Technology, nonlinearities and the determinants of inequality: New panel evidence

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Abstract

Relying on data for a panel of 90 advanced and emerging economies spanning the 1970-2015 period and System-GMM dynamic panel estimation, we extend the standard 'Kuznets-curve' empirical framework to investigate how globalisation, financial sector development and technology influence changes in the distribution of income. We take account of potential nonlinearities for all the factors involved and distinguish two technological categories: General-Purpose Technology (GPT) and Investment-Specific Technology (IST). Our empirical findings highlight technological progress as playing a key role in determining inequality dynamics. In particular, we find strong evidence supporting the 'Schumpeterian view' of the interplay between changes in income inequality and IST. This is characterised by a U-shaped pattern indicating that, beyond a certain threshold, IST worsens inequalities – in line with technology turning from labour-complementary to labour-replacing. The results are robust to the inclusion of additional socioeconomic and institutional quality variables in the models. In light of the growing automation process we are witnessing in recent years, these findings have significant implications for policy strategies aimed at reducing income inequality.

Keywords: Inequality, technology, nonlinearity, panel data.

JEL classification: C01, C33, F63, O11, O15, O33

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1 Introduction

The economic, social and political determinants and effects of inequality are the subject of a substantial and growing literature, which has been reignited in the last decade by the questions raised on the causes and consequences of the Great Recession. In fact, if at the beginning of the second half of last century the efforts were directed in assessing the effects of economic development on income distribution (Kuznets, 1955), over time several scholars sought to examine, reversely, how income inequality influences various socioeconomic outcomes, such as the process of income per-capita growth, in the presence of credit market imperfections and nonconvexities in the production of human capital (Galor and Zeira, 1993); the socio-political instability and investments (Alesina and Perotti, 1996); the escape from extreme poverty (Ravallion, 1997); happiness, health and well-being (Easterlin, 1974; Subramanian and Kawachi, 2006; Clark *et al.*, 2008).

Though the debate is still open, in recent years economists have reached a significant consensus on the role played by some factors as key determinants of income distribution dynamics: namely, globalisation, technological progress and financial sector development (e.g., Dabla-Norris *et al.*, 2015; Milanovic, 2016). The academic and public debate on inequality has focused on figuring out which of these forces has a predominant influence and, therefore, which policy measures are more appropriate to target the double goal of fast economic growth and a more egalitarian distribution of income.

The many empirical studies conducted in the field rely on different methodologies of analysis, estimation techniques and/or data and, crucially, provide conflicting results. For instance, if the assessment of globalisation effects is confined to trade in goods and services, empirical findings frequently indicate beneficial effects on income distribution (e.g., Reuveny and Li, 2003; Ghose, 2004); conversely, when focusing on the impact of foreign direct investments, globalisation is typically associated with an increase in wage disparities (e.g., Choi, 2006; Basu and Guariglia, 2007). The same occurs for financial sector development: some studies establish a positive impact on inequality, while others point to a negative effect (e.g., Beck *et al.*, 2007; Kappel, 2010; Jauch and Watzka, 2016). When it comes to technological progress, the issue becomes even more complicated. Specifically, since there is no unambiguous definition of technological progress, empirical analyses can only rely on proxy measures for it, and this can lead to contradictory or misleading results. Specifically, the impact of technological progress on inequality is likely to vary depending on the type of technology, its purpose and, in particular, its degree of diffusion within society and the economy.

To address these issues, among other things, some studies have recently begun to test the hypothesis of nonlinear effects for some determinants of inequality, assuming that nonlinearities might be at the basis of the mixed empirical evidence so far uncovered. In particular, the possible nonlinear impact of financial sector development has been thoroughly analysed (e.g., Nikoloski, 2013; Jauch and Watzka, 2016; Brei *et al.*, 2018), while the same is not true in relation to globalisation and technological progress. However, lack of a consistent treatment of nonlinearities is not the only problem with the available empirical literature. For instance, most studies tend to focus on the abovementioned three key factors separately, thus providing only a partial view of the dynamics of inequality; and critical estimation issues, such as variable endogeneity, are often not properly taken account of.

This paper contributes to the literature on the determinants of inequality in several ways. Relying on a panel of 90 advanced and emerging economies and annual data over the 1970-2015 years, we extend the standard 'Kuznets-curve' (Kuznets, 1955) empirical framework to investigate the role played by technological progress, globalisation and financial sector development as determinants of changes in income inequality, by assuming potential nonlinearities for all the aforementioned channels. To deal with persistency in inequality and variable endogeneity, estimations are carried out relying on a dynamic panel data model and System-GMM techniques (Arellano and Bover, 1995; Blundell and Bond, 1998). Furthermore, we tackle the issues relating to the ambiguous role played by technological progress distinguishing between two general technological categories:

- Investment-Specific Technology (hereafter 'IST'), which influences directly firms' production processes but only indirectly other economic agents, as its direct effects are limited to the production side of the economy. As an indicator for IST, we rely on the *Relative Price of Investment Goods* which is proposed and used as a general IST proxy in a significant part of the literature (e.g., De Long and Summers, 1993; Jones, 1994; Greenwood *et al.*, 1997, 2000; Krusell, 1998; Krusell *et al.*, 2000; Cummins and Violante, 2002; Hsieh and Klenow, 2007);

- General-Purpose Technology (hereafter 'GPT'), which includes technological innovations that, contrary to IST, gradually assume widespread and direct effects on consumers' and other economic agents' incomes (e.g., Rosenberg, 1982; Bresnahan and Trajtenberg, 1995; Aghion, 2002; Landes, 2003; Lipsey *et al.*, 2005). The literature on GPT considers a wide set of possible alternative indicators so that, taking account of data availability, we consider several GPT proxies. Specifically, we rely on: *Energy Use* (per-capita); *Air Transport*, defined by passengers carried by national vectors (per 100 people); *Patent Applications* by residents (per million population) and *Mobile Cellular Subscriptions* (per 100 people).

The main results of the paper support the hypothesis of nonlinearities in the relationship between growth of inequality and technological progress. In particular, IST seems to be the prime suspect for these changes, being characterised by a U-shaped relationship – i.e. technology initially acts as an equaliser channel, but once a certain threshold is surpassed, it may trigger a process of growing disparities. Furthermore, the classical 'Kuznets-curve' hypothesis for the interplay between economic growth and inequality is supported by the data. Finally, the results turn out to be robust when we extend the models to control for socioeconomic and institutional quality factors.

The remaining part of the paper is organised as follows: Section 2 presents an overview of the literature; Section 3 illustrates the data used, the empirical framework and econometric issues dealt with in our analysis; Section 4 provides and discusses the results, while Section 5 concludes.

2 Overview of related literature

Much of the empirical literature aimed at investigating the impact of the main drivers of inequality – globalisation, technological progress, financial sector development – essentially tends to consider these factors one at a time, while controlling for other economic, political and institutional aspects[1]. Such studies often lead to mixed results: for example, in the interplay between globalisation and income inequality Gourdon *et al.* (2006), Chen (2007) and Helpman *et al.* (2017) observe that greater openness to trade is associated with an increase in wage disparities, whereas Reuveny and Li (2003) and Jaumotte *et al.* (2013) come to the opposite conclusion. Moreover, in the context of financial globalisation, Furceri and Loungani (2018) find evidence of growing income disparities associated to capital account liberalisation reforms. Similarly, conflicting results have emerged for the finance-inequality nexus. Among others, Beck *et al.* (2007), Kappel (2010) and Hamori and Hashiguchi (2012) provide evidence pointing to a decrease in wage disparities associated with greater financial sector development, while the findings in Jaumotte *et al.* (2013), and Jauch and Watzka (2016) support the opposite hypothesis.

The assessment of the available evidence is even more complex when it comes to the role played by technological progress. Since there exist different types of technological advances, and these are typically difficult to define and measure, empirical findings are often in contradiction. Considering the evidence, Iacopetta (2008) pointed out that price-cutting technological progress is associated to a reduction in inequality, whereas product innovations increase it. There are also several studies on the so-called *skill-biased* effects of technological progress within the labour market: for example, Katz and Murphy (1992), Card and DiNardo (2003), Moore and Ranjan (2005), Wang (2009) and Acemoglu and Autor (2011) provide

[1] In this regard, the economic development of a country can still be considered as an additional core factor driving changes in income inequality. Specifically, the inverted U-shaped variant, proposed by Kuznets (1955), is explicitly tested in many recent empirical works in this field. See, for instance, Barro (2000); Reuveny and Li (2003); Baiardi and Morana (2016); Jauch and Watzka (2016); Clarke *et al.* (2006); Dobson and Ramlogan (2009); Brueckner *et al.* (2015). See also Atkinson and Brandolini (2006) for a survey of studies related to the sociological and political determinants of income distribution.

strong evidence indicating that technological progress raises income inequalities between skilled and unskilled workers.

With specific reference to GPTs, Aghion *et al.* (2002) state that technology raises long-run within-group inequality through an increased market premium and demand for adaptable workers, whereas Jacobs and Nahuis (2002) observe a fall in real wages of unskilled workers. From the IST perspective, He and Liu (2008) argue that technological change can explain the rise in wage inequality experienced since the early 1980s in the U.S. economy. Further, Krusell *et al.* (2000) claim that improvements in ISTs, as proxied by the decline in the relative price of investment, increased the wage gap between skilled and unskilled workers, suggesting that better education and training for the latter would reduce income inequality. Finally, Karabarbounis and Neiman (2013) show that the decrease in the relative price of investment goods can explain around half of the decline in the labour share.

In the light of all this, recent literature on the drivers of income inequality has begun to investigate the possibility that the lack of consistent results could be due to nonlinear, 'Kuznets-curve' style effects. For instance, in relation to globalisation, Dobson and Ramlogan (2009) and Jalil (2012) point out the likely existence of a curvilinear relationship between international trade and inequality – the Openness Kuznets Curve – for some Latin American countries and China. Moreover, Figini and Görg (2011) find that foreign direct investment has positive effects on wage disparities in advanced economies but a negative impact in emerging economies, noting the presence of an inverted U-shaped curve for this channel. Meanwhile, the hypothesis of a nonlinear relation between income inequality and technological progress has been put forward in two distinct theoretical approaches:

- The 'Schumpeterian view' (e.g., Aghion and Howitt, 1992; Malerba and Orsenigo, 1995; Aghion, 2002), which involves a U-shaped interplay whereby technology initially tends to reduce disparities through "creative destruction" processes, and then increases them in subsequent phases, when wealth concentration benefits those who are able to profit from large investments in research and development (Kim, 2012);

- The 'Kuznets-curve' approach (e.g., Aghion *et al.*, 1998; Barro, 2000; Conceição and Galbraith, 2000), which implies an inverted U-shaped relationship. In the early stages of development, increasing per-capita income is associated to worsening inequality, as only a small part of the population benefits from technological advancements. When the gains from technological progress start to gradually spread more evenly, wage and income disparities start to shrink too (Galor and Tsiddon, 1997; Weil, 2013; Shin and Yamamura, 2018).

The question of a nonlinear relationship between inequality and financial sector development has been more widely dealt with in the literature. Recent empirical evidence supporting the inverted U-shaped hypothesis, initially advanced by Greenwood and Jovanovic (1990), has been provided by Clarke *et al.* (2006), Nikoloski (2013) and Jauch and Watzka (2016) both for advanced and emerging countries as well as by Baiardi and Morana (2016) for the Euro area. These studies indicate that income inequality initially rises with financial sector expansion, then starts to decrease beyond a certain threshold value for the size of the financial sector in the economy (usually measured by the ratio of credit to the private sector over GDP). In contrast, Tan and Law (2012) and Brei *et al.* (2018) observe a U-shaped pattern.

To sum up, while more studies are now formally taking account of nonlinearities, most contributions in the literature still typically examine the main drivers of inequality separately or, though providing a broad analysis of inequality determinants, do not assess their potentially nonlinear effects (e.g., Jaumotte *et al.*, 2013; Dabla-Norris *et al.*, 2015). This paper fills these gaps and contributes to the literature by providing a comprehensive and empirically robust investigation of the determinants of inequality.

3 Data and empirical framework

The empirical analysis carried out in this paper is based on a panel of annual data for 90 countries (33 advanced and 57 emerging economies) over the 1970-2015 period[2]. Sources of the data, time coverage and countries included in our sample,

[2] The time-period of analysis and the countries considered are determined by data availability.

which vary depending on the variables involved, are reported, respectively, in Table A1 and A2 of the Appendix. We estimate dynamic panel data models relying on a sample of 9 (non-overlapping) five-year periods from 1970 to 2015.[3] The use of five-year averages of the data is common to several studies on inequality, such as Forbes (2000), Voitchovsky (2005), Nikoloski (2013), Ostry *et al.* (2014), Sturm and De Haan (2015), Jauch and Watzka (2016). Averaging allows to reduce the impact of business cycle effects and gaps in data on the estimates (especially for inequality and financial sector development). Moreover, it is particularly useful when, as in our case, GMM estimation is carried out with macro-panels, as it reduces the likelihood of overfitting bias by holding down the number of instruments.

The measure of inequality we rely upon is the so-called Net-Gini, which is based on disposable income and, thus, embodies the impact of redistributive systems.[4] Our baseline models include the following variables:

- *Growth of Gini*: Annual growth rate of the Net-Gini index. i.e. the log-difference between two consecutive years of Gini coefficients. This is the dependent variable in all the model specifications estimated;

- GDP_{PC}: *Real GDP per-capita* (in thousands 2011 dollars). GDP_{PC} and its square are introduced in the model to take account of the Kuznets (1955) hypothesis, i.e. the nonlinear, inverted-U relationship between income inequality and economic development;

- EGI: *Economic Globalisation Index.* Ranging from 0 to 100, this indicator

[3] Given that the overall time-series length is 46 years, the last sub-period considers a 6-year average over 2010-2015.

[4] We make use of the Net-Gini index in order to make our estimates directly comparable to the results in some of main references in the literature, such as Nikoloski (2013), Baiardi and Morana (2016), Brei *et al.* (2018). SWIID also provides a different measure of the Gini index, the so-called Market- or Gross-Gini, which does not account for redistributive policies. For advanced countries, taxation and transfers can lead Net- and Market-Gini to be significantly different (see, for instance, Battisti and Zeira (2016) and Ostry *et al.* (2014)). However, in our panel the annual growth rates of the two measures are highly correlated: for annual data, the correlation coefficient is about 0.73, which increases up to about 0.83 when we refer to five-year averages. For these reasons, when *Growth of Market-Gini* index is used as dependent variable the main results of the analysis do not change: these additional estimates are reported in Tables A3a and A3b in the Appendix.

summarizes the degree of economic and financial globalisation for each country, by considering the intensity of foreign trade and financial flows, as well as restrictions such as hidden import barriers, customs tariffs and investment limitations. This variable is included in the model to assess whether the recent findings of a curvilinear relationship between inequality and trade openness (e.g., Dobson and Ramlogan, 2009; Figini and Görg, 2011) are confirmed when 'openness' is proxied with an index capturing more than one aspect of globalisation;

- *GPT*: All the GPT variables are included in the models with linear and squared terms, in order to capture possible nonlinear effects. Drawing on the related literature, we rely on the following GPT proxies:
  - ◇ *Energy Use (tons of oil equivalent per-capita)*. Energy allows the transformation of raw materials into intermediate or final goods, within the industrial sector, or the direct provision of services for domestic uses for the rest of society. Its pervasiveness, the variety of use and increased availability among the economic agents make energy use a reliable GPT proxy (e.g., Dalgaard and Strulik, 2011). Following Rosenberg (1982), Mokyr (1992) and Fouquet and Pearson (1998), energy use can be considered one of the engines of industrialization and economic growth (Ozturk, 2010; Coccia, 2015).[5] Similarly to Muller (1988), we can expect a 'Kuznets-style' evolution between *Energy Use (per-capita)* and *Growth of Gini*;
  - ◇ *Air Transport, Passengers Carried (per 100 people)*. Powered by another GPT, namely the internal combustion engine (Helpman, 1998; Jovanovic and Rousseau, 2005), air transport evolved to a pervasive technology, contributing to the recovery of globalisation after the end of the Second World War (Lipsey *et al.*, 2005; Ruttan, 2006). Air transport industry represents a crucial factor for economic development, being able to boost, among others, employment, tourism, local businesses

[5] For a detailed description of the WDI variables included in the analysis, see the "Development Relevance" of the World Bank's World Development Indicators.

and international trade (e.g., United Nations Conference on Trade and Development, 2001). In line with this, we can expect a negative correlation between Air Transport and income inequality: the available empirical evidence seems to support this (e.g., Wu and Hsu, 2012);

- ◇ *Patent Applications, Residents (per million population).* The role of creating and spreading new knowledge is crucial for the development of GPTs (e.g., Hall and Trajtenberg, 2004). The number of patents published is a good approximation for the accumulation (e.g., Aghion and Howitt, 1992; Kleinert, 2004) and diffusion (e.g., Grossman and Helpman, 1991; Jaffe *et al.*, 2000) of new knowledge in an economy;
- ◇ *Mobile Cellular Subscriptions (per 100 people).* Several studies have been conducted to investigate how "mobile penetration" can affect income inequality, especially in emerging countries, where it can be considered a more appropriate technological progress proxy with respect to other similar alternatives (e.g., Jensen, 2007; Maurer, 2008; Donner and Tellez, 2008; Merritt, 2011; Aker and Mbiti, 2010; Asongu, 2013; Asongu and Nwachukwu, 2016; World Bank, 2012; Brynjolfsson and McAfee, 2014). In line with the evidence available in the literature (e.g., Asongu, 2015), the expected sign on the coefficient for *Mobile Cellular Subscriptions (per 100 people)* is negative;

- *IST*: *Relative Price of Investment Goods.* This is our proxy for Investment-Specific Technology. IST affects directly only the production side of the economy (e.g., Greenwood *et al.*, 2000; Caselli and Feyrer, 2007; Leonardi, 2007; Karabarbounis and Neiman, 2013; Dao *et al.*, 2017; Allard, 2018), so its effects are less widespread with respect to GPT and its impact could be significantly different. Thus, whether IST affects inequality positively or negatively, as well as linearly or nonlinearly, is an empirical question;

- *FIN*: *Financial Sector Development Index.* The index is defined as private credit (by deposit money banks and other financial institutions) over GDP. The large literature using FIN as a proxy for financial sector development provides consistent evidence of an inverted-U relationship with income inequality with, respectively, positive and negative signs for linear and squared terms (e.g., Clarke *et al.*, 2006; Nikoloski, 2013; Jauch and Watzka, 2016).

Descriptive statistics for these and all other variables included in the empirical analysis in this paper are reported in Table 1, while estimation issues and techniques are discussed in the next section.

Table 1: Descriptive statistics

Variable	No. of observations	Mean	Standard deviation	Minimum	Maximum
Growth of Net-Gini	616	0.104	0.807	-3.883	3.971
Growth of Market-Gini	616	0.179	0.712	-2.422	3.459
Economic Globalisation Index	767	54.163	16.148	12.82	93.069
Energy Use (per-capita)	718	2.293	2.252	0.012	17.781
Air Transport (per 100 people)	720	64.193	131.33	0	2072.789
Patent Applications (per million population)	613	126.438	298.615	0.038	2918.683
Mobile Cellular Subscription (per 100 people)	782	27.8	44.227	0	168.663
Relative Price of Investment Goods	767	0.52	0.267	0.063	1.629
Financial Sector Development	732	48.511	39.265	0.146	246.187
Real GDP per-capita	767	14.382	12.905	0.436	90.497
Government Expenditure (% of GDP)	767	19.403	8.656	3.722	63.427
Inflation (annual %)	732	33.005	186.308	-0.516	3373.474
Human Capital Index	722	2.406	0.669	1.021	3.719
Corruption	532	3.454	1.354	0	6
Industry + Services Value Added (% of GDP)	605	81.974	8.472	48.842	98.929
Government Stability	540	7.682	1.689	2.979	12
Democracy	701	5.057	8.358	-69.2	10
Polity	701	4.393	6.649	-10	10

Notes: Sources of the data, time coverage and countries included in the sample are reported, respectively, in Table A1 and A2 of the Appendix.

3.1 Panel estimations and econometric issues

Building on the contributions by Beck *et al.* (2007), Jaumotte *et al.* (2013), Jalil (2012), Nikoloski (2013) and Furceri and Loungani (2018), the benchmark 'Non-linear model' of our empirical analysis relies on the following dynamic panel specification:

$$\begin{aligned}\Delta(GINI)_{i,t} = \alpha_i &+ \beta[\Delta(GINI)]_{i,t-1} + \gamma_1 EGI_{i,t} + \gamma_2 EGI^2_{i,t} + \gamma_3 GPT_{i,t} \\ &+ \gamma_4 GPT^2_{i,t} + \gamma_5 IST_{i,t} + \gamma_6 IST^2_{i,t} + \gamma_7 FIN_{i,t} + \gamma_8 FIN^2_{i,t} \\ &+ \delta_1 (GDP_{PC})_{i,t} + \delta_2 (GDP_{PC})^2_{i,t} + \nu_t + \varepsilon_{i,t}\end{aligned} \tag{1}$$

where $i = 1, \ldots, N$ and $t = 1, \ldots, T$ indicate, respectively, country and time; $\Delta(GINI)_{i,t}$ is the log-difference of our inequality measure; GPT and IST are the two technological progress proxies, i.e. *Energy Use, Air Transport, Patent Applications* and *Mobile Cellular Subscriptions* as alternative GPT proxies and *Relative Price of Investment Goods* for IST; α_i indicates fixed effects, ν_t time dummies, $\varepsilon_{i,t}$ is the error term and all other variables are as defined above.[6]

For comparability purposes, we also consider a simpler 'Linear' model where the main drivers of changes in income inequality enter the dynamic panel specification only linearly, except for the terms referring to the well-known 'Kuznets-curve' hypothesis:

$$\begin{aligned}\Delta(GINI)_{i,t} = \alpha_i &+ \beta[\Delta(GINI)]_{i,t-1} + \gamma_1 EGI_{i,t} + \gamma_2 GPT_{i,t} + \gamma_3 IST_{i,t} \\ &+ \gamma_4 FIN_{i,t} + \delta_1 (GDP_{PC})_{i,t} + \delta_2 (GDP_{PC})^2_{i,t} + \nu_t + \varepsilon_{i,t}\end{aligned} \tag{2}$$

As is well known, OLS and fixed effects (FE) estimates of dynamic panel data models such as those specified in (1) and (2) are inconsistent due to the "dynamic panel bias" (Nickell, 1981; Arellano and Bond, 1991; Baltagi, 2008). Since Monte Carlo evidence indicates that the Nickell-bias may be substantial when the time-series dimension is short (e.g., Judson and Owen, 1999), relying on the OLS or FE estimators may be particularly problematic in our case. Additionally, the

[6] Setting the maximum number of lags to 3, lag selection is performed with a general-to-specific procedure which, in all cases, indicates the optimal lag length is 1.

potential endogeneity of at least some of the regressors raises further concerns regarding the reliability of OLS and FE estimates. To deal with these issues, estimations are carried out using the System-GMM (S-GMM) estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998), where both lagged levels and differences of the endogenous variables are used as instruments. S-GMM is preferred over Difference-GMM (Arellano and Bond, 1991) because of its better performance when dealing with highly persistent variables, such as our measure of income inequality (Blundell and Bond, 2000). Specifically, for each S-GMM model estimate, we treat *EGI*, *GPT* and *IST* as exogenous variables and the first lag of the dependent variable, *FIN* and GDP_{PC} as endogenous variables.

4 Results and discussion

S-GMM estimates of the dynamic panel data models specified in (1) and (2) are presented in Table 2a and 2b. For comparability purposes, for each model estimation the results from our baseline 'Nonlinear' specification and from its 'Linear' version are reported in two adjacent columns. This set-up is replicated for each of the four versions of the baseline model, each including a different GPT proxy: *Energy Use (per-capita)* for Model v1 and *Air Transport (per 100 people)* for Model v2, in Table 2a; *Patent Applications (per million population)* for Model v3 and *Mobile Cellular Subscriptions (per 100 people)* for Model v4, in Table 2b.

For all of the models estimated, the outcome of the Hansen test is in line with the overall validity of the instruments. Furthermore, all tests for first- and second-order autocorrelation of the residuals provide evidence in favour of, respectively, rejection of the AR(1) and no rejection of the AR(2) hypotheses. The first lag of the dependent variable, *Growth of Gini*, is constantly strongly significant and the associated coefficient is in line with the expected high degree of persistence of inequality – thus supporting both the adoption of a dynamic panel specification and the S-GMM estimation technique.

Turning to the estimation results, we start by noting that none of the 'Linear' specifications provide evidence of significant effects for the main drivers of changes in income inequality: indeed, the only variable consistently significant in these specifications turns out to be the lagged dependent variable. When the analysis is carried out relying on the 'Nonlinear' specifications, the results turn out to be quite different. Specifically, while the evidence indicating substantial persistence in inequality is confirmed, with the first lag of *Growth of Gini* always strongly significant and entering with the expected positive sign, the 'Nonlinear' specifications return several other significant estimates as well. This outcome is in line with the view that neglecting nonlinearities may produce biased results and a misleading picture of the role played by the various determinants of inequality.

The nonlinear dynamics uncovered for inequality include evidence supporting the standard 'Kuznets-curve' hypothesis, in its typical inverted U-shaped structure, for three out of four model versions estimated. The consistent evidence in favour of a nonlinear relationship between *Growth of Gini* and *Real GDP per-capita* is, however, reversed for *Financial Sector Development* in which case, while their signs are in line with the estimates presented by Nikoloski (2013) and Jauch and Watzka (2016), both the linear and quadratic terms turn out to be always not significant. As for the interplay between *Growth of Gini* and the *Economic Globalisation Index*, our findings are less clear-cut. While estimates from Model v2 are not statistically significant for this channel, Models v1, v3 and v4 provide evidence of a nonlinear trend, suggesting a potential U-shaped pattern. In this respect, the signs on the associated coefficients are in contrast with those in Dobson and Ramlogan (2009) and Jalil (2012) who find evidence of an "Openness Kuznets Curve", i.e. an inverted U-shaped structure for the relationship between inequality and economic globalisation.

Turning to the main focus of our analysis, the investigation of the role played by technological progress in shaping the dynamics of income inequality provides several noteworthy insights. Firstly, for the relationship between *Growth of Gini* and our IST proxy – *Relative Price of Investment Goods* – we obtain fairly similar results in all four estimations, providing evidence of a 'Schumpeterian' U-shaped structure. This is consistent with a setting in which IST initially operates in a labour-augmenting way, so that it pushes up labour productivity and wages and, thus, lowers inequality. Subsequently, further declines of the *Relative Price of Investment Goods* foster the development and adoption of labour-substituting or *skill-biased* technology, with harmful effects on employment and inequality (e.g., Aghion, 2002; Acemoglu, 2003; Acemoglu and Autor, 2011; Decker *et al.*, 2017). Interestingly, such an outcome seems to recall the findings of Goldin and Katz (2009), who highlighted two opposite inequality trends in the interplays between education, technological changes and wage differentials in the U.S. – specifically, a narrowing process up to the 1980 and a rising trend from 1980 to 2005.

With respect to our GPT proxies, we identify two different outcomes. The interplay between *Growth of Gini* and *Energy Use (per-capita)* appears to be characterised by a 'Kuznets-curve' pattern, i.e. an inverted U-shaped structure, in line with Muller (1988). *Air Transport (per 100 people)*, instead, seems to be negatively associated to *Growth of Gini*, i.e. changes in the distribution of income decrease as *Air Transport* increases. Finally, there is no evidence of a statistically significant effect for the last two GPT proxies – *Patent Applications (per million population)* and *Mobile Cellular Subscriptions (per 100 people)* – in Model v3 and v4.

To sum up, our empirical investigation brings qualified support to the hypothesis that an appropriate analysis of inequality determinants should take account of nonlinearities and the issues related to the role played by different types of technology. The next section further explores the features of these nonlinear relationships relying on the Lind and Mehlum (2010) test and, more generally, investigates the robustness of the estimates in Tables 2a and 2b.

Table 2a: S-GMM regression results: Dependent variable is Growth of Gini

	Model v1		Model v2	
	Linear	Nonlinear	Linear	Nonlinear
(Growth of Gini)$_{t-1}$	0.4743***	0.5314***	0.4661***	0.4860***
	(0.0673)	(0.0647)	(0.0526)	(0.0638)
Economic Globalisation Index	-0.0021	-0.0849**	-0.0061	-0.0882
	(0.0080)	(0.0416)	(0.0104)	(0.0695)
(Economic Globalisation Index)^2		0.0005*		0.0006
		(0.000)		(0.001)
Energy Use (per-capita)	0.0301	0.2016*		
	(0.0643)	(0.1153)		
[Energy Use (per-capita)]^2		-0.0136**		
		(0.0058)		
Air Transport (per 100 people)			-0.0004	-0.0038**
			(0.0005)	(0.0018)
[Air Transport (per 100 people)]^2				0.0000
				(0.0000)
Relative Price of Investment Goods	0.2734	-4.3396*	0.2179	-4.4859***
	(0.3839)	(2.3467)	(0.4964)	(1.6933)
(Relative Price of Investment Goods)^2		2.6318*		2.9679**
		(1.3657)		(1.2132)
Financial Sector Development	-0.0035	0.0001	-0.0025	0.0088
	(0.0022)	(0.0065)	(0.0021)	(0.0069)
(Financial Sector Development)^2		-0.0000		-0.0001
		(0.0000)		(0.0000)
Real GDP per-capita	0.0173	0.0530*	0.0267	0.0754**
	(0.0185)	(0.0274)	(0.0168)	(0.0293)
(Real GDP per-capita)^2	-0.0001	-0.0006**	-0.0002	-0.0006**
	(0.0001)	(0.0003)	(0.0001)	(0.0002)
No. Observations	503	503	494	494
No. Groups	89	89	88	88
No. Instruments	56	76	60	80
Years effects	Yes	Yes	Yes	Yes
Hansen test	0.2478	0.6186	0.4223	0.5772
AR(1)	0.0006	0.0004	0.0009	0.0011
AR(2)	0.3029	0.2539	0.4798	0.4298

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.
Estimates are based on dynamic panel data estimation, using data averaged over five-years periods, two-step system GMM. Models v1 and v2 instrument as endogenous the dependent variable, financial sector development and the real GDP per-capita. Time dummies are included as strictly exogenous instruments in the level equations for all models. All models are estimated with Windmeijer (2005) finite sample correction and FOD transformation; p-values are reported for Hansen, AR(1) and AR(2) tests.

Table 2b: S-GMM regression results: Dependent variable is Growth of Gini

	Model v3		Model v4	
	Linear	Nonlinear	Linear	Nonlinear
(Growth of Gini)$_{t-1}$	0.4533***	0.4937***	0.4827***	0.5454***
	(0.0554)	(0.0729)	(0.0674)	(0.0940))
Economic Globalisation Index	0.0009	-0.1176**	-0.0090	-0.1387**
	(0.0094)	(0.0523)	(0.0099)	(0.0670)
(Economic Globalisation Index)^2		0.0010**		0.0010*
		(0.0004)		(0.0005)
Patent Applications (per million population)	0.0002	0.0014		
	(0.0005)	(0.0008)		
[Patent Applications (per million population)]^2		-0.0000		
		(0.0000)		
Mobile Cellular Subscriptions (per 100 people)			0.0037	0.0019
			(0.0038)	(0.0118)
[Mobile Cellular Subscriptions (per 100 people)]^2				-0.0000
				(0.0001)
Relative Price of Investment Goods	0.4665	-3.6602*	0.3126	-5.2007***
	(0.6390)	(2.1031)	(0.4534)	(1.6654)
(Relative Price of Investment Goods)^2		2.2861*		3.4183***
		(1.2988)		(1.1707)
Financial Sector Development	-0.0005	0.0036	-0.0031	0.0079
	(0.0026)	(0.0068)	(0.0021)	(0.0070)
(Financial Sector Development)^2		-0.0000		-0.0001
		(0.0000)		(0.0000)
Real GDP per-capita	0.0029	0.0145	0.0196	0.0586*
	(0.0205)	(0.0278)	(0.0160)	(0.0332)
(Real GDP per-capita)^2	-0.0000	-0.0002	-0.0001	-0.0006*
	(0.0002)	(0.0003)	(0.0002)	(0.0004)
No. Observations	452	452	509	509
No. Groups	82	82	88	88
No. Instruments	54	68	54	74
Years effects	Yes	Yes	Yes	Yes
Hansen test	0.3363	0.3010	0.2705	0.7036
AR(1)	0.0004	0.0008	0.0005	0.0013
AR(2)	0.3508	0.3067	0.2940	0.3060

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.
Estimates are based on dynamic panel data estimation, using data averaged over five-years periods, two-step system GMM. Models v3 and v4 instrument as endogenous the dependent variable, financial sector development and the real GDP per-capita. Time dummies are included as strictly exogenous instruments in the level equations for all models. All models are estimated with Windmeijer (2005) finite sample correction and FOD transformation; p-values are reported for Hansen, AR(1) and AR(2) tests.

4.1 Testing for monotonicity in nonlinear relationships

The presence of different kinds of nonlinearities in the relationships between the dynamics of inequality and its main drivers is a relevant matter from a policy perspective, as it adds a new dimension of complexity to the traditional trade-off between efficiency and equity. In this respect, therefore, our findings deserve further scrutiny.

Typically, the policy trade-off arises because growth-boosting policy measures, such as incentives for investment in innovation and R&D, may result in rising income inequality via *skill premium* and/or labour-substitution mechanisms. For instance, such a trade-off exists when the nonlinear relationship between growth of income inequality and technological progress is characterized by a well-identified minimum. In such a case, while initially fostering a more equal income distribution, the positive effects of technological advances become gradually smaller with their progressive diffusion in the economy and, beyond a certain threshold value, the relationship changes sign and further spreading of the technology starts exacerbating income inequality. On the contrary, when the relationship is nonlinear but also monotonic there exists no clear threshold beyond which further technological diffusion raises inequality: thus, there is no policy trade-off either. For these reasons, a formal assessment of whether the nonlinear relationships uncovered in the previous section are characterised by well-defined extreme points, i.e. minimum or maximum within the data range, turns out to be a crucial question.

To investigate this issue, we rely on the test for (inverted) U-shaped relationships proposed by Lind and Mehlum (2010) (hereafter 'LM test'). These authors point out that estimation of quadratic relationships may inaccurately yield an extreme point and therefore (inverted) U-shaped structures when the true relationships are characterised by convexity as well as monotonicity. In order to obtain reliable extreme points, and thus correct (inverted) U-shaped structures, the LM test checks whether the nonlinear relationship is (increasing) decreasing at low values and (decreasing) increasing at high values within the data range. In such a case, rejection of the null hypothesis of monotonicity would provide evidence in favour of (inverted) U-shaped relationships.

In this section, we carry out LM tests for (inverted) U-shaped structures for all the estimated models presented in Table 2a and 2b where nonlinear relationships have been detected.

The results in Table 3a-3d indicate that, in all cases, the relationship between *Growth of Gini* and *Relative Price of Investment Goods* is characterised by the presence of a well-identified minimum point, with the null hypothesis of monotonicity systematically rejected at the 5% significance level in favour of U-shaped structures. Thus, the existence of a policy trade-off between promoting IST and a reduction of inequality is supported by the empirical evidence, which is consistent with the existence of threshold values (ranging from 0.755 for Model v2 to 0.824 for Model v1) beyond which IST becomes harmful for the dynamics of inequality. Additionally, the LM tests provide supporting evidence for the 'Kuznets-curve' hypothesis, rejecting the null in favour of the alternative hypothesis of an inverted U-shaped pattern for the relationship between *Growth of Gini* and *Real GDP per-capita*. In particular, maximum points are located at per-capita GDP values going from 45,815 to 60,242 in 2011 dollars, respectively, for Models v4 and v2. Similarly, the LM test indicates the existence of an inverted U-shaped 'Kuznets-curve' pattern for the relationship between *Growth of Gini* and *Energy Use*, with a maximum point identified at a value of 7.44 tons of oil equivalent per-capita (Table 3a). The results are less clear-cut for the relationship between *Growth of Gini* and the *Economic Globalisation Index*. Specifically, in one case out of three (Table 3a) the LM test cannot reject the null hypothesis of monotonicity – that is, changes in inequality decrease at decreasing rates as globalisation increases and a minimum point is never reached. In the remaining two cases, however, the LM tests provide support for a U-shaped structure, with minimum points located at values of about 59 and 67 of the EGI, respectively (Tables 3c and 3d).

Table 3a: Tests for U-shape and Inverse U-shape: Model v1

Relationship	Growth of Gini and Economic Globalisation Index		Growth of Gini and Energy Use (per-capita)		Growth of Gini and Relative Price of Investment Goods		Growth of Gini and Real GDP per-capita	
	Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Slope at	-0.070	0.017	0.201	-0.280	-4.007	4.234	0.052	-0.050
t-value	-2.116	0.776	1.747	-2.733	-1.841	1.959	1.932	-2.039
p-value	0.018	0.22	0.042	0.00	0.034	0.03	0.028	0.02
Test	H1: U shape vs. H0: Monotone or Inverse U shape		H1: Inverse U Shape vs. H0: Monotone or U shape		H1: U shape vs. H0: Monotone or Inverse U shape		H1: Inverse U shape vs. H0: Monotone or U shape	
Overall significance	0.78		1.75		1.84		1.93	
p-value	0.22		0.04		0.03		0.03	
Extreme point	77.446		7.440		0.824		46.525	
Confidence interval	[-Inf; 61.430] U [-12.186; +Inf]		[-5.505; 10.232]		[-Inf; +Inf]		[-11.192; 82.956]	

Notes: The confidence intervals are calculated by the Fieller method.

Table 3b: Tests for U-shape and Inverse U-shape: Model v2

Relationship	Growth of Gini and Relative Price of Investment Goods		Growth of Gini and Real GDP per-capita	
	Min	*Max*	*Min*	*Max*
Slope at	-4.111	5.182	0.074	-0.037
t-value	-2.657	2.178	2.569	-1.821
p-value	0.004	0.02	0.005	0.04
Test	H1: U shape vs. H0: Monotone or Inverse U shape		H1: Inverse U Shape vs. H0: Monotone or U shape	
Overall significance	2.18		1.82	
p-value	0.02		0.04	
Extreme point	0.755		60.242	
Confidence interval	[.577; 1.271]		[37.528; 98.842]	

Notes: The confidence intervals are calculated by the Fieller method.

Table 3c: Tests for U-shape and Inverse U-shape: Model v3

Relationship	Growth of Gini and Economic Globalisation Index		Growth of Gini and Relative Price of Investment Goods	
	Min	*Max*	*Min*	*Max*
Slope at	-0.092	0.066	-3.371	3.787
t-value	-2.231	2.000	-1.732	1.657
p-value	0.014	0.024	0.04	0.05
Test	H1: U shape vs. H0: Monotone or Inverse U shape		H1: U Shape vs. H0: Monotone or Inverse U shape	
Overall significance	2.00		1.66	
p-value	0.02		0.05	
Extreme point	59.458		0.800	
Confidence interval	[39.066; 92.007]		[-Inf; +Inf]	

Notes: The confidence intervals are calculated by the Fieller method.

Table 3d: Tests for U-shape and Inverse U-shape: Model v4

Relationship	Growth of Gini and Economic Globalisation Index		Growth of Gini and Relative Price of Investment Goods		Growth of Gini and Real GDP per-capita	
	Min	*Max*	*Min*	*Max*	*Min*	*Max*
Slope at	-0.112	0.054	-4.769	5.935	0.058	-0.057
t-value	-2.079	1.543	-3.124	2.572	1.764	-1.492
p-value	0.020	0.06	0.001	0.01	0.040	0.07
Test	H1: U shape vs. H0: Monotone or Inverse U shape		H1: U Shape vs. H0: Monotone or Inverse U shape		H1: Inverse U Shape vs. H0: Monotone or U shape	
Overall significance	1.54		2.57		1.49	
p-value	0.06		0.01		0.07	
Extreme point	66.864		0.760		45.815	
Confidence interval	[-Inf; 44.397] U [-488.708; +Inf]		[.592; 1.083]		[-Inf; +Inf]	

Notes: The confidence intervals are calculated by the Fieller method.

By selecting Model v1 as our preferred specification – by virtue of the fact that both the technological proxies present nonlinearities in the interplay with *Growth of Gini* – we can establish how countries are located with respect to the different estimated turning points[7], *ceteris paribus*, and thus providing insights for policy-makers. For the relationship between changes in income inequality and *Energy Use (per capita)*, only four countries (Canada, Iceland, Luxembourg and Trinidad and Tobago) are placed beyond the threshold of 7.44 tons of oil equivalent per-capita where such interplay becomes negative. Similarly, five developed economies are located beyond the threshold of 46,52 in 2011 dollars of *Real GDP per-capita* where the relationship between economic development and *Growth of Gini* changes from positive to negative – namely, Luxembourg, Norway, Singapore, Switzerland and United States. On the contrary, the scenario for the interplay between changes in income inequality and IST is slightly more balanced. Indeed, the estimated threshold of 0.824 for *Relative Price of Investment Goods* identifies approximately half of the advanced countries (these include, among others, Estonia, Greece, Ireland, Italy, Malta, Singapore and Portugal) and the overwhelming majority of the emerging economies included in our sample for which the relationship with *Growth of Gini* becomes positive. Symmetrically, we find mostly advanced countries (e.g., Australia, Canada, France, Germany, Japan, Norway, United Kingdom and United States) and only two emerging economies (Armenia and Kazakhstan) where the interplay between changes in income inequality and IST turns out to be negative.

Overall, therefore, the LM test results are consistent with the existence of clear policy trade-offs associated to the nonlinear effects of the main drivers of inequality, with the evidence being particularly robust for the interplay between *Growth of Gini* and *Relative Price of Investment Goods* (our IST proxy). This provides strong evidence in favour of the 'Schumpeterian view' for all the estimated models.

[7] The complete list of countries is not given here for reasons of space, but is available from the authors upon request as well as the results for other estimated models. We exclude from this analysis the relationship between *Growth of Gini* and *Economic Globalisation Index* because, for Model v1, LM test cannot reject the null hypothesis of monotonicity.

4.2 Robustness analysis

Since our main focus is devoted to distinguishing, among others, the effects of GPT and IST on changes in income inequality, we limit our robustness analysis to the specifications in Table 2a and 2b which have proved to be better suited to explaining such dynamics. These are Model v1 and Model v2 which include, respectively, *Energy Use (per-capita)* and *Air Transport (per 100 people)* as GPT proxies. To test whether the findings in the previous sections are robust, we extend these specifications including a number of control variables typically considered as possible additional determinants of inequality in the literature. Specifically, we consider the following variables:

- *Human Capital Index.* This index is constructed using the average years of schooling from Barro and Lee (2013) and an assumed rate of return to education, based on Mincer-equation estimates around the world (Psacharopoulos, 1994). The role played by human capital accumulation can only be ascertained empirically as, from a theoretical viewpoint, it can potentially reduce inequality by leading to a fall in wage disparities (e.g., Galor and Moav, 2004; Beck *et al.*, 2007), but also lead to rising inequality via *skill-premium* effects (Acemoglu *et al.*, 2012; Dabla-Norris *et al.*, 2015);

- *Sum of Industry and Services Value Added (% of GDP).* Kuznets (1963) suggests that structural change influences the evolution of inequality, arguing that an increasing weight for the 'modern sector' of the economy (i.e. industry and services) vis-à-vis agriculture fosters a more egalitarian distribution of income. Clarke *et al.* (2006) provide empirical evidence contrasting this view;

- *Government Expenditure (% of GDP).* By including a measure of public spending, we target the double goal of testing the hypothesis that government intervention may reduce income inequality and taking into account that redistribution may produce considerable effects on our inequality of disposable income measure (Ostry *et al.*, 2014; Battisti and Zeira, 2016). In addition, we check for potential endogeneity and reverse causality, on the basis that a growing income inequality produces political pressures for redistribution (e.g., Meltzer and Richard, 1981; Persson and Tabellini, 1994;

Olivera, 2015);

- *Corruption* and *Government Stability* indexes. Lower values for the *Corruption* and *Government Stability* indicators correspond, respectively, to higher risk of corruption and lower government stability. Both indexes are often used as proxies for institutional quality, which can be expected to mitigate income disparities (e.g., Gupta *et al.*, 2002; Chong and Gradstein, 2007);

- *Democracy* and *Polity*. *Democracy* is an indicator comprising the degree of political participation, executive recruitment and constraints on the chief executive. The *Polity* score is computed by subtracting the institutionalised autocracy component from the *Democracy* indicator. For both indexes, lower (higher) scores are registered for less (more) democratic systems. As for institutional quality, more democratic systems are typically expected to reduce inequality (e.g. Reuveny and Li, 2003; Chong and Gradstein, 2007; Amendola *et al.*, 2013);

- *Inflation (annual %).* Romer and Romer (1998), Easterly and Fischer (2001), and Albanesi (2007), among others, find evidence of harmful effects of inflation on income inequality, especially for the poor- and the middle-class, so we can expect a positive sign for the associated coefficient;

Taking into account the limited dimension of our panel, in our robustness analysis we considered all possible extensions of the model resulting from combinations of a maximum of four additional control variables. Tables 4 and 5 present S-GMM estimation results for a selection of these extended model specifications, in which at least one of the control variables turns out to be statistically significant.[8]

[8] The remaining estimations produce statistically insignificant estimates of the control variables and, thus, do not alter the main conclusions of the analysis. To save space, these results are not included in the paper – they are available upon request.

Table 4: S-GMM robustness checks results: Dependent variable is Growth of Gini and Energy Use (per-capita) as GPT proxy

	Model v5	Model v6	Model v7
(Growth of Gini)$_{t-1}$	0.4727***	0.3659***	0.3543***
	(0.0840)	(0.0956)	(0.0962)
Economic Globalisation Index	-0.1025	0.0165	0.0187
	(0.0646)	(0.0445)	(0.0405)
(Economic Globalisation Index)^2	0.0007	-0.0002	-0.0002
	(0.0005)	(0.0003)	(0.0003)
Energy Use (per-capita)	0.2373*	0.3244**	0.3018**
	(0.1378)	(0.1440)	(0.1474)
[Energy Use (per-capita)]^2	-0.0152**	-0.0195**	-0.0187**
	(0.0069)	(0.0081)	(0.0080)
Relative Price of Investment Goods	-6.2205*	-5.5503*	-5.3884*
	(3.5216)	(3.0710)	(2.9278)
(Relative Price of Investment Goods)^2	3.7853*	2.9314*	2.9466*
	(1.9838)	(1.6766)	(1.6435)
Financial Sector Development	0.0004	0.0002	0.0004
	(0.0071)	(0.0081)	(0.0086)
(Financial Sector Development)^2	-0.0000	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)
Real GDP per-capita	0.0300	0.0408	0.0339
	(0.0375)	(0.0325)	(0.0278)
(Real GDP per-capita)^2	-0.0005	-0.0003	-0.0003
	(0.0004)	(0.0003)	(0.0003)
Inflation (annual %)	0.0007		
	(0.0017)		
Human Capital	0.2930		
	(0.3390)		
Corruption	0.1890*		
	(0.0978)		
Industry + Services Value Added (% of GDP)		-0.0292*	-0.0324*
		(0.0151)	(0.0174)
Government Stability		-0.2021*	-0.1941*
		(0.1039)	(0.1017)
Government Expenditure (% of GDP)			0.0035
			(0.0137)
No. Observations	443	396	396
No. Groups	79	82	82
No. Instruments	72	72	74
Years effects	Yes	Yes	Yes
Hansen test	0.7565	0.3419	0.2822
AR(1)	0.0012	0.0020	0.0018
AR(2)	0.5585	0.5258	0.5164

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses. Estimates are based on dynamic panel data estimation, using data averaged over five-years periods, two-step system GMM. For the setup of the estimations, see the notes below the Table 2a.

Table 5: S-GMM robustness checks results: Dependent variable is Growth of Gini and Air Transport (per 100 people) as GPT proxy

	Model v8	Model v9	Model v10
(Growth of Gini)$_{t-1}$	0.4498***	0.4639***	0.4179***
	(0.0541)	(0.0587)	(0.0718)
Economic Globalisation Index	-0.0991	-0.0698	-0.0733
	(0.0769)	(0.0635)	(0.0693)
(Economic Globalisation Index)^2	0.0007	0.0004	0.0004
	(0.0006)	(0.0005)	(0.0005)
Air Transport (per 100 people)	-0.0046*	-0.0060	-0.0041**
	(0.0027)	(0.0037)	(0.0019)
[Air Transport (per 100 people)]^2	0.0000	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)
Relative Price of Investment Goods	-3.4052*	-3.8847*	-5.9282**
	(1.9415)	(2.2072)	(2.4863)
(Relative Price of Investment Goods)^2	2.1719*	2.5407*	3.6703**
	(1.2430)	(1.3451)	(1.4505)
Financial Sector Development	0.0074	0.0082	0.0129*
	(0.0076)	(0.0085)	(0.0077)
(Financial Sector Development)^2	-0.0000	-0.0001	-0.0001**
	(0.0000)	(0.0000)	(0.0000)
Real GDP per-capita	0.0685**	0.0964***	0.0807***
	(0.0290)	(0.0351)	(0.0284)
(Real GDP per-capita)^2	-0.0006**	-0.0008**	-0.0006**
	(0.0003)	(0.0003)	(0.0003)
Government Expenditure (% of GDP)			0.0182*
			(0.0095)
Inflation (annual %)	0.0007	0.0005	0.0002
	(0.0013)	(0.0016)	(0.0011)
Government Stability			0.0374
			(0.0834)
Human Capital	0.2558		
	(0.2930)		
Democracy	-0.0389*		
	(0.0197)		
Polity IV		-0.0482*	
		(0.0278)	
No. Observations	476	477	438
No. Groups	82	82	82
No. Instruments	80	80	79
Years effects	Yes	Yes	Yes
Hansen test	0.5654	0.6659	0.4400
AR(1)	0.0008	0.0011	0.0021
AR(2)	0.5728	0.4915	0.8182

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses. Estimates are based on dynamic panel data estimation, using data averaged over five-years periods, two-step system GMM. For the setup of the estimations, see the notes below the Table 2a.

Two noteworthy conclusions reached in the previous section prove to be robust to all six new model specifications in Tables 4 and 5. The first is that changes in income inequality are fairly persistent: the autoregressive coefficient on the first lag of *Growth of Gini* is always strongly significant and its size is between 0.36 and 0.47, depending on the specification considered. The second is that Investment-Specific Technology plays a prominent role as a determinant of inequality dynamics: our IST proxy, i.e. *Relative Price of Investment Goods*, turns out to be always significant and its U-shaped nonlinear effects are confirmed in all model versions. Another outcome which is common to all model versions in the two tables is the lack of statistical significance for the *Economic Globalisation Index*. This result runs contrary to the evidence reported in Tables 2a-2b and, together with the findings relating to *Financial Sector Development* (which, just as in Tables 2a-2b, is not significant in all specifications considered, although with one exception, in Model v10 of Table 5), gives a clear indication in relation to the four main determinants of inequality dynamics highlighted in the literature. That is, the only channel for which the data support empirically robust effects on inequality operates via technological progress.

But while, as mentioned, the results remain consistently robust for IST, our robustness analysis paints a more variegated picture in relation to GPT. Specifically, Table 4 reports estimates from four different model versions where the GPT proxy included is *Energy Use (per-capita)*. Both linear and quadratic terms for this variable turn out to be significant in all cases and their signs reflect the inverted U-shaped structure uncovered in the previous section, confirming the robustness of the estimates in Table 2a. On the contrary, we find a slightly weaker evidence for the robustness of *Air Transport*, the GPT proxy included in the specifications in Table 5. While the negative linear relationship is confirmed in Models v8 and v10 (as in our baseline model results in Table 2a), estimates for Model v9 turn out to be not significant. Similarly, the evidence for the standard Kuznets-curve hypothesis is mixed: specifically, it is strongly supported only for the specification involving *Air Transport* as GPT proxy, in Table 2b, where both the linear and quadratic Real GDP per-capita terms have statistical significance.

Turning to the additional control variables included in the robustness analysis, there are two main results to highlight. First, we find supportive evidence for a significant role played by institutional quality. Both *Democracy* (Model v8) and *Polity* (Model v9) turn out to be significant and enter with a negative sign, which is consistent with a higher degree of democracy leading to decreasing inequality (e.g., Acemoglu and Robinson, 2000; Reuveny and Li, 2003; Lindert, 2004). *Corruption* (Model v5) is statistically significant too but, somewhat unexpectedly, enters with a positive sign – indicating that lower levels of corruption are associated to growing income inequality. This is not an entirely new finding in the literature and, in particular, work by Dobson and Ramlogan (2010, 2012) and Andres and Ramlogan (2011) produces similar evidence. These authors argue that – especially in emerging economies – the negative correlation between corruption and inequality can be explained on the grounds that countries characterised by weak institutions and a large informal sector may experience a rise in income inequality as a result of institutional reforms aimed at combating corruption. Specifically, according to one of the possible explanations, firms employing the poorest workers in the informal sector observe rising compliance costs after institutional reform as well as new taxes necessary to pay to make it effective; these higher costs translate into a direct impact on employment within the informal sector. Though entering with the expected sign, *Inflation* turn out to be not significant (Models v5, v8, v9 and v10), whereas *Human Capital* shows an unexpected sign but is not significant too (Models v5 and v9). On the contrary, in line with Kuznets (1963) and differently to what observed by Clarke *et al.* (2006) and Nikoloski (2013), we find evidence indicating that a higher share of GDP for the modern sector of the economy has a significantly negative impact on inequality growth as well as the remaining institutional quality proxy, *Government Stability* (Models v6 and v7). The evidence for the role played by *Government Expenditure* in determining changes in income inequality is mixed, depending on the model specification considered, and *prima facie* puzzling. In fact, by assuming potential endogeneity for this channel, in Model v10 *Government Expenditure* turns out to be statistically significant and positively associated with *Growth of Gini*. Since our income inequality measure takes into account the redistributive effects, such a finding is in line with the expectation of increasing disparities as a result of corruption and rent-seeking strategies (e.g., Alesina and Angeletos, 2005; Spinesi, 2009) as well as not well targeted or inefficient spending policies (e.g., Korpi and Palme, 1998; Afonso *et al.*, 2010). In contrast, in Model v7, though entering with the same positive sign, public spending does not show statistical significance. Interestingly, given the results of the baseline models and all other robustness checks, when controlling for *Government Expenditure*, in Model v10 *Financial Sector Development* becomes significant in the inverted U-shaped structure[9] observed, among others, by Nikoloski (2013) and Baiardi and Morana (2016). From this model estimate, the level of private credit over GDP beyond which the relationship with *Growth of Gini* becomes negative is approximately 79%.

Overall, our robustness analysis supports the view that empirical studies of inequality should consider all four of its main determinants jointly, while taking account of nonlinearities and endogeneity. The results consistently indicate Investment-Specific Technology as playing the fundamental role in determining inequality dynamics, while the evidence on General-Purpose Technology seems to depend on the specific measure considered. As for the other two main determinants, our estimates of the effects of both financial sector development and globalisation are either insignificant or not robust – an outcome in line with the mixed results in the literature.

5 Conclusions

Relying on a panel dataset of annual data over the 1970-2015 period for 90 advanced and emerging economies, this paper carries out an empirical investigation of the determinants of inequality dynamics. We pay special attention to the role played by globalisation, financial sector development and economic growth and, in particular, two kinds of technology – General-Purpose Technology (GPT) and Investment-Specific Technology (IST). To take account of persistence in inequality and variable endogeneity, the empirical analysis is based on system-GMM estimations.

While the estimates provide only weak evidence for a significant effect of globalisation and financial sector development, or mixed for the role played by economic

[9] LM test rejects the null hypothesis of monotonicity at the 5% significance level.

growth, our main findings highlight technology as the key driver of changes in inequality. In particular, out of the four proxies considered for GPT, we find evidence of a significant and inverted U-shaped impact for *Energy Use (per-capita)*, whereas *Air Transport (per 100 people)* mostly exhibits a negative linear association with changes in the distribution of income, even though the latter is not fully robust to the introduction of additional control variables in the model. More importantly, throughout our empirical analysis the interplay between inequality and IST turns out to be always strongly significant and characterised by a U-shaped pattern. This is consistent with the 'Schumpeterian view' of technology fostering a reduction in income inequality only in the early stages of its adoption, when it spurs creative destruction processes. In the subsequent phases of its diffusion, when new innovations typically become increasingly dependent on large investments in R&D, technological progress both increasingly depends on and furthers wealth concentration, thus promoting inequality.

By making use of a formal approach (Lind and Mehlum, 2010) to determine analytically whether the examined nonlinear relationships are characterised by well-identified extreme points – namely, minimum or maximum within the data range – we can empirically establish the presence of potential trade-offs between the different levers of economic development and equity. Specifically, for the interplay between changes in income inequality and IST, being depicted by a U-shaped structure, our findings have significant implications for policy strategies aimed at reducing income inequality. Beyond a certain threshold, technologies operating in the production-side of the economy may trigger a process of worsening inequalities, turning from labour-complementary to labour-replacing, in line with the scenario of increased automation we are witnessing in recent years. In this respect, economic growth, good-quality democratic institutions as well as modern labour markets seem to play a key role in mitigating income inequality.

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Appendix

Table A1: Data sources and coverage

Variable	Source	Time span	Countries
Growth of Net-Gini	Standardized World Inequality Database (SWIID), v7.1, August 2018, Solt (2016)	1970-2014	90
Growth of Market-Gini	Standardized World Inequality Database (SWIID), v7.1, August 2018, Solt (2016)	1970-2014	90
Economic Globalisation Index	KOF Index of Globalisation, Gygli et al. (2018)	1970-2015	90
Energy Use (per-capita)	World Development Indicators, World Bank	1970-2014	90
Relative Price of Investment Goods	Penn World Tables 9.0, Feenstra et al. (2015)	1970-2014	90
Air Transport (per 100 people)	World Development Indicators, World Bank	1970-2014	88
Patent Applications (per million population)	World Development Indicators, World Bank	1970-2014	83
Mobile Cellular Subscriptions (per 100 people)	World Development Indicators, World Bank	1970-2014	88
Financial Sector Development	Financial Development and Structure Dataset, July 2018, Beck et al. (2010)	1970-2015	90
Real GDP per-capita	Penn World Tables 9.0, Feenstra et al. (2015)	1970-2014	90
Government Expenditure (% of GDP)	Penn World Tables 9.0, Feenstra et al. (2015)	1970-2014	90
Inflation (annual %)	World Development Indicators, World Bank	1970-2015	90
Human Capital Index	Penn World Tables 9.0, Feenstra et al. (2015)	1970-2014	85
Corruption	International Country Risk Guide, Political Risk Services Group (2017)	1984-2015	81
Industry + Services Value Added (% of GDP)	World Development Indicators, World Bank	1970-2015	90
Government Stability	International Country Risk Guide, Political Risk Services Group (2017)	1984-2015	82
Democracy	Integrated Network for Societal Conflict Research, Center for Systemic Peace (2017)	1970-2015	83
Polity	Integrated Network for Societal Conflict Research, Center for Systemic Peace (2017)	1970-2015	83

Table A2: List of countries included in the analysis

Advanced countries	Australia, Austria, Belgium, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States
Emerging countries	Albania, Algeria, Angola, Argentina, Armenia, Bahamas, Barbados, Botswana, Brazil, Bulgaria, Cameroon, Chile, China, Colombia, Costa Rica, Croatia, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, Grenada, Guatemala, Hungary, India, Indonesia, Jamaica, Jordan, Kazakhstan, Lesotho, Malaysia, Mauritius, Mexico, Mongolia, Morocco, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Senegal, Serbia, Seychelles, South Africa, Sri Lanka, Suriname, Swaziland, Thailand, Trinidad and Tobago, Tunisia, Turkey, Uruguay, Yemen, Zambia

Notes: Countries are classified according to the International Monetary Fund (2016).

Table A3a: S-GMM regression results: Dependent variable is Growth of Market-Gini

	Model v1		Model v2	
	Linear	Nonlinear	Linear	Nonlinear
(Growth of Market-Gini)$_{t-1}$	0.4778***	0.5577***	0.4889***	0.5519***
	(0.0739)	(0.0778)	(0.0710)	(0.0664)
Economic Globalisation Index	-0.0007	-0.1063**	-0.0073	-0.0803**
	(0.0088)	(0.0405)	(0.0095)	(0.0338)
(Economic Globalisation Index)^2		0.0008**		0.0006**
		(0.003)		(0.003)
Energy Use (per-capita)	0.0191	0.2390*		
	(0.0430)	(0.1228)		
[Energy Use (per-capita)]^2		-0.0139**		
		(0.0067)		
Air Transport (per 100 people)			-0.0000	-0.0011
			(0.0006)	(0.0014)
[Air Transport (per 100 people)]^2				0.0000
				(0.0000)
Relative Price of Investment Goods	-0.1957	-3.7235**	-0.1925	-4.6751**
	(0.4544)	(1.7496)	(0.5133)	(1.1721)
(Relative Price of Investment Goods)^2		2.5083**		2.7710**
		(1.1214)		(1.1721)
Financial Sector Development	-0.0023	0.0034	-0.0023	0.0015
	(0.0016)	(0.0057)	(0.0019)	(0.0060)
(Financial Sector Development)^2		-0.0000		-0.0000
		(0.0000)		(0.0000)
Real GDP per-capita	0.0179	0.0194	0.0361**	0.0716***
	(0.0179)	(0.0194)	(0.0171)	(0.0205)
(Real GDP per-capita)^2	-0.0001	-0.0004	-0.0003*	-0.0007***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)
No. Observations	503	503	494	494
No. Groups	89	89	88	88
No. Instruments	75	84	62	82
Years effects	Yes	Yes	Yes	Yes
Hansen test	0.1808	0.3225	0.1408	0.5071
AR(1)	0.0004	0.0003	0.0007	0.0003
AR(2)	0.4930	0.2304	0.4841	0.4319

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.
Estimates are based on dynamic panel data estimation, using data averaged over five-years periods, two-step system GMM. Models v1 and v2 instrument as endogenous the dependent variable, financial sector development and the real GDP per-capita. Time dummies are included as strictly exogenous instruments in the level equations for all models. All models are estimated with Windmeijer (2005) finite sample correction and FOD transformation; p-values are reported for Hansen, AR(1) and AR(2) tests.

Table A3b: S-GMM regression results: Dependent variable is Growth of Market-Gini

	Model v3		Model v4	
	Linear	Nonlinear	Linear	Nonlinear
(Growth of Market-Gini)$_{t-1}$	0.4983***	0.5653***	0.5042***	0.5862***
	(0.0792)	(0.0833)	(0.0820)	(0.0817))
Economic Globalisation Index	-0.0057	-0.1009**	-0.0061	-0.0816**
	(0.0099)	(0.0412)	(0.0132)	(0.0361)
(Economic Globalisation Index)^2		0.0008**		0.0006*
		(0.0004)		(0.0003)
Patent Applications (per million population)	-0.0002	0.0007		
	(0.0004)	(0.0007)		
[Patent Applications (per million population)]^2		-0.0000		
		(0.0000)		
Mobile Cellular Subscriptions (per 100 people)			-0.0008	-0.0011
			(0.0037)	(0.0076)
[Mobile Cellular Subscriptions (per 100 people)]^2				-0.0000
				(0.0001)
Relative Price of Investment Goods	-0.0290	-4.0940**	0.1122	-3.7932*
	(0.3799)	(1.9933)	(0.5514)	(1.9491)
(Relative Price of Investment Goods)^2		2.4562**		2.3664**
		(1.1954)		(1.1311)
Financial Sector Development	-0.0017	0.0056	-0.0024	0.0039
	(0.0027)	(0.0059)	(0.0015)	(0.0065)
(Financial Sector Development)^2		-0.0000		-0.0000
		(0.0000)		(0.0000)
Real GDP per-capita	0.0285	0.0369	0.0308	0.0598***
	(0.0182)	(0.0341)	(0.0204)	(0.0207)
(Real GDP per-capita)^2	-0.0002	-0.0004	-0.0002	-0.0006**
	(0.0002)	(0.0004)	(0.0002)	(0.0002)
No. Observations	452	452	509	509
No. Groups	82	82	88	88
No. Instruments	54	68	56	76
Years effects	Yes	Yes	Yes	Yes
Hansen test	0.1055	0.4568	0.0968	0.5119
AR(1)	0.0005	0.0004	0.0006	0.0004
AR(2)	0.4375	0.3519	0.3492	0.2780

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.
Estimates are based on dynamic panel data estimation, using data averaged over five-years periods, two-step system GMM. Models v3 and v4 instrument as endogenous the dependent variable, financial sector development and the real GDP per-capita. Time dummies are included as strictly exogenous instruments in the level equations for all models. All models are estimated with Windmeijer (2005) finite sample correction and FOD transformation; p-values are reported for Hansen, AR(1) and AR(2) tests.