market indexes) or structure (physical versus synthetic).

CRediT authorship contribution statement

Adam Marszk: Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Ewa Lechman:** Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition.

Table 2A
Dynamic panel regression estimates: ETF share and its determinants, 2004–2019 (annual series).

$LnETFshare_{(i,y)}$	**DPD_1**	**DPD_2**	**DPD_3**	**DPD_4**	**DPD_5**	**DPD_6**	**DPD_7**	**DPD_8**	**DPD_9**	**DPD_10**
LnETFshare_lag_1	**0.73 [0.15]**	**0.81 [0.23]**	**0.74 [0.11]**	**0.82 [0.08]**	**0.63 [0.18]**	**0.58 [0.06]**	**0.81 [0.11]**	**0.57 [0.08]**	**0.55 [0.14]**	**0.54 [0.14]**
$LnIU_{(i,y)}$	**0.68 [0.43]**	2.4 [1.01]	**0.88 [0.41]**	0.09 [0.89]	-0.11 [0.87]	-0.25 [0.28]	-0.51 [0.78]	-0.58 [0.37]		
$LnFD_{(i,y)}$									**1.3 [0.75]**	
$LnFI_{(i,y)}$										0.13 [0.51]
$LnFM_{(i,y)}$	0.99 [0.58]	3.32 [1.48]			**0.91 [0.035]**			**1.36 [0.48]**		
$Crisis_{(i,y)}$									-0.02 [0.24]	
$LnEF_{(i,y)}$										
$LnINF_{(i,y)}$										-1.8 [2.23]
$LnFF_{(i,y)}$	-1.04 [1.22]			-2.19 [1.62]						
$LnRQ_{(i,y)}$		-0.58 [0.39]		**0.36 [0.14]**		**0.12 [0.04]**	**0.32 [0.13]**	0.01 [0.08]		
$LnRoL_{(i,y)}$										0.03 [0.22]
$LnBD_{(i,y)}$			**-1.02 [0.41]**							
$LnMFA_{(i,y)}$	-0.12 [0.11]									
$LnTax_{(i,y)}$		-2.15 [1.59]	-1.34 [0.54]							
$LnSMC_{(i,y)}$										
$LnSMTVT_{(i,y)}$				0.06 [0.14]			-0.001 [0.12]			
Sargan test χ^2 [Prob>χ^2]	13.7 [0.13]	20.93 [0.013]	11.55 [0.20]	6.1 [0.73]	11.9 [0.06]	5.6 [0.18]	5.8 [0.19]	13.3 [0.06]	13.7 [0.00]	13.2 [0.06]
# of instruments [Instruments for differenced equation GMM-type]	15	15	12	15	9	9	11	12	8	12
Wald χ^2 [Prob>χ^2]	510.5 [0.00]	999.7 [0.00]	26,163 [0.00]	911.7 [0.00]	232.9 [0.00]	301.0 [0.00]	575.9 [0.00]	288.5 [0.00]	177.8 [0.00]	101.3 [0.00]
# of countries	10	10	10	10	10	10	10	10	10	10
# of obs.	83	91	83	77	91	97	77	91	91	87

Note: constant included but not reported; standard errors in square brackets below coefficients; panel – strongly balanced; results statistically significant at the 5% level in bold; two-step system GMM estimator applied; all values are logged; Switzerland and the UK are excluded.
Source: Authors` estimations.

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Table 3A
ETF shares versus Internet Users: Country-specific models, 2004–2019[8] (annual series).

	$LnETFshare_{(i,y)}$									
		France				**Germany**				
$LnIU_{(i,y)}$	**2.8**	**2.5**	**2.59**	**2.89**	**2.29**	1.08	**1.41**	**1.98**	**3.07**	**3.16**
	[0.51]	**[0.56]**	**[0.47]**	**[0.58]**	**[0.56]**	[0.58]	**[0.61]**	**[0.74]**	**[0.40]**	**[0.40]**
$LnINF_{(i,y)}$		1.05			0.85		1.54			-1.09
		[0.93]			[1.22]		[1.04]			[0.63]
$LnRQ_{(i,y)}$			-3.11		-4.5			-1.72		0.22
			[1.54]		[2.6]			[0.97]		[0.57]
$LnTax_{(i,y)}$				0.05	-3.26				**-3.33**	**-4.10**
				[3.52]	[3.71]				**[0.53]**	**[0.73]**
R^2	0.69	0.71	0.76	0.69	0.81	0.19	0.31	0.35	0.83	0.87
F. Prob > F	31.0 [0.00]	16.4	20.9	13.5	10.3	3.45	2.97	3.54	30.42	17.3
		[0.00]	[0.00]	[0.00]	[0.00]	[0.08]	[0.08]	[0.05]	[0.00]	[0.00]
Root MSE	0.49	0.49	0.45	0.53	0.46	0.20	0.19	0.19	0.09	0.09
# of obs.	16	16	16	16	15	16	16	15	15	15
		Hungary				**Italy**				
$LnIU_{(i,y)}$	2.37	2.56	-3.51	1.25	-3.77	**3.41**	**4.39**	**3.41**	**3.78**	**4.15**
	[2.56]	[2.6]	[5.4]	[4.22]	[7.79]	**[0.45]**	**[0.98]**	**[0.92]**	**[0.55]**	**[1.09]**
$LnINF_{(i,y)}$		6.28			10.1		-2.9			-3.11
		[7.54]			[11.5]		[2.61]			[3.47]
$LnRQ_{(i,y)}$			-2.96		-1.92			-0.004		-0.88
			[2.42]		[3.34]			[1.27]		[1.49]
$LnTax_{(i,y)}$				-1.69	-3.55				4.29	2.9
				[2.85]	[3.02]				[0.369]	[1.24]
R^2	0.07	0.13	0.19	0.14	0.39	0.81	0.83	0.81	0.83	0.84
F. Prob > F	0.86	0.76	1.19	0.74	1.13	55.25	28.8	25.5	29.04	13.31
	[0.37]	[0.49]	[0.34]	[0.51]	[0.41]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Root MSE	1.06	1.08	1.04	1.12	1.07	0.40	0.39	0.42	0.42	0.42
# of obs.	13	13	13	12	12	15	15	15	15	15
	Norway					**Poland**				
$LnIU_{(i,y)}$	9.64	31.62	**45.2**	**19.3**	**57.6**	1.65	-1.69	1.53	2.22	-9.00
	[7.12]	[26.97]	**[17.2]**	**[8.11]**	**[22.0]**	[1.47]	[3.82]	[1.63]	[2.27]	[7.68]
$LnINF_{(i,y)}$		-8.87			-8.56		4.93			10.59
		[10.5]			[8.98]		[5.18]			[7.68]
$LnRQ_{(i,y)}$			**15.3**		-9.38			-0.77		-8.56
			[6.95]		[6.7]			[2.86]		[6.00]
$LnTax_{(i,y)}$				2.2	0.28				-4.39	-12.93
				[2.31]	[2.34]				[8.89]	[12.1]
R^2	0.13	0.18	0.41	0.39	0.59	0.13	0.23	0.14	0.14	0.48
F. Prob > F	1.83	1.25	3.67	3.22	2.94	1.27	1.08	0.60	0.50	0.93
	[0.21]	[0.32]	[0.06]	[0.08]	[0.09]	[0.29]	[0.39]	[0.57]	[0.63]	[0.52]
Root MSE	1.23	1.25	1.07	1.00	0.92	0.48	0.49	0.52	0.55	0.52
# of obs.	14	15	14	13	13	10	10	10	9	9
	Spain					**Turkey**				
$LnIU_{(i,y)}$	1.32	-3.12	0.01	1.32	-2.81	-3.73	-1.35	-8.89	-2.39	-3.22
	[0.84]	[1.42]	[1.00]	[1.07]	[1.50]	[1.71]	[0.91]	[4.05]	[3.16]	[4.36]
$LnINF_{(i,y)}$		12.9			**10.1**		**-16.06**			-10.9
		[3.76]			**[3.28]**		**[3.27]**			[5.8]
$LnRQ_{(i,y)}$			-2.27		-1.17			-0.39		-0.15
			[1.13]		[0.88]			[0.52]		[0.52]
$LnTax_{(i,y)}$				**-1.2**	**-0.57**				-6.00	-4.63
				[0.54]	**[0.31]**				[11.5]	[6.53]
R^2	0.16	0.61	0.39	0.51	0.78	0.44	0.91	0.83	0.47	0.95
F. Prob > F	2.44	8.28	3.53	5.10	7.33	4.72	23.51	9.67	2.21	9.76
	[0.14]	[0.00]	[0.06]	[0.02]	[0.00]	[0.07]	[0.00]	[0.02]	[0.20]	[0.09]
Root MSE	0.53	0.38	0.47	0.42	0.31	0.85	0.57	0.57	0.91	0.43
# of obs.	14	14	14	13	13	8	8	7	8	7

Note: robust SE in square brackets below coefficients; constants included but not reported; statistically significant results in bold; Switzerland and the UK are excluded.
Source: Authors` estimations.

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Appendix

Table. A1, Table. A2, Table. A3

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[8] Number of observations varies across countries.

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