Digital Connectivity and Income Inequality in Europe: A Macro-Panel Study of Moderating Effects

Over the last two decades, digital technologies have transformed how individuals, firms, and public institutions access services, communicate, and participate in economic and social life. Internet, mobile networks, and broadband have expanded access to information, education, work, and welfare, and are often associated with higher productivity and broader opportunities (Dutton, 2004; Ahmed & O'Connor, 2022).

However, their effects are not uniform. Critical research shows that digitalization can also reinforce existing inequalities when access, digital skills, and institutional support are uneven. This became especially clear during the COVID-19 pandemic, when digital tools were essential for work, education, and social interaction, making the digital divide a structural form of inequality rather than a purely technical issue (De', Pandey & Pal, 2000; Hsieh, Rai & Keil, 2001).

Linear models often fail to capture this complexity because they assume a direct relationship between digital infrastructure and income inequality. Yet inequality, especially when measured by the Gini index of disposable income, is highly persistent and shaped by long-term institutional, labor market, educational, and welfare dynamics (Hasell, 2023; Pellegrino, 2020). The weak direct effect of digitalization may therefore reflect the structural rigidity of inequality rather than its irrelevance (Canh, Schinckus et al., 2020).

To address this limitation, this paper treats digitalization not as a direct driver of inequality, but as a macro-level moderator that conditions the impact of other structural factors. Rather than asking whether digital infrastructure reduces inequality on its own, the paper examines whether it changes the effectiveness of human capital, labor market structures, and state redistribution in shaping distributive outcomes. In this view, digitalization is not simply another explanatory variable; it reshapes the context in which other drivers of inequality operate (DiMaggio & Hargittai, 2001; Krasna, 2016).

By framing digital connectivity as a moderator, the study shifts analytical attention away from the narrow question of physical access and toward the broader capacity of national socio-economic systems to convert technological availability into inclusive outcomes. This is an important distinction. A country may exhibit high rates of internet penetration or broadband diffusion, but the distributive consequences of that connectivity depend on whether workers possess adequate digital skills, whether educational systems can support effective technological use, whether labor market institutions protect vulnerable groups, and whether welfare systems are capable of leveraging digital tools to enhance coverage and efficiency. In this sense, digital technology should not be seen as inherently egalitarian or inherently unequalizing. Rather, its effects are contingent, relational, and embedded in broader institutional and structural configurations (Scheerder, Van Deursen & van Dijk, 2017). Where favorable conditions exist, digitalization can strengthen inclusion and opportunity; where they do not, it may deepen polarization and exclusion.

To empirically test this moderation framework, the paper draws on a balanced annual panel dataset covering 23 European countries over a 24-year period from 2000 to 2023. The dataset combines harmonized indicators from Eurostat, the World Bank, and the International Telecommunication Union, thereby ensuring a high degree of comparability and consistency across countries and over time (OECD, 2021; World Bank, 2023). The main dependent variable is the Gini index of disposable income, selected because it captures the concentration of income after taxes and transfers and therefore reflects the combined effect of market-generated inequality and state-mediated redistribution (Hasell, 2023; Pellegrino, 2020).

This dependent variable is modeled as a function of a set of structural drivers that the literature identifies as central to inequality dynamics. Human capital is proxied through tertiary education rates, which capture the stock of advanced skills in the population and the extent to which an economy is equipped to generate knowledge-intensive forms of employment and productivity growth (Dragoescu, 2013). Labor market structure is represented by variables such as service-sector employment shares and contract typologies, since the composition and quality of employment strongly influence primary income distribution and the exposure of workers to wage instability and precariousness (Kołodziejczak, 2020). Institutional and redistributive capacity is approximated through measures such as total tax revenues and social protection expenditures, both of which reflect the extent to which the state is able to cushion market inequalities and support vulnerable groups through fiscal and welfare mechanisms (Wahrig & Vallina, 2011).

The distinctive contribution of the model lies in the fact that these direct structural drivers are explicitly interacted with indicators of digital infrastructure maturity. More specifically, the analysis considers household internet penetration, fixed broadband density, and mobile subscriptions as three complementary dimensions of digital development. Household internet access captures the social diffusion of connectivity at the domestic level; fixed broadband density reflects the quality, reliability, and stability of internet infrastructure; and mobile subscriptions indicate the spread and everyday ubiquity of digital access across the population (Savage & Waldman, 2005; Greenstein & McDevitt, 2011; Annafari & Bohlin, 2014). By interacting these digital indicators with the core explanatory variables, the model is able to isolate whether digitalization changes the magnitude or direction of the relationship between education, labor market conditions, welfare capacity, and inequality.

Methodologically, the study addresses the limitations of conventional macro-panel analyses by relying on a robust static Fixed Effects framework with explicit interaction terms and structural time lags. This choice is motivated by both theoretical and econometric considerations. While dynamic panel estimators such as the Generalized Method of Moments are often highly effective in datasets characterized by a large number of cross-sectional units and a relatively short time span, their application to macro-panels with a long temporal dimension can generate severe problems of instrument proliferation. In such cases, the number of instruments can grow excessively, weakening overidentification tests and reducing the overall reliability and efficiency of the estimator (Blundell, Bond & Windmeijer, 2001;

Roodman, 2009). Given the structure of the dataset used in this study, a fixed-effects specification is more appropriate because it controls for all time-invariant and unobserved country-specific characteristics, thereby focusing the analysis on within-country changes over the 24-year period (Nickell, 1981; Wooldridge, 2010).

In addition, the inclusion of explicit temporal lags in both the independent variables and the digital moderators helps mitigate concerns related to contemporaneous endogeneity and reverse causality. This is especially important in a context where the effects of digital infrastructure are unlikely to emerge instantaneously. Investments in connectivity, the accumulation of digital competences, and the adjustment of labor market and welfare institutions all require time before they translate into observable effects on income distribution. By introducing lag structures, the analysis acknowledges that technological transformation is a gradual process whose distributive implications unfold over time rather than immediately upon implementation (Nickell, 1981; Granger, 1969). This strengthens the interpretive credibility of the model and aligns the econometric design more closely with the real temporal dynamics of structural change.

The empirical findings strongly support the moderation hypothesis and show that the interaction terms are highly statistically significant, revealing mechanisms that are obscured in conventional direct-effect models. Most notably, the interaction between tertiary education rates and household internet access exhibits a statistically significant negative coefficient. This indicates that higher levels of education are considerably more effective in reducing income inequality in countries where digital infrastructure is already widespread and socially embedded. In such contexts, internet access appears to amplify the equalizing potential of human capital by enabling educated individuals to access knowledge-intensive jobs, digital services, information networks, and new forms of productivity and mobility. The result is consistent with theories of skill-biased technological change, according to which technology increases the returns to advanced skills and thus changes the distributive implications of education depending on the surrounding technological environment (Acemoglu & Autor, 2011; Goldfarb & Prince, 2004).

At the same time, the interaction between digital access and precarious or service-oriented forms of employment points in the opposite direction, suggesting that the spread of digital infrastructure may also contribute to widening wage and income gaps under certain labor market conditions. More specifically, where employment is concentrated in vulnerable service occupations or unstable contractual arrangements, digital expansion may intensify labor market polarization rather than alleviate it. Without targeted investments in digital skills, retraining, and labor protections, technological development may push lower-skilled workers into fragmented, platform-based, or low-value-added forms of employment, thereby reinforcing rather than reducing socio-economic inequality (Hsieh, Rai & Keil, 2008; Robinson, Cotten et al., 2015). This finding further reinforces the argument that digitalization should not be conceptualized as a uniformly beneficial force. Its distributive consequences depend

critically on the structure of employment and the quality of institutional support available to workers.

The analysis also highlights a crucial interaction between digitalization and institutional welfare capacity. The results show that digital access significantly improves the redistributive efficiency of social protection systems in countries characterized by stronger and more comprehensive welfare regimes. In these settings, digital tools can facilitate administrative coordination, expand access to benefits, reduce procedural barriers, and improve the delivery of public support to target populations. However, where institutional frameworks are weaker, less inclusive, or less capable of integrating digital systems into social policy, the expansion of digital infrastructure may fail to produce similar gains and may even widen existing inequalities. Once again, the central message is that technology does not operate independently of institutions; rather, it modifies the performance of institutional arrangements that are already in place.

Taken together, these findings carry important implications for European public policy. The first and perhaps most important implication is that digital expansion strategies cannot be designed in structural isolation. Investments in broadband networks, household connectivity, and mobile access are necessary, but they are not sufficient to ensure more equal economic outcomes (Onoja & Ajala, 2022). If policymakers aim to use digitalization as a tool for reducing inequality, infrastructure policies must be accompanied by broader interventions that strengthen the underlying socio-economic conditions necessary for inclusive technological uptake. This includes targeted investments in adult digital literacy, lifelong learning, educational attainment, and reskilling initiatives for workers employed in sectors most exposed to technological disruption (Hargittai, 2001; Robinson et al., 2015).

Moreover, because digital access can improve the reach and effectiveness of welfare delivery, governments should also prioritize the development of inclusive e-government systems and ensure affordable internet access for low-income households. Making public digital services more accessible, user-friendly, and socially inclusive is essential if the administrative benefits of digitalization are to translate into more effective redistribution rather than into new forms of bureaucratic exclusion. In this respect, digital policy and social policy should not be conceived as separate domains, but as deeply interconnected areas of intervention that must be designed in a coordinated way (West, 2015; Djatmiko, Sinaga & Pawirosumarto, 2025).

Ultimately, this research provides strong empirical support for the argument that digitalization does not automatically reduce inequality and should not be treated as an autonomous equalizing force. Its role is better understood as that of a structural modifier: a factor that changes the economic returns to education, reshapes the consequences of labor market structures, and alters the redistributive performance of public institutions. For this reason, the key policy challenge is not simply to expand access to technology, but to ensure that the social, educational, and institutional conditions necessary to convert digital access into broadly shared welfare gains are also in place. Only under these conditions can digital transformation contribute to genuinely inclusive economic growth rather than acting as a mechanism that

accelerates and deepens inequalities already embedded in the social structure (Van Dijk, 2020; Wei, 2020).