Wealth inequality in the long run:
A Schumpeterian growth perspective

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Abstract

This paper studies the dynamics of wealth inequality over the long-term horizon. We first provide a Schumpeterian interpretation of Piketty's second law of capitalism using a quality-ladder growth model with physical capital accumulation. Second, we test the predictions of the model using data for 21 OECD countries over the period 1860-2015. We find that, along with investment in physical capital, wealth inequality rises with the rate of investment in R&D whenever these activities do not translate into adequate rates of innovation and faster rates of income growth. These findings are shown to be robust to a wide array of econometric issues (reverse causality, heterogeneity, cross-sectional dependence, etc.). We also study the short-run responsiveness of wealth inequality to its determinants (and vice-versa) over the period 1970-2015: shocks to income growth are shown to reduce temporarily the wealth-to-income ratio whilst un-expected increases in investment rates in physical capital or R&D have positive and cumulative effects on wealth inequality. Our results point to the need to implement structural policies in order to promote economic growth and reduce the wealth-to-income ratio.

Keywords: Wealth-to-income Ratio, Piketty's Second Law, Schumpeterian Growth Theory
JEL Classification: D30, E10, E20, O30

1 Introduction

In his book *Capital in the 21st Century*, the French economist Thomas Piketty argues that the decline in the rate of economic growth in recent decades has been responsible for the increase in the wealth-to-income ratio in

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modern capitalist economies. Piketty advances his argument through the formulation of what he calls the "second fundamental law of capitalism". This law states that in the long run, the wealth-to-income ratio, β, converges to s/g, where s is the saving rate net of wealth depreciation and g is economy's growth rate inclusive of population growth.[1] Piketty uses the second law to assert that future declines in economic growth –stemming from reduced productivity and population growth–will likely lead to dramatic increases in the concentration of wealth.

The formula $\beta = s/g$ coincides with the famous Harrod-Domar-Solow condition for the steady state of an economy with capital accumulation. Piketty and Zucman (2014, pp. 272-273) claim that this formula holds in the steady state of a very large set of economic models, independently of the nature of saving motives. Besides the neoclassical growth model with exogenous saving rate, they state that this condition holds true in different variants of the bequest-in-the-utility function model, in overlapping generation models, and in most endogenous growth models. They also conclude that g is still the main force driving changes in β in models in which s is endogenous.

In this paper we provide a Schumpeterian interpretation of Piketty's second law and relate the dynamics of the wealth-to-income ratio to those of endogenous innovation. To this end, we posit that technical change is the outcome of costly and deliberative research aimed at the development of higher quality product and extend the canonical quality-ladder growth model developed by Grossman and Helpman (1991) to allow for physical capital accumulation. In this set-up, aggregate wealth amounts to the sum of the market values of all the operating firms and the capital stock, whereas aggregate savings are equal to the sum of R&D and capital expenditures. The model predicts that the wealth-to-income ratio, β, is negatively affected by the rate of economic growth, g, and positively related to the shares of national income spent on R&D activities, $s_{R\&D}$, and on investment in physical assets, s_K.

In order to study the macroeconomic patterns of wealth inequality and identify which forces drive the aggregate wealth-to-income ratio in the long run, we then perform an econometric analysis on 21 OECD countries between 1860 and 2015, using our Schumpeterian growth model as guideline. Specifically, we estimate a stochastic version of the equation for the wealth-to-income ratio, applying a novel regression technique, namely the Cross-Sectionally Augmented Distributed Lags (CS-DL) estimator (Chudik *et al.*, 2016). This approach is based on a dynamic representation yielding estimates for the long-run parameters which are robust along a number of important dimensions (namely, misspecification of dynamics, error serial correlation, cross-sectional dependence, etc.).

Our estimates show that wealth inequality widens in the long-term horizon the higher are the rates of investment in physical capital and R&D. However, as long as these investments translate into higher rates of economic expansion, income growth decreases the gap between the levels of wealth and income. We assess the robustness of our estimates to omitted variables' problems, i.e. accounting for an array of control factors not included in the theoretical model. We also inspect whether the assumed homogeneity across countries and over time in the impact of the explanatory variables may influence the results. For this reason, we estimate the long-run specification allowing for fully heterogeneous parameters. Then, we inspect whether the impact of the drivers of wealth inequality has changed across different periods, finding that responsiveness of β to s and g is much higher in the latest decades (since 1970 on). These estimates are therefore almost fully consistent with the predictions of Piketty's theory and

[1] Piketty (2014, pp. 230-231) observes that when the formula $\beta = s/g$ was explicitly introduced for the first time by the economists Roy Harrod and Evsey Domar in the late 1930s, it was common to invert it as $g = s/\beta$. It was Robert Solow's pathbreaking research on economic growth that made it clear that, in the long run, the capital/income ratio adjusts to the savings rate and structural growth rate of the economy rather than the other way around, which made it possible to invert the formula and write $\beta = s/g$.

our model that β should respond one-to-one to changes in saving rates and income growth. Finally, we study the short-run responsiveness of wealth inequality to its determinants over the most recent period, 1970-2015 (and verify whether there are feedbacks from inequality onto saving rates and income growth). We document that shocks to income growth reduce temporarily the wealth-to-income ratio and progressively vanish. Conversely, shocks to the rate of investment in physical capital or R&D have positive and cumulative effects on wealth inequality. Therefore, our evidence seems to suggest that expansionary policy (fiscal shocks) that promote income growth may have short-lasting effects on the ratio between wealth and income. Conversely, following the pattern of long-run results, structural policies able to increase the effectiveness of R&D investment in translating into higher rates of innovation and economic growth, such as education policies or product/factor market reforms, are likely to permanently reduce wealth inequality.

Our paper does relate to two important strands of economic literature. First, it is closely related to the recent debate among academics on the robustness of Piketty's theoretical apparatus and, more generally, to the discussion on the evolution of the wealth-to-income ratio (see, e.g., Acemoglu and Robinson, 2015; Krusell and Smith, 2015; Blume and Durlauf, 2015; Mankiw, 2015; Weil, 2015). Krusell and Smith (2015), in particular, focus on the second law of capitalism and argue that the capital-income ratio in modern textbook growth models is not s/g, but is instead $s/(g+\delta)$, where δ is the rate of capital depreciation. They also criticize that Piketty's assumption of a constant (positive) net saving rate because it requires that the gross saving rate tends to one as g goes to zero, which seems quite implausible. Another related paper is Cozzi and Impullitti (2015), who explore the role of globalization, in the form of fiercer foreign technological competition, for the dynamics of the wealth-to-income ratio. The authors develop a quality-ladder growth model with asymmetric countries and heterogeneous workers that is calibrated on US data. It is shown that the decline in the innovation technology gap between this country with the rest of the world has increased wealth-income ratio in the United States. This finding reproduces about two thirds of the change in wealth inequality documented by Piketty and Zucman (2014) for the period between 1980 and 2000.

Our paper is also related to a recent strand of the literature which, taking Schumpeterian growth theory as guideline, investigates the macroeconomic implications of top income inequality. Jones and Kim (2014) show how a Pareto distribution for top incomes may result from a Schumpeterian growth model in which entrepreneurs expend effort to increase the profits from their existing ideas while researchers seek new ideas to replace incumbents in the process of creative destruction. The model predicts that economic forces that increase the effort of entrepreneurs in improving their products can increase top inequality, whereas forces that enhance creative destruction or that raise the rate at which entrepreneurs lose that status can decrease top inequality. Aghion *et al.* (2015) develop a Schumpeterian growth model where growth results from quality-improving innovations by incumbents and/or from potential entrants and show that (i) facilitating innovation increases top income inequality as top incomes are earned by innovators and (ii) innovation by entrants increases social mobility. Moreover, using cross-state data for the US over the period 1975-2010, they also find a positive and significant correlation between various measures of innovativeness and top income inequality and show that this correlation partly reflects a causality from innovativeness to top income inequality.

The structure of the paper is the following. Section 2 describes the theoretical setting and derives a Schumpeterian version of Piketty's second law of capitalism. Section 3 presents the econometric model and the estimation procedure

used, whilst Section 4 describes the data. Section 5 presents the results and, finally, Section 6 concludes.

2 Theoretical setup

In this Section, we develop a quality-ladder growth model with physical capital accumulation to derive a Schumpeterian version of Piketty's second law.

2.1 Model assumptions and equilibrium conditions

There is a homogeneous final good, Υ, that is produced by fully competitive firms and that may be consumed or accumulated as physical capital. The economy has a fixed number of identical households that provide labor services in exchange for wages. Each individual member of a household lives forever and is endowed with one unit of labor, which is inelastically supplied. Households maximize

$$U \equiv \int_0^\infty e^{-\rho t} \log C(t) dt,$$

where ρ is the subjective discount rate, and $C(t)$ denotes their consumption of the homogeneous final good at time t. We take the final good as the numeraire and normalize its price, p_Υ, to 1 in every period. Production of the final output requires intermediate products, labor and capital goods and occurs according to the following constant-returns Cobb–Douglas production function

$$\Upsilon = A_\Upsilon L_\Upsilon^{1-\beta-\eta} K^\beta D^\eta, \qquad \text{with} \qquad 0 < \beta, \eta, \qquad \text{and} \qquad \beta + \eta < 1, \tag{1}$$

where A_Υ is a constant reflecting the choice of units, L_Υ is the amount of labor devoted to the production of final output, K denotes the aggregate capital stock, and D represents an index of intermediate inputs with

$$\log D(t) \equiv \int_0^1 \log \left[\sum_j q_j(\omega) d_{jt}(\omega) \right] d\omega,$$

where $d_{jt}(\omega)$ represents the input of quality j of intermediate product ω at time t, and $q_j(\omega)$ is its quality level. Normalizing the quality of each input at time $t = 0$ to one, we denote quality j of product ω as $q_j(\omega) = \lambda^j$, where $\lambda > 1$ represents the extent to which higher quality inputs improve upon lower quality inputs.

Aggregate demands for labor, capital and intermediate inputs by producers of the final good write respectively as

$$L_\Upsilon = (1 - \beta - \eta) \frac{\Upsilon}{w_L}, \qquad K = \beta \frac{\Upsilon}{w_K}, \qquad D = \frac{\eta \Upsilon}{p_D}. \tag{2}$$

where w_L is the wage rate of labor, w_K is the rental rate on capital, and p_D is the price index reflecting the prices of intermediates. Competition among suppliers of the final output leads to a price p_D equal to the minimum unit production cost, that is

$$p_D = exp \left\{ \int_0^1 \log \left[\frac{\tilde{p}(\omega)}{\tilde{q}(\omega)} \right] d\omega \right\},$$

where $\tilde{p}(\omega)$ and $\tilde{q}(\omega)$ are the price and quality, respectively, of the brand of intermediate product ω that is sold at the lowest quality-adjusted price at time t. Firms that produce D units of the final good use, in the aggregate, $\tilde{d}(\omega) = Dp_D/\tilde{p}(\omega)$ units of this variety, and no units of any other brand of input ω. Using the fact that $D = \eta\Upsilon/p_D$ by Eq. (2), the aggregate demand of intermediate input ω can be expressed as $\tilde{d}(\omega) = \eta\Upsilon/\tilde{p}(\omega)$.

In the intermediate goods sector, labor is the only primary factor of production. Any intermediate good can be produced using one unit of labor, regardless of quality. Thus, the marginal cost of each intermediate input amounts to the wage rate, w_L. Producers of intermediate goods compete in prices. Since all innovations are carried out by followers, who find themselves exactly one step ahead of the former leaders, all intermediate inputs bear the same price, that is $\tilde{p}(\omega) = \tilde{p} = \lambda w_L$. Consequently, each quality leader earns a flow of profits given by

$$\pi = \left(\frac{\lambda - 1}{\lambda}\right) p_D D = \left(\frac{\lambda - 1}{\lambda}\right) \eta\Upsilon. \tag{3}$$

The R&D sector is characterized by a perfectly competitive environment, with free entry and a constant return to scale technology. Any firm that invests resources in this activity at intensity $\tilde{\imath}$ for a time interval of length dt will succeed with probability $\tilde{\imath}dt$. To achieve an R&D intensity $\tilde{\imath}$, the firm must invest $a_I\tilde{\imath}$ units of labor per unit of time. We let v denote the stock market value of an industry-leading firm. An entrepreneur can realize v with probability $\tilde{\imath}dt$ by investing resources $a_I\tilde{\imath}$ in R&D for an interval dt at cost $w_L a_I \tilde{\imath}dt$. Therefore, in any industry ω targeted by a positive and finite amount of labor to R&D, maximizing $v\tilde{\imath}dt - w_L a_I \tilde{\imath}dt$ leads to the following condition

$$v = w_L a_I. \tag{4}$$

We now turn to the stock-market valuation of profit-making enterprises. A no-arbitrage condition relates expected equity returns to the interest rate on a riskless bond. Equity claims pay a dividend of πdt over a time interval of length dt, and appreciate by $\dot{v}dt$ if no entrepreneur innovates in this elapse of time. However, if an innovation occurs during the interval dt, the shareholder suffers a capital loss of size v. This event occurs with probability ιdt, where ι denotes the aggregate intensity of research. The shares bear an expected rate of return of $(\pi + \dot{v})/v - \iota$ per unit of time. Efficiency in the stock market requires that the expected rate of return from holding a share of an industry-leading firm is equal to the risk-free interest rate, r. Therefore, the no-arbitrage condition for the stock market writes as $\pi/v + \dot{v}/v = r + \iota$. Using Eqs. (3) and (4), this condition can be expressed as

$$\left(\frac{\lambda - 1}{\lambda}\right) \frac{\eta\Upsilon}{w_L a_I} + \frac{\dot{w}_L}{w_L} = r + \iota \tag{5}$$

In the model, a second no-arbitrage condition applies to the return to physical capital. Each capital good costs p_Υ to purchase and earns an instantaneous rental charge of w_K. Assuming that capital depreciates geometrically at rate δ, the net profit from a purchase-and-rent strategy is $w_K - \delta p_\Upsilon + \dot{p}_\Upsilon$, which amounts to income from renting, minus loss of depreciation plus capital gain from the change in price of capital. Taking account of our normalization ($p_\Upsilon \equiv 1$), the total yield on installed capital amounts to $w_K - \delta$. Equating this return to the interest rate, r, we easily get

$$w_K = r + \delta. \tag{6}$$

Let us now derive the market-clearing conditions that apply to the labor market and to the market for final output. Labor is used in R&D and in the production of intermediate and final goods. Total employment in R&D equals $a_I \iota$. The quantity of labor used in manufacturing intermediates amounts to $\eta\Upsilon/(\lambda w_L)$. Demand for labor by final good producers, L_Υ, is instead equal to $(1-\beta-\eta)\Upsilon/w_L$. The labor market is in equilibrium, so that the sum of labor demands equals labor supply, L, that is

$$\left[1-\beta-\left(\frac{\lambda-1}{\lambda}\right)\eta\right]\frac{\Upsilon}{w_L}+a_I\iota=L. \tag{7}$$

Final output is either consumed or invested in capital equipment. Investment demand equals $\dot{K}+\delta K$, where $\dot{K}$ represents the rate of increase in the capital stock. Consumption of the final good by the household sector is equal to C. Market clearing therefore requires

$$\dot{K}+\delta K+C=\Upsilon. \tag{8}$$

2.2 Steady-state analysis

In what follows, we concentrate on the steady-state properties of the model. Eqs. (5) and (7) require that the long-run ratio between final output and the wage rate of labor, Υ/w_L, is constant, which implies that the wage rate of labor grows at same rate as final output in the steady state. Then, Eq. (8) requires that the rate of investment, $(\dot{K}+\delta K)/Y$, and the consumption-to-output ratio, C/Υ, are both constant, which involves that capital, consumption and output must grow at the same rate in the steady state, that is $g_K=g_C=g_\Upsilon$. To compute this growth rate, we first need to derive the rate of change of the index of intermediate inputs, g_D. Since only state-of-the-art varieties are demanded in positive quantities, we substitute aggregate demand $\tilde{d}_t=\eta\Upsilon/(\lambda w_L)$ into $\log D(t)$. We easily obtain

$$\log D=\log\frac{\eta\Upsilon}{\lambda w_L}+\int_0^1\log\tilde{q}_t(\omega)\mathrm{d}\omega=\log\frac{\eta\Upsilon}{\lambda w_L}+\Phi_t\log\lambda, \tag{9}$$

where $\Phi_t\equiv\int_0^t\iota(\tau)\mathrm{d}\tau$ is the expected number of R&D successes in the typical industry before time t. As the wage rate of labor, w_L, grows over time at the same rate as does final output, Υ, and research intensity, ι, is constant along a balanced-growth path, differentiation of (9) yields

$$g_D=\iota\log\lambda.$$

Now, differentiating the production function of final output with respect to time we get $g_\Upsilon=\beta g_K+\eta g_D$. Using the latter relationship, together with the fact that $g_K=g_\Upsilon$ and $g_D=\iota\log\lambda$, we can express the rate of expansion of output in the steady state as

$$g_\Upsilon=\frac{\eta}{1-\beta}g_D=\frac{\eta}{1-\beta}\iota\log\lambda. \tag{10}$$

2.3 The distribution of income in the economy and the wealth-to-income ratio

The economy has two assets in positive net supply, namely claims on physical capital and shares in the intermediate good firms. Given that the measure of industries is one and there is a single quality leader in each industry, the

value of shares in the intermediate good firms is simply equal to v. Thus, the aggregate stock of assets, W, can be written as $K+v$. Let us now specify the national budget constraint. Gross domestic product (GDP), Y, represents the total value added in the economy which amounts to the sum of total output of the final good and the value created by the R&D sector, namely $\Upsilon + v\iota$.[2] GDP can also be expressed as the sum of consumption and investment (savings) or, equivalently, as the sum of labor income, capital income and firm profits, namely

$$Y = \Upsilon + v\iota = \underbrace{C}_{Consumption} + \underbrace{w_L a_I \iota + \dot{K} + \delta K}_{Savings} = \underbrace{\left[1 - \beta - \left(\frac{\lambda - 1}{\lambda}\right)\eta\right]\Upsilon + w_L a_I \iota}_{Labor\ Income} + \underbrace{w_K K}_{Capital\ Income} + \underbrace{\left(\frac{\lambda - 1}{\lambda}\right)\eta\Upsilon}_{Firm\ Profits}.$$

In the economy, national income is equal to total income net of capital depreciation, that is $Y - \delta K$. We denote $s_{R\&D} \equiv w_L a_I \iota/(Y - \delta K)$ the proportion of national income devoted to R&D investment and $s_K = \dot{K}/(Y - \delta K)$ the one devoted to the investment in physical capital. The wealth-to-income ratio, β, is defined as the ratio between the aggregate stock of assets and national income, that is

$$\beta \equiv \frac{W}{Y - \delta K} = \frac{K + v}{Y - \delta K}.$$

The steady-state value of β can be determined as follows. Let us express β as the sum of $K/(Y - \delta K)$ and $v/(Y - \delta K)$. As capital and final output grow at the same rate in the steady state, $K/(Y - \delta K)$ amounts to

$$\frac{K}{Y - \delta K} = \frac{K}{\dot{K}} \times \frac{\dot{K}}{Y - \delta K} = \frac{s_K}{g_K} = \frac{s_K}{g_\Upsilon}.$$

Since $v = w_L a_I$ by Eq. (4) and $\iota = g_\Upsilon(1 - \beta)/(\eta \log \lambda)$ by Eq. (10), $v/(Y - \delta K)$ can be written as

$$\frac{v}{Y - \delta K} = \frac{w_L a_I}{Y - \delta K} = \frac{1}{\iota} \times \frac{w_L a_I \iota}{Y - \delta K} = \frac{s_{R\&D}}{\iota} = \frac{s_{R\&D}}{g_\Upsilon} \times \frac{\eta \log \lambda}{1 - \beta}.$$

Using these results, the wealth-to-income ratio, β, can be expressed as

$$\beta = \underbrace{\frac{s_K}{g_\Upsilon}}_{Piketty} + \underbrace{\frac{s_{R\&D}}{g_\Upsilon} \cdot \Gamma}_{Schumpeter}, \tag{11}$$

where $\Gamma \equiv \frac{\eta \log \lambda}{1 - \beta}$ is a collection of parameters. Eq. (11) states that, in the steady state, the wealth-to-income ratio, β, is positively affected by the shares of national income devoted to capital accumulation and R&D activities, namely s_K and $s_{R\&D}$, and negatively related to the economic growth rate, g_Υ.

[2] This follows from the definition of aggregate value added as the sum of value added in all sectors, namely $(\Upsilon - p_D D) + p_D D + v\iota$ where the expression in parenthesis is the value added in the final-good sector, whereas the second and the third term represent the value added in the intermediate-good sector and in the R&D sector, respectively.

3 Empirical setting

3.1 Specification and Econometric procedure

Our model predicts that the wealth-to-income ratio, β, is positively related to the share of income spent on innovation and physical capital, $s_{R\&D}$ and s_K, and negatively to the rate of economic growth, g (Eq. 11). We test econometrically this prediction by estimating a linear specification (in logs) relating the wealth-to-income ratio to $s_{R\&D}$, s_K and g on a panel sample of countries over the time span 1860-2015, that is

$$\ln \beta \quad = \quad \eta_{0i} + \eta_1 \ln s_{R\&D,it} + \eta_2 \ln s_{K,it} + \eta_3 \ln g_{it} + \epsilon_{it}, \tag{12}$$

where the subscript i refers to country i and the subscript t to the year of observation. The model predicts that $\eta_1 > 0$, $\eta_2 > 0$ and $\eta_3 < 0$.

The analysis is developed by means of a novel technique of panel time-series regression, the cross-sectionally augmented distributed lag (CS-DL) approach (Chudik *et al.*, 2016). To derive the estimated specification, let us consider the long-run version of the relationship of interest

$$y_{it} = \theta x_{it} + \epsilon_{it}.$$

that can be expressed as dynamic specification in the form of an Auto-Regressive Distributed Lags (ARDL) model, assuming for simplicity one lag of the variables ($p = 1$) and no deterministic components:

$$y_{it} = \alpha_1 y_{it-1} + \alpha_2 x_{it} + \alpha_3 x_{it-1} + \epsilon_{it}.$$

This equation can be reformulated by removing the lagged dependent variable to circumvent the bias in the long-run coefficients arising from the inconsistent estimate of y_{it-1} (Nickel effect)

$$y_{it} = \theta x_{it} + \beta \Delta x_{it} + \omega_{yp} \sum_{p=0}^{P_y} \overline{y}_{it-p} + \omega_{xp} \sum_{p=0}^{P_x} \overline{x}_{it-p} + \tilde{\epsilon}_{it}, \tag{13}$$

where $\theta = (\alpha_2 + \alpha_3)/(1 - \alpha_1)$ is the long-run parameter, $\beta = \alpha_2 + \alpha_3$ and $\tilde{\epsilon}_{it} = \epsilon_{it}/1 - \alpha_1$. Basically, the CS-DL procedure estimates a (log-)level specification for the long-run relationship, augmented with i) current and lagged values of first-differenced regressors to mitigate the effect of reverse causality, and ii) cross-sectional averages of dependent and explanatory variables to account for unobservable common factors.[3]

The CS-DL estimator is shown to provide consistent estimates in a range of conditions, namely when variables are stationarity or not, are serially correlated or in presence of breaks in errors, dynamic mis-specification or strong cross-sectional dependence. We estimate the empirical model assuming homogeneous parameters (pooled estimator). However, given the small panel size and long time dimension of the data, below we also assess the stability of the

[3] If un-accounted for, unobserved common factors would yield inefficient estimates if they are uncorrelated with regressors, but would produce inconsistent estimates if correlated with the explanatory variables. As in Chudik *et al.* (2015), we fix to zero the maximum number of lags for the cross-sectional mean of the dependent variable, P_y, whilst we follow the rule-of-the-thumb $P_x = T^{1/3}$ for the explanatory variables.

results to the heterogeneity in the impact of the explanatory variables across countries and over time. Moreover, given that the CS-DL estimator is not immune to simultaneity feedbacks, we assess the results' robustness adopting an alternative long-run estimator (ARDL) which is robust to this kind of mis-specification, as well as an Instrumental Variable-type of regression in which exogenous variation in our key explanatory variables is predicted with data on natural disasters.

4 Data

The analysis is based on a long-run (historical) dataset covering the period 1860-2015 for 21 OECD countries: Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece Ireland, Italy, Japan The Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, the UK and the US.

The wealth-income ratio, β, is primarily measured the value of R&D and physical capital stocks over GDP and, secondarily, by the stock market capitalization over GDP as a robustness check. The latter is built multiplying the value of capital stocks with the Tobin Q, as estimated in Madsen and Davis (2006). The stock of R&D is constructed accumulating R&D investment, expressed at constant prices, with the perpetual inventory method assuming a 15% depreciation rate. Similarly, capital stock is derived from investment in (residential and non-residential) structures and equipment assuming a depreciation of 3 and 17% respectively. The rate of savings is defined in terms of or investment rates. They are measured as the fraction of GDP invested in R&D and in capital goods ($s_{R\&D}$ and s_K). s_K can be decomposed in the fractions of GDP accruing to residential, machinery and structure investments, respectively. The rate of economic growth is expressed as the annual rate of change in real income (GDP), either adjusted or not for capital depreciation ($g + \delta$ and g). GDP (income) is expressed in constant 1990 dollars valued at PPP and real terms. In robustness checks we also use g as proxied by the growth rate of income per capita or income per worker. Further data details will be given below.

Table 1: **Summary statistics, 1860-2015**

		Mean	SD	Median
Wealth-income ratio, β				
R&D stock/GDP	$\beta_{R\&D}$	0.042	0.044	0.026
Total capital stock/GDP	β_K	3.122	1.398	2.810
(R&D + capital stocks)/GDP	$\beta_{R\&D+K}$	3.163	1.397	2.875
Stock mkt capitalization/GDP	β_{SMC}	1.527	0.981	1.432
Saving/investment rate				
R&D investment/GDP	$s_{R\&D}$	0.007	0.009	0.002
Capital investment/GDP	s_K	0.166	0.141	0.189
(R&D + Capital investment)/GDP	$s_{R\&D}+s_K$	0.173	0.144	0.194
Income growth				
GDP	g	0.017	0.054	0.019
GDP+ depreciation	$g+\delta$	0.108	0.055	0.109

Table 1 reports the summary statistics for the main variables used in the analysis. On average, the wealth-to-income ratio, given by the sum between physical capital and R&D stocks, amounts to around 3. This value is roughly comparable in size to the measure of wealth, expressed at market prices, provided by Piketty and Zucman (2014). The measure of β based on inflating capital stocks with Tobin Q is much lower, given the nature of number

index of the latter variable. Investment in physical capital accounted for around 18% of GDP, that on R&D to less to 1%. The latter measure of investment shows a large variation across countries. Between 1860 and 2015, the mean rate of income growth was 1.7%, the median rate of 1.9% (around 10% if expressed gross of total asset depreciation).

5 Econometric results

Our theoretical setting shows that investment in R&D (and physical assets) leads to higher levels of the wealth inequality. However, as long as R&D activities do translate into higher rates of innovation, this leads to a faster rate of economic expansion, and the latter reduces the wealth-to-income ratio. This occurs as innovation-driven income growth favours distribution from capital owners to workers, given that the new innovation destroys the market value of incumbent firm, promoting the turnover across monopolists whilst preserving employment opportunities.

In this section, we first perform an empirical analysis to understand which factors drive wealth inequality in the long run. Secondly, we assess whether (and how) wealth inequality responds to short-run variation (unanticipated shocks) in investment rates and income growth, as well as whether there are feedbacks among these variables in the short-term horizon. Table 2 reports our baseline estimates for the long run. It shows a battery of regressions which assess whether our estimates change with the nature of the variables used. Table 3 evaluates the robustness of the long-run results to the inclusion of control variables. Table 4 accounts for heterogeneity in the drivers of wealth inequality across countries and years, whilst Table 5 quantifies the impact of wealth inequality's drivers over different time intervals. Simultaneity issues related to our long-run analysis are addressed in Table 6.

In the last part of the paper, we lay out the results, based on panel VAR analysis, on short-run causality (Table 7) and an impulse response function analysis assessing how shocks to one endogenous variable of the model propagates into the economy (Figure 1 . The part of the analysis will use data from 1970 onwards (see the discussion below).

5.1 Long-run estimates

Baseline results

We start the analysis using a measure of s_K reflecting the fraction of GDP invested in capital assets, given by the sum between residential and non-residential capital. Income growth is expressed in gross terms and hence, following Piketty and Zucman (2014), this rate is adjusted for capital depreciation ($g' = g + \delta$). Both the rates of investment in physical and knowledge assets are significant and with a positive coefficient. However, the elasticity of physical investment is found to be three times as large as that of R&D investment. In line with the prediction of the model, income growth is found to reduce wealth inequality. In the light of the estimated coefficients (elasticities), our evidence indicates that one percent increase in the GDP share of R&D investment (from 1 to 2%) or capital investment (from 17 to 18%) induce between 0.02 and 0.4 percent points increase in wealth inequality; conversely, a permanent one-percent increase in the rate of income growth would yield a 0.02 percent reduction in the wealth-to-income ratio. In col. 2, we exclude residential structures from investment flows and capital stocks. This is done to ascertain whether our results are driven by housing, as argued in Bonnet *et al.* (2014). Moreover, the measure of productive capital used in col. 2 is more comparable to investment performed by the firms in knowledge generating activities

(i.e. R&D investment). In col. 2, the magnitude of the effects is larger, especially for capital investment, suggesting that wealth inequality is particularly sensitive to private savings channelled towards investment in productive capital (structures, machinery and equipment, etc.).[4] In cols. 3, we assess to what extent our results are sensitive to the adjustment of income growth for depreciation, being this variable expressed in gross terms. Our results do not change using non-adjusted series for income growth. In col. 4, we seek to assess whether our results are affected by how capital stock is measured. It is standard in studies based on historical data to use an index number measure of total capital summing up various asset types with weights taken at a base year (Laspeyres index). However, there could be distortions associated with the changing composition of aggregate capital and with the productive services provided by each asset type does vary with the prevailing conditions on the financial market, its physical depreciation or the rate of technological obsolescence. For this reason, we have built a measure capital stock that aggregates asset types with time-varying (two-year chained) weights (Tornqvist index); these weights reflect the share of each asset (structure, machinery, equipment and R&D) on total capital compensation on the basis of their user cost (Jorgenson and Stiroh, 2000). Estimates obtained with this alternative capital measure fall close to our benchmark results (col. 4 vs col. 2). In the last regression, we approximate the wealth-to-income ratio with a measure reflecting the stock market capitalisation of capital. This is obtained by multiplying the capital-to-income ratio with a proxy the Tobin's q computed at the country level. In col. 5, the coefficient size of income growth reduces considerably and this variable is no longer significant. The fall in the absolute magnitude of coefficients might be due to a strong attenuation bias associated with the measurement of the long-run value of Tobin's q for our entire set of countries.

Table 2: **Determinants of the Wealth-Income ratio, β (1860-2015)**

		1	2	3	4	5
R&D investment/GDP	$s_{R\&D}$	0.018***	0.029***	0.028***	0.025**	0.022**
		(0.005)	(0.010)	(0.010)	(0.010)	(0.010)
Capital investment/GDP	s_K	0.043***	0.154***	0.153***	0.155***	0.050***
		(0.004)	(0.007)	(0.007)	(0.007)	(0.008)
Income growth	g'	-0.020***	-0.050***	-0.048***	-0.051***	-0.004
		(0.002)	(0.005)	(0.004)	(0.005)	(0.005)
Physical investment		Total	Non-residential	Non-residential	Non-residential	Non-residential
Income growth		$g+\delta$	$g+\delta$	g	$g+\delta$	$g+\delta$
Number index base		Fixed	Fixed	Fixed	Chained	Fixed
Wealth-income						Stock market cap
Obs.		3,276	3,276	3,276	3,276	3,276
R-squared		0.076	0.318	0.317	0.296	0.314

Notes: Standard errors in parentheses. Variables are in logs. All regressions include country-specific fixed effects. Long-run parameters. ***, **, * significant at 1, 5 and 10%.

[4]It should be observed that the same pattern of results emerges when we regress the ratio between residential structure and income against our set of regressors (un-reported).

Control variables

Table 3 reports a battery of robustness checks on our benchmark specification by including some control variables (financial development, inflation, taxation rate and trade openness).[5] It is legitimate to wonder whether the rise in wealth-inequality has been caused by the development of financial markets rather than by investment in research or tangible assets. Earlier studies, based on historical data, have documented that financial development has been one of key drivers of investment in R&D, human capital, patenting activities, as well as the rate of economic growth (see, among others, Madsen and Ang, 2016). Hence, the coefficient estimated for our set of regressors might be upward biased, given that these variables are likely to be correlated with financial development. In col. 2, we include the ratio to GDP of bank credit as control. This variable turns out to be positively and significantly related to the wealth-to-income ratio, suggesting that as long as financial markets develop the base of capital widens more than proportionally to the expansion in the level of economic activities and income created. Nonetheless, the impact estimated for key regressors of our analysis remains unchanged. Our main findings are confirmed even when we include the inflation rate,[6] as this measure of macroeconomic instability turns out to be insignificantly related to β. In col. 3, we introduce the average income taxation. The effect of fiscal burden on investment, or GDP growth, has been object of a very extensive literature (see among others Djankov *et al.*, 2010, Arnold *et al.*, 2011). The impact of taxation changes with the nature of the fiscal variable (marginal or average rate), the type of taxation, i.e. taxation (or fiscal incentives) on consumption, personal income, corporate income, or R&D, and clearly with the nature of the empirical model and the data used (economy-wide level, industry level, etc.). In col. 4, we use a measure of effective (average) rate of income taxation. This control variable does not allow us to assess the progressivity of income taxation and hence to understand whether wealth inequality can be reduced by higher marginal taxation rates on top income earners. However, our evidence shows that income taxation act as an effective instrument to reduce wealth inequality and that, in the long run, its effect is orthogonal to the impact of s and g. In col. 5, we control for the effect of trade openness but it does not appear related to wealth inequality (col. 5).[7] In col. 6, we refine identification of the impact of income growth. and check the effect on wealth inequality of this variable is related to the outcome of innovation activities as predicted by our theoretical model, or rather its reflects the effect of other growth drivers. To this aim, in col. 6 we use the patenting rate as regressor in place of g (i.e., the ratio between new patent applications and the patent stock Venturini, 2012). This variable is found to be negatively related to β and with an effect much stronger than the one found above for g (-0.145).[8]

[5]Financial development is measured as the ratio between private bank credit/GDP, the inflation rate as the annual rate of change in the Consumer Price Index, whilst we use the average taxation rate on GDP as a proxy for fiscal burden (i.e. tax revenues over GDP at current price). Trade openness is measured as the ratio of exports to total trade openness (imports plus exports). Note that using a measure of import intensity on total trade, or the ratio to GDP of exports or imports does not modify significantly our inference.

[6]See Chu *et al.* (2015) for an analysis on inflation effects within a Schumpeterian growth framework.

[7]This finding may be explained with the fact that we control for strong cross-sectional dependence through the use CCE terms. These terms should capture global interdependence in dynamics of wealth inequality (and its drivers). Since they are constructed as cross-country means of β, s and g, CCE terms are likely to weak the explanatory power of trade openness' variables. See Madsen *et al.* (2015) for a discussion.

[8]Below, in the section on simultaneity issues, we more formally identify the effect of income growth with cross-country variation in innovation (patenting) rates.

Table 3: **Determinants of the Wealth-Income ratio, β: control variables (1860-2015)**

		1	2	3	4	5	6
R&D investment/GDP	$s_{R\&D}$	0.029***	0.033***	0.029***	0.030***	0.032***	0.025***
		(0.010)	(0.009)	(0.010)	(0.009)	(0.010)	(0.010)
Capital investment/GDP	s_K	0.154***	0.152***	0.155***	0.153***	0.140***	0.131***
		(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Income growth	g'	-0.050***	-0.050***	-0.051***	-0.049***	-0.048***	
		(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	
Bank credit/GDP			0.077***				
			(0.007)				
Inflation rate				0.000			
				(0.007)			
Taxation rate					-0.091***		
					(0.009)		
Trade openness						-0.017	
						(0.014)	
Patenting rate							-0.145***
							(0.026)
Obs.		3,276	3,276	3,276	3,276	3,068	3,269
R-squared		0.318	0.342	0.319	0.342	0.284	0.297

Notes: Standard errors in parentheses. Variables are in logs. All regressions include country-specific fixed effect. Long-run parameters. ***, **, * significant at 1, 5 and 10%.

Heterogeneous effects across countries and over time

In the analysis developed thus far, we have assumed that the impact of investment rates and income growth on the wealth-to-income ratio is homogeneous across countries and over time. One may debate that this assumption is too restrictive in a time horizon of over one century and a half, and may result into biased long-run estimates whenever the impact of one or more explanatory variables do differ along the time dimension or across panel units (Pesaran and Smith, 1995). We address this issue in two respects. First, we assess whether the magnitude of the effects estimated for investment rates and income growth over the period between 1860 and 2015 changes by admitting full parameter heterogeneity (Table 4). Second, we inspect whether the pattern on the drivers of the wealth-to-income ratio has changed across time periods, namely before and after the WWII as well as in the latest decades (Table 5).

In Table 4 we allow for parameter heterogeneity in our long-run estimates (1860-2015). For comparison aims, col. 1 reports the estimates for the benchmark regression, shown above, with homogeneous coefficients and accounting for strong cross-sectional dependence (through CCE terms). In col. 2, we admit heterogeneity across countries in the impact of investment rates and income growth (θ_i in eq. 13). We estimate the CS-DL specification country by country and compute the mean value of the parameters, robust to outliers, following the procedure devised by Bond *et al.* (2010). In these estimates, investment rates show a greater impact on the wealth-to-income ratio than before, especially $s_{R\&D}$ (0.056 vs 0.021), whilst the effect of income growth is smaller (-0.025). Notice that, probably due to a large variation across countries in R&D-based generating activities, the impact of $s_{R\&D}$ is statistically significant at a 10% only. In col. 3, we allow for parameter heterogeneity along both the cross-sectional dimension (i.e. across countries) and along time (i.e. across years) using the Mean Observation OLS estimator, MO-OLS, developed by Neal (2016). This procedure assumes that the impact of one variable is the sum of component unit-specific i, time-specific t and a common constant ($\theta_{it} = \theta + \theta_i + \theta_t$). Similarly to the Mean Group estimators, θ_{it} is

Table 4: **Determinants of the Wealth-Income ratio, β: heterogeneity across countries and time (1860-2015)**

		1	2	3	4	5
R&D investment/GDP	$s_{R\&D}$	0.021**	0.056*	0.065**	0.143***	0.144***
		(0.009)	(0.030)	(0.028)	(0.036)	(0.019)
Capital investment/GDP	s_K	0.162***	0.177***	0.331***	0.331***	0.277***
		(0.007)	(0.061)	(0.030)	(0.047)	(0.015)
Income growth	g'	-0.051***	-0.025**	-0.100**	-0.053	-0.066***
		(0.005)	(0.011)	(0.042)	(0.079)	(0.025)
Parameter		Homog	Hetero	Hetero	Hetero	Hetero
CSD		CCE	CCE	no	TD	CCE
Estimator		FE-OLS	MG-OLS	MO-OLS	MO-OLS	MO-OLS
Observations		3,486	3,066	3,276	3,276	3,276

Notes: Cross-Sectionally Augmented Distributed Lags estimates. Standard errors in parentheses. Variables are in logs. All regressions include country-specific fixed effects. Long-run parameters. CCE: Common Correlated Effects. TD: time dummies. FE: fixed effect estimator. MG: Mean Group. estimator. MO: Mean Observation estimator. ***, **, * significant at 1, 5 and 10%.

estimated at level of single country and then it is averaged across the panel units. The MO-OLS estimator has been proved to yield consistent estimates in moderate to large sample (N and T), both within a static and a dynamic setting of analysis. However, this procedure has been developed for cross-sectional independent framework. As a consequence, its statistical properties are still unknown in settings with weak to strong levels of cross-sectional dependence. For this reason, in col. 3 through 5, we perform an explorative analysis reporting MO-OLS estimates for our CS-DL specification without controlling for cross-sectional dependence (col. 3), controlling for weak cross sectional dependence (i.e. with time dummies, TD; col. 4) and for strong cross-sectional dependence (i.e., with CCE terms; col. 5). Overall, the pattern of results is quite consistent across regressions. Findings in col. 5, which are the most comparable to our benchmark estimates (col. 1), show that the proportion of GDP allocated to R&D and physical investments may have a much greater impact on wealth inequality than estimated within a parameter homogeneous regression framework (0.144 and 0.277). As a result, our benchmark estimates look rather conservative and have to be regarded as lower-bound values.

Table 5: **Determinants of the Wealth-Income ratio over time intervals, β**

		1	2	3	4
		1860-2015	1860-1945	1945-2015	1970-2015
R&D investment/GDP	$s_{R\&D}$	0.029***	0.089***	0.054***	0.149***
		(0.010)	(0.012)	(0.010)	(0.014)
Capital investment/GDP	s_K	0.154***	0.045***	0.668***	0.761***
		(0.007)	(0.005)	(0.017)	(0.024)
Income growth	g'	-0.050***	-0.025***	-0.047***	-0.632***
		(0.005)	(0.003)	(0.005)	(0.056)
Obs.		3,276	1,785	1,470	945
R-squared		0.318	0.283	0.635	0.714

Notes: Standard errors in parentheses. Variables are in logs. All regressions include country-specific fixed effect. Long-run parameters. ***, **, * significant at 1, 5 and 10%.

In Table 5 we analyse more in depth whether the impact of the determinants of wealth inequality has changed

across periods due to structural breaks induced for instance by wars, globalisation, etc. In this step of the analysis, the empirical model is estimated with homogeneous coefficients (FE OLS), as the relative short time span of the data may yield less precise (mean group) estimates compared to those obtained over the entire time period (1860-2015). The WWII is used as watershed, and hence in cols. 2 and 3 we illustrate estimates for the period 1860-1945 and 1945-2010. These estimates differ from the general pattern as the impact of s_K is considerably much larger in the Second post-War (0.668). In col. 4, we restrict the focus over the period since 1970 on. Looking at the latest decades, the magnitude of the effects of the variables is rather different. The coefficient estimated for the share of GDP invested in R&D and physical capital amounts to 0.149 and 0.761, whilst the coefficient estimated for income growth is -0.632. From this perspective, the results of our empirical model look much closer to the original predictions of Piketty's theory according to which β should react equiproportionally to changes in s and g.

5.2 Simultaneity issues

This section addresses potential simultaneity issues. The CS-DL model has been proved to provide consistent estimates in an array of conditions but it does not allow for feedback effects from the dependent variable onto the regressors. To assess whether our long-run estimates are affected by reverse causality problems we perform two types of checks. First, following Chudik *et al.* (2015), we estimate the empirical specification reformulated as an ARDL model. The fixed effect OLS estimation of this dynamic model provides consistent estimates in the presence of endogenous regressors when the lag structure of the variables is correctly specified, irrespective of whether they are or not stationary (see Pesaran and Shin, 1999). Second, we perform an Instrumental Variable (IV) type of regression in which we predict the impact of the right-hand variables exploiting exogenous variation in the natural disasters that affected the economies of our sample over one century. Following the strategy of analysis devised by Bloom *et al.* (2013), in the first step, we estimate a set of auxiliary regressions in which each endogenous (right-hand side) variables is regressed on a pair of instruments. For each economy, these instruments are constructed as the inverse distance-weighted number of natural disasters affecting the other countries included in our sample. The idea is that the larger the number of natural disasters hitting the partner economies (and the resulting disruptions), the lower is the demand for domestic goods, reducing thus firms' investment and hence income growth at home.[9] First-step regressions are estimated using static specifications including country fixed effects, common time dummies, and correcting standard errors for serial correlation and heteroskedasticity (Newey-West regression).[10] The predicted values of such auxiliary regressions are used as explanatory variables in the long-run CS-DL specifications. Due to the generated (non-random) nature of instrumented variables, the second step uses standard errors bootstrapped with 200 replications.

We present this group of estimates in Table 6. Since data on natural disasters span from 1900 on, this set of robustness checks is conducted on the period between 1900 and 2015. For comparative terms, col. 1 reports

[9] Skidmore and Toya (2002) and Cavallo *et al.* (2013) are amongst the most influential papers assessing the long-run growth effects of natural disasters. Fomby *et al.* (2013) examine the short-run impact of various disaster types on GDP, its components and other macroeconomic indicators with a VAR analysis. See Shabnam (2014) for a recent review of the literature.

[10] Data on natural disasters are taken from EM-DAT, the International Disaster Dataset, the Université Catholique de Louvain. Bilateral distances between countries are taken from CEPII dataset; distance weights are immune to reverse causality problems associated with trade flows, as the pattern of imports or exports sensitive to the level of development and/or intensity of investment of a country.

our benchmark estimates, obtained over the entire time span. Col. 2 shows the CS-DL estimates for the shorter time interval (1900-2015), yielding almost identical results. In col. 3 we estimate the ARDL specification finding and obtain much larger coefficients, taken in absolute terms, than in CS-DL estimates. IV-type estimates are illustrated in col. 4 through 6, in which we predict the variation in $s_{R\&D}$, s_K and g taking one variable at time as endogenous. In col. 4, the GDP share of R&D investment is predicted with the distance-weighted number of geo-physical disasters such as land movements, and the total amount of climatological disasters (i.e., the sum of droughts, extreme temperatures, floods, fog, storms and wildfires). These variables are found to be negatively related to $s_{R\&D}$ (-0.009 and -0.028). Moreover, the Wald test of joint significance takes the value of 19.79, which is well above is the rule-of-thumb value of 10. In second step of the regression, the parameter estimated for (the fitted value) of $s_{R\&D}$ amounts to 0.220, and this does not differ much from the value found for this variable in the ARDL estimation (col. 3). In col. 4 we predict the impact of the rate of physical capital investment, expressed as a share of GDP, with the the inverse distance-weighted number of landslides and storms affecting foreign countries. These variables turn out to be good predictor for s_K, either in terms of expected sign (-0.014 and -0.020) or statistical power (joint Wald test equal to 11.95). However, for this regression, second-step estimates are much closer to CS-DL than ARDL estimates and the instrumented variable is significant at a 10% only (col. 2). In the last column, we instrument income growth. In the light the identification strategy followed for $s_{R\&D}$ and s_K, the impact of g is not predicted with variation in foreign natural disasters as our assumption is that these environmental factors affect domestic demand and, through this channel, are likely to reverberate on income growth. As a consequence, in line with the model, variation in g is inferred with the domestic rate of innovation (see eq. 10) and the rate of innovation of foreign countries. The latter variable is built as an inverse distance-weighted rate of patenting. Rather reasonably, these predictors are found with a positive and negative coefficient, 0.020 and -0.004 respectively (the joint Wald test is 12). Interestingly, as for $s_{R\&D}$, the second-step estimate for for g falls quite close to the ARDL estimates of col. 3. Overall, the set of estimates addressing possibly simultaneity issues confirms the validity of our long-run estimates shown in the previous sections.

5.3 Short-run effects and feedbacks (1970-2015)

In this section, we depart from the long-run (steady-state) equilibrium framework and perform a panel Vector Auto-Regression (VAR) analysis to investigate how the wealth-to-income ratio reacts, in the short run, variation in its determinants, and whether there are feedbacks from β on the other key variables of the model. This analysis is restricted to the 1970-2015 period. In fact, most of the debate on Piketty's laws of capitalism has focused on the early 1970s on, due to the new wave of free market policies that have been pursued by most industrialized countries and that are supposed to be behind the steep upward swing in wealth-to-income ratio. Moreover, as our long-run estimates above have shown, the empirical evidence for the latest decades is more consistent with Piketty's theory and the theoretical framework we developed in the first part of the work, as both postulate that wealth inequality should one-to-one related to changes in investment rates and income growth. Last but not least, the evidence arising over the latest decades appears of greater value from a policy-making perspective, especially for understanding the capacity of governments to hinder the widening gap between wealth and income levels through policies able to

Table 6: **Simultaneity issue: ARDL and IV estimates (1900-2015)**

		1	2	3	4	5	6
		CSDL	CSDL	ARDL	CSDL	CSDL	CSDL
		1860-2015	1900-2015	1900-2015	1900-2015	1900-2015	1900-2015
						Instrumented	
					$s_{R\&D}$	s_K	g
R&D investment/GDP	$s_{R\&D}$	0.029***	0.030***	0.200*	0.220**	0.052***	0.029**
		(0.010)	(0.011)	[0.090]	(0.095)	(0.016)	(0.010)
Capital investment/GDP	s_K	0.154***	0.153***	0.335***	0.142*	0.122*	0.129***
		(0.007)	(0.008)	[0.000]	(0.088)	(0.070)	(0.007)
Income growth	g	-0.050***	-0.051***	-0.143***	-0.050***	-0.016***	-0.141***
		(0.005)	(0.005)	[0.010]	(0.009)	(0.004)	(0.052)
						1st step	
Instrument 1					-0.009***	-0.014***	0.020***
					(0.004)	(0.004)	(0.004)
Instrument 2					-0.028***	-0.020***	-0.004***
					(0.005)	(0.005)	(0.001)
						F-test	
					19.79	11.35	12.00
					Land movements	Landslides	Dom. patenting
					Climatic	Storms	Foreign patenting
Obs.		3,276	2,436	2,436	2,436	2,436	2,436
R-squared		0.319	0.303	0.988	0.293	0.198	0.222

SE in parentheses (bootstrapped with 200 reps. in cols. 4-6). P-value in square brackets. Variables in logs. Country-specific FE included. ***, **, * significant at 1, 5 and 10%.

affect the rates of investment (broadly intended) and GDP growth. The econometric model used in this section is a fixed-effects panel VAR model, defined as:

$$l\mathbf{y_{it}} = \alpha_\mathbf{i} + \Phi_1 \mathbf{y_{it-1}} + + \Phi_2 \mathbf{y_{it-2}} + \epsilon_\mathbf{it} \tag{14}$$

where $\mathbf{y_{it}}' = \{s_{R\&D},\ s_K,\ g,\ \beta\}$. We assume homogeneous parameters, Φ_i, and homogeneous error structure, as well as error independence within and across equations. The equation system is estimated with the Generalized Method of Moments (GMM) in which panel-specific fixed effects are removed with Helmert transformation.[11]

Table 7 shows the results of panel Granger-causa test. According to the joint χ^2 test, each variable is Granger-caused by the other variables of the system, taken as a whole. However, the share of GDP invested in R&D appears to be not related to (Granger caused by) any single variable, whilst the wealth-to-income ratio is responsive to all investment rates and the rate of income growth, in line with the long-run prediction of the model.

Table 7: **Panel Granger-causa test**

Dep: $s_{R\&D}$	chi2	df	p-value
s_K	2.279	2	0.320
g	4.146	2	0.126
β	0.346	2	0.841
ALL	14.75	6	0.0220
Dep: s_K			
$s_{R\&D}$	2.357	2	0.308
g	7.665	2	0.022
β	9.452	2	0.009
ALL	112.161	6	0.000
Dep: g			
$s_{R\&D}$	10.685	2	0.005
s_K	1.524	2	0.467
β	9.125	2	0.010
ALL	45.253	6	0.000
Dep: β			
$s_{R\&D}$	11.367	2	0.003
s_K	6.162	2	0.046
g	5.777	2	0.056
ALL	41.254	6	0.000

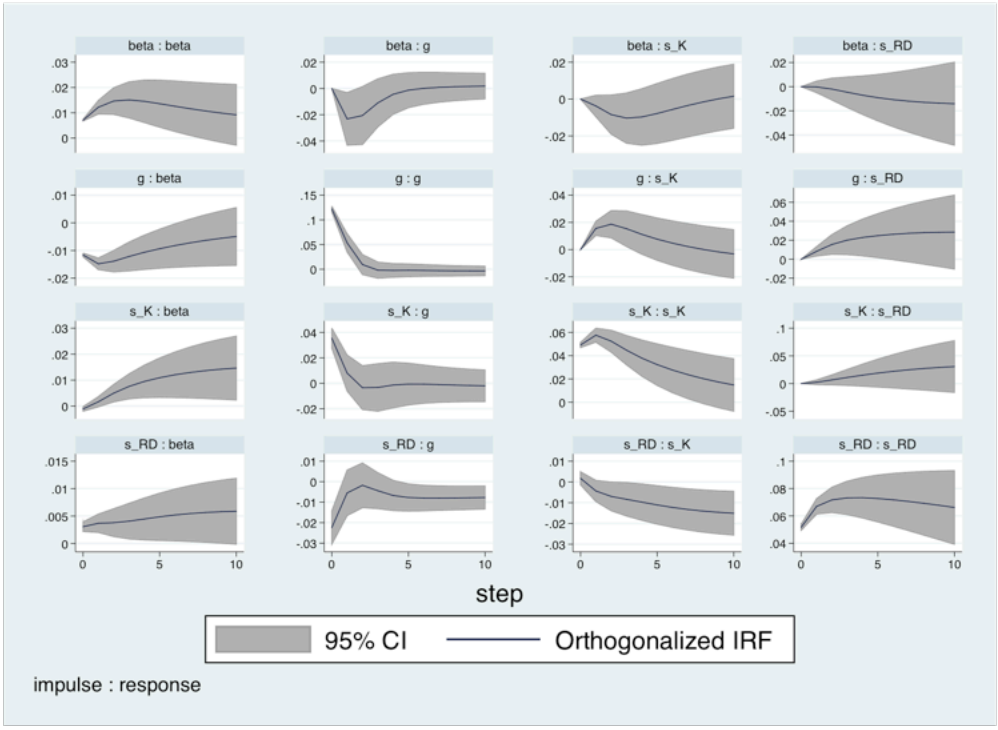
Notes: H0: the explanatory variables do not Granger-cause the dependent variable. Number of lags selected with Q information criterion.

Figure 1 illustrates the result of the impulse response function (based on 10 steps) associated with the estimates of panel VAR (eq. 14). It shows how the variables of the system (response variable) react to a orthogonalized shock in each other endogenous variable (impulse variable). These shocks could consist in an increase of the amount of the resources invested in physical capital or R&D, as well as an acceleration in income growth induced for instance by an expansive fiscal policy. If we limit our attention to the effects on β caused by a 1% unexpected shocks on the endogenous variable (plots in the first column of the table), it can be observed that the effect of an un-anticipated increase of β is at maximum after three periods (around 0.015) and then reduces. After a 10-year period from the

[11]The optimal number of lags is selected using the set of moment model selection criteria developed by Andrews and Lu (2001).

shock, the estimated effect of the impulse is 0.01%. Secondly, shocks to income growth are effective in the very short time (after year 0.013%) but are quite short-lived. Indeed, at the end of the period, the impact of original shock is around one-third of the maximum effect (0.04%). The impulse exerted by increases in investment rates are cumulative and persistent over time. After a ten year period, unexpected shocks in s_K and $s_{R\&D}$ amount to 0.015 and 0.005% of the initial impulse.

Figure 1: **Orthogonalized Impulse Response Function (10 steps)**



6 Conclusions

In this paper we have studied patterns and drivers of macroeconomic inequality over a century and a half of time, using Piketty's theory as guidelines. In order to trace mechanisms leading to a widening in the wealth-to-income ratio in knowledge-based economies, we have first derived a Schumpeterian growth framework à la Grossman and Helpman (1991), based on intentional innovation and capital accumulation. The model predicts that the wealth-to-income ratio, β, is negatively affected by the rate of economic growth, g, and is positively related to the shares of national income spent on R&D activities, $s_{R\&D}$, and on investment in physical assets, s_K. In the second part of the work, we have checked the predictions of the model by performing an econometric analysis on 21 OECD countries between 1860 and 2015. Then, we have studied the short-run sensitivity of the wealth-to-income ratio to unexpected shocks affecting the variables of the model. Our estimates have shown that wealth inequality widened in the *long-term* horizon as a result of higher rates of investment in physical capital and R&D. However, as long as these investments translated into higher rates of economic expansion, income growth reduced the gap between the levels of wealth and income. Looking at the short-run sensitivity of the variables between 1970 and 2015, we

have documented that shocks to income growth reduce temporarily the wealth-to-income ratio and progressively vanish. Conversely, shocks to investment rates in physical capital or R&D yield positive and cumulative effects on wealth inequality. Our evidence hence suggests that expansionary policy (fiscal shocks) that promote income growth may have short-lasting effects on β. Conversely, on the basis of long-run results, structural policies able to increase the effectiveness of R&D investment in translating into higher rates of innovation and economic growth (education policies, product or factor market regulation reforms) are likely to permanently reduce wealth inequality.

References

Acemoglu, D. and Robinson, J. A. (2015). "The Rise and Decline of General Laws of Capitalism". *Journal of Economic Perspectives*, **29**(1):3–28.

Aghion, P., Akcigit, U., Bergeaud, A., Blundell, R., and Hémous, D. (2015). "Innovation and Top Income Inequality". *Harvard University, mimeo.*

Andrews, D. W. and Lu, B. (2001). "Consistent model and moment selection procedures for {GMM} estimation with application to dynamic panel data models". *Journal of Econometrics*, **101**(1):123 – 164.

Arnold, J. M., Brys, B., Heady, C., Åsa Johansson, Schwellnus, C., and Vartia, L. (2011). "Tax Policy for Economic Recovery and Growth". *Economic Journal*, **121**(550):59–80.

Bloom, N., Schankerman, M., and Van Reenen, J. (2013). "Identifying Technology Spillovers and Product Market Rivalry". *Econometrica*, **81**(4):1347–1393.

Blume, L. E. and Durlauf, S. N. (2015). "Capital in the Twenty-First Century: A Review Essay Review". *Journal of Political Economy*, **123**(4):749–777.

Bond, S., Leblebicioglu, A., and Schiantarelli, F. (2010). "Capital Accumulation and Growth: A New Look at the Empirical Evidence". *Journal of Applied Econometrics*, **25**(7):1073–1099.

Bonnet, O., Bono, P.-H., Chapelle, G., and Wasmer, E. (2014). "Does Housing Capital Contribute to Inequality? A Comment on Thomas Piketty's Capital in the 21st Century". Technical Report 2014-07, Sciences Po Departement of Economics.

Cavallo, E., Galiani, S., Noy, I., and Pantano, J. (2013). "Catastrophic Natural Disasters and Economic Growth". *The Review of Economics and Statistics*, **95**(5):1549–1561.

Chu, A. C., Cozzi, G., Lai, C.-C., and Liao, C.-H. (2015). "Inflation, R&D and growth in an open economy". *Journal of International Economics*, **96**(2):360–374.

Chudik, A., Mohaddes, K., Pesaran, M. H., and Raissi, M. (2015). "Is There a Debt-Threshold Effect on Output Growth?" *Review of Economics and Statistics, forthcoming.*

Chudik, A., Mohaddes, K., Pesaran, M. H., and Raissi, M. (2016). "Long-Run Effects in Large Heterogenous Panel Data Models with Cross-Sectionally Correlated Errors". In "Advances in Econometrics", volume 36. Essays in Honor of Aman Ullah, Emerald Publishing.

Cozzi, G. and Impullitti, G. (2015). "Globalization and Wage Polarization". *Review of Economics and Statistics, forthcoming.*

Djankov, S., Ganser, T., McLiesh, C., Ramalho, R., and Shleifer, A. (2010). "The Effect of Corporate Taxes on Investment and Entrepreneurship". *Journal of International Economics*, **2**:31–64.

Fomby, T., Ikeda, Y., and Loayza, N. V. (2013). "The growth aftermath of natural disasters". *Journal of Applied Econometrics*, **28**(3):412–434.

Grossman, G. M. and Helpman, E. (1991). "Quality Ladders in the Theory of Growth". *Review of Economic Studies*, **58**(1):43–61.

Jones, C. I. and Kim, J. (2014). "A Schumpeterian Model of Top Income Inequality". NBER Working Paper No. 20637.

Jorgenson, D. W. and Stiroh, K. J. (2000). "Raising the Speed Limit: US Economic Growth in the Information Age". *Brookings Papers on Economic Activity*, **31**(1):125–236.

Krusell, P. and Smith, T. (2015). "Is Piketty's Second Law of Capitalism Fundamental?" *Journal of Political Economy, forthcoming.*

Madsen, J. B. and Ang, J. B. (2016). "Finance-Led Growth in the OECD since the Nineteenth Century: How Does Financial Development Transmit to Growth?" *The Review of Economics and Statistics*, **98**(3):552–572.

Madsen, J. B. and Davis, E. P. (2006). "Equity Prices, Productivity Growth and 'The New Economy'". *Economic Journal*, **116**(513):791–811.

Madsen, J. B., Minniti, A., and Venturini, F. (2015). "Assessing Piketty's laws of capitalism". Monash Economics Working Papers 34-15, Revision April 2017, Monash University, Department of Economics.

Mankiw, G. (2015). "Yes, r>g. So What?" *American Economic Review, Papers and Proceedings, forthcoming.*

Neal, T. (2016). "Multidimensional Parameter Heterogeneity in Panel Data Models". mimeo, University of New South Wales,.

Pesaran, M. H. and Shin, Y. (1999). "An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis". In S. Strøm, editor, "Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium", chapter 11, pages 371–413. Cambridge University Press, Cambdrige.

Pesaran, M. H. and Smith, R. (1995). "Estimating long-run relationships from dynamic heterogeneous panels". *Journal of Econometrics*, **68**(1):79–113.

Piketty, T. (2014). *Capital in the Twenty-First Century.* Harvard University Press, Cambdrige and London.

Piketty, T. and Zucman, G. (2014). "Capital is Back: Wealth-Income Ratios in Rich Countries, 1700-2010". *Quarterly Journal of Economics*, **123**(3):1155–1210.

Shabnam, N. (2014). "Natural disasters and economic growth: A review". *International Journal of Disaster Risk Science*, **5**(2):157–163.

Skidmore, M. and Toya, H. (2002). "Do natural disasters promote long-run growth?" *Economic Inquiry*, **40**(4):664–687.

Venturini, F. (2012). "Looking into the Black Box of Schumpeterian Growth Theories: An Empirical Assessment of R&D Races". *European Economic Review*, **56**(8):1530–1545.

Weil, D. (2015). "Capital and Wealth in the 21st Century". *American Economic Review, Papers and Proceedings, forthcoming.*