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Secular Trends and Technological Progress

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Abstract

We study the redistributive effects of a gradual productivity shift from tangible to intangible capital. Intangible asset creation relies on the commitment of skilled human capital. To ensure retention, firms reward innovators by deferred compensation, so funding demand by firms drops as the importance of intangible assets rises. Since human capital income is not tradable, the supply of investable assets falls and innovator rents rise. The general equilibrium effect is a fall in interest rates, while surplus savings are stored in higher asset valuations. This shift leads to increasing inequality and skewness in both the capital and labor income share. Rising house prices and wage inequality lead to higher household leverage.

Keywords. Intangible capital, skill-biased technological change, human capital, excess savings, house prices

JEL classifications. D33, E22, G32

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1. Introduction

Interest rates have been on a long-term decline, accompanied by a rising surplus of savings over productive investment. This phenomenon has been defined as a phase of "secular stagnation", reflecting demographic or techonological changes (Summers, 2014; Eichengreen, 2015). While many factors contribute to this evolution, we propose a novel interpretation for a direct effect of the transition to a knowledge-based economy. This technological transition is well recognized as a leading cause for a shift in skilled worker productivity and relative wages (e.g. see Autor et al., 1998, 2003). Our framing extends the analysis to the capital income share, with novel implications driven by the nature of human capital incorporated in intangible investment.

The impact of new technology on corporate assets has been a marked shift towards intangible capital since 1980, as Figure 1 shows.[1] Corrado and Hulten (2010) define intangible capital as the capitalization of investment in corporate knowledge, organizational capability, computerized information and internal software.

We study the long-term effects of this transformation, in order to interpret current economic trends and their likely evolution. Our key insights derive from observing how intangible capital creation relies on skilled human capital, and increasingly substitutes physical assets. The rise in intangible capital shifts funding demand and skews income shares within both the labor and capital share, with first order effects on credit demand, interest rates and asset prices. This interpretation also foresees a rising divergence in investment scale and return between innovator and skilled inside investors on one side and capital market investors on the other.

[1]The Compustat series capitalizes R&D and organizational capital expenditures (Peters and Taylor, 2017), while BEA data measures intellectual property products (IPP).

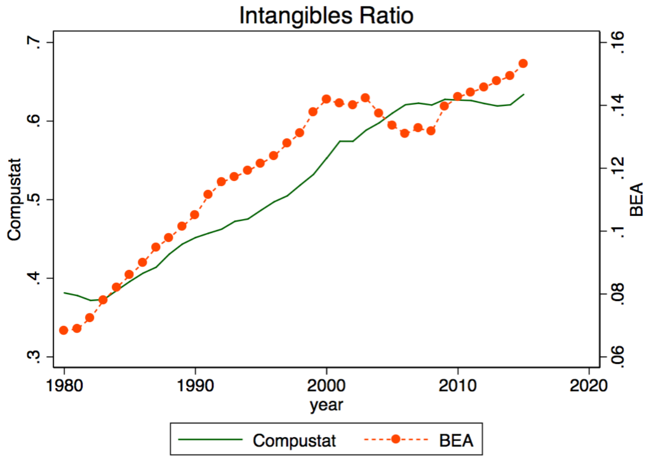

Figure 1: Ratio of intangible to total capital since 1980.

It is well established that firms with more intangible assets choose more equity financing (Bates et al., 2009). As intangible assets are poor collateral in default (as "assets can simply walk out of the door"), the asset shift can explain the fall in corporate net leverage (Falato et al., 2018).

Critically, firms cannot purchase human capital as innovators can leave at will (Hart and Moore, 1994). As a result, firms need to defer the bulk of compensation to human capital to ensure its motivation and retention until output is realized (Oyer and Schaefer, 2005). This reflects a shift from wages that compensates for operating current assets, to a capital share grant that rewards an investment process to create new intangibles. Eisfeldt et al. (2019) shows how compensation for highly skilled workers is increasingly done in deferred form, while its wage component declines.

More productive intangible assets lead to two consequences. First, more firm value must be promised to innovators (Eisfeldt and Papanikolaou, 2014; Eisfeldt et al., 2019), leading to more future profits being assigned to innovators. Second, firms have lower borrowing capacity as their assets are less pledgeable, yet because of co-investment by human capital they fund a smaller share of capital formation. Firms do co-invest in intangible assets (e.g. patents, data and advertising), but deferred compensation needs for human capital implies that firms have lower investment funding needs, and may even become net lenders (Döttling et al., 2020).

We incorporate this notion in an overlapping generations (OLG) growth model, with a general CES production function where physical capital is complementary with manual labor, while intangible capital is complementary with skilled labor. Land (housing) serves as durable consumption good as well as a store of value for life-cycle retirement savings.

The inability to contract on future human capital rewards implies that, as the intangible capital share rises, investors have fewer investable claims for their retirement savings, and face lower returns than innovators and their inside financiers. The result is a growing excess of savings over investment funding needs, and a divergence between outsider and insider investor returns. Indeed, the productive sector has become a net lenders in most developed economies (Gruber, 2015), while the number of listed securities has been in steady decline (Doidge et al., 2018; Kahle and Stulz, 2017).

In the model, each cohort has inelastic retirement needs,[2] so in equilibrium excess savings are reallocated to fund durable assets. In other words, the decline in investable assets induces some savings to be *stored* in higher valuation of long-term assets (equities and real estate).

In equilibrium, positive growth and a rising intangible capital ratio may be generated by many factors affecting factor productivity or their supply. We show analytically how in our setup only a highly redistributive shift towards intangibles is able to account simultaneously for a drop in physical investment and the interest rate. Clearly, a decline in both quantity and price of a physical factor can only be explained by declining demand. The general equilibrium

[2] Empirically, savings are inelastic to changes in interest rates (Blinder and Deaton, 1985; Matthew Canzoneri and Diba, 2007), perhaps reflecting a target retirement income.

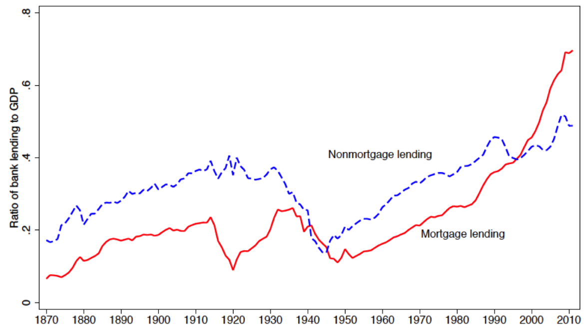

Figure 2: Mortgage and commercial credit in OECD countries (Jordà et al., 2016)

effects are driven by the special contractual nature of the emerging factor, since human capital investment cannot be funded externally.

Our results are closely linked to the insight from the labor literature on how new technologies not just reprice but also replace old factors at the technological frontier (e.g. Acemoglu and Autor, 2011). The equivalent process for firm capital is that more productive intangible capital substitutes for physical investment at the productive frontier. This leads to both a quantity and value shift within the capital share, boosting skill premia as well as innovative rents.

The combined effect on wage and capital markets leads to a rising demand for mortgage credit since house prices rise relative to unskilled wages. This may account for the vast rise of mortgage credit in all OECD countries (Jordà et al., 2016, see Figure 2), now amply larger than credit to the productive sector. Our results interpret higher asset prices as the result of the need to store wealth in excess of profitable investment.

While the model predicts a rise over time in the mortgage default rate, its neoclassical framing implies a dynamically efficient equilibrium. We discuss how mortgage credit limits to reduce defaults may be Pareto-improving only under a strong financial stability externality, an important issue beyond the scope of our model.

The rest of the paper is organized as follows. Section 2 describes key trends since 1980 that suggest a shift from their historical evolution. Section 3 presents the model. Section 4 shows analytically how a redistributive technological shift can account for the observed trends, discusses the main alternative explanations and our key assumptions, and places our work in the literature. Section 5 concludes by discussing the economic and social impact of this transition and frames some policy issues arising from rising household leverage, while pointing to the need for a broader model to draw precise policy recommendations.

2. Major Long-Term Trends

Several trends in labor and capital markets since 1980 represent a break from their earlier historical experience.

Falling real interest rates Real rates have gradually fallen across advanced economies since the early 1980s (King and Low, 2014), reaching unprecedented lows relative to its historical average. After reaching a peak above 8% in the early 1980s, US and world real rates have steadily declined even during the credit boom, falling below 0% in recent years.

Rising intangible investment ratio Even as firm physical investment declined since 1980, firm investment in intangibles has risen. Figure 1 shows both a narrow BEA definition (intellectual property rights and capitalized R&D), and the broader measure by Peters and Taylor (2017) which includes measures of goodwill and organizational capital but is only available for Compustat firms. While the measures differ in the range of firms they cover and type of assets they include, both show a clear upward trend.

Decreasing corporate funding needs and investable assets Next to a falling physical investment, the left panel of Figure 3 shows a steadily rising net financial position for the U.S.

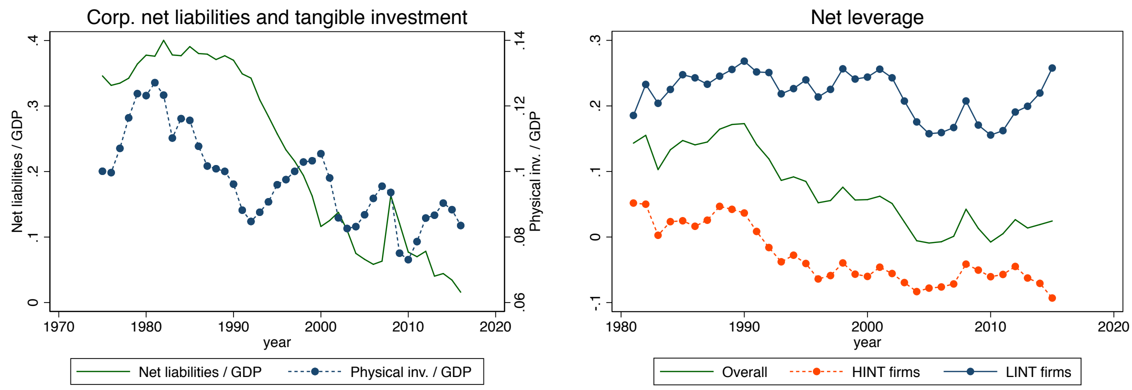

Figure 3: Net leverage of non-financial corporations

non-financial sector using Flow of Funds data, reflecting falling net leverage and rising cash holdings,[3] a trend confirmed in most OECD countries (Gruber, 2015). The right panel shows the evolution of leverage ratios for the average Compustat firm as well as for firms high-intangibles (HINT) firms, defined as those in the top tercile of the intangible-to-total assets, compared to low-intangible (LINT) firms. This broad aggregate trend has been obscured by rising leverage in unlisted firms, especially those run by private equity, where debt has funded equity withdrawals rather than new investment.

The drop in credit and capital expenditures is puzzling at a time of falling real rates, but is consistent with a falling demand for physical investment and external financing. The corporate finance literature suggests that a rise in intangibles should lead to more demand for equity financing, as intangibles cannot be easily pledged to outsiders (Bates et al., 2009). Yet lower net leverage has been accompanied since 1980 by large net equity outflows (Lazonick, 2015). A recent surge in US corporate bond issuance has been largely used to repurchase shares, while the number of listed securities (investables for the general public) has steadily dropped since 1980 (Kahle and Stulz, 2017).

[3] Net liabilities are defined as total liabilities net of total financial assets.

Allocation of credit Credit to private firms has been on a long secular rise since the industrial revolution. However, since 1980 mortgage credit has grown rapidly, and now vastly exceeds total credit to the productive sector across all OECD countries, as Figure 2 shows (Jordà et al., 2016). Household leverage has been also rising rapidly, suggesting mortgage borrowing has exceeded income for some time. Such a generalized reallocation of credit suggests a common long term factor, rather than country-specific factors (such as massive capital inflows or national regulatory choices).

Land and share prices Real house prices across advanced economies were remarkably stable for a century, but rose sharply since 1980 across all OECD countries (Knoll et al., 2017), as Figure 4 shows.

US stock market capitalization over GDP rose from 50% in 1980 to over 150% in recent years. Though profit rates have risen in recent years, equity withdrawals have been massive. Thus the rise mainly reflects an historically high price-earning ratio, even though its volatility has ranged from 7 to 44 in the period 1980-2016. This extreme valuation has been soon restored since the financial crisis, consistently with a structural abundance of savings above new investment.

Rising inequality Recent decades have seen a sharp increase in relative earnings of skilled workers across OECD countries, a trend widely interpreted in terms of skill-biased technological change (Acemoglu and Autor, 2011).[4] New technology on automation has led to replacing many low-skill functions, just as intangible capital has substituted physical assets in our setup.

[4]Labor wages have risen in industrializing countries where physical investment has been strong, reflecting diffusion of basic technology.

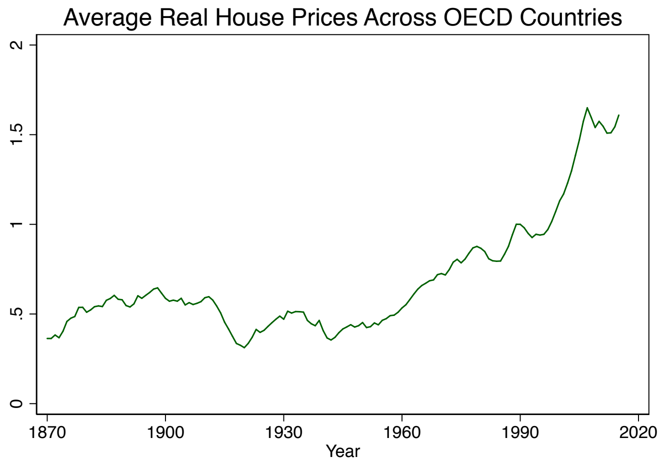

Figure 4: Average real house prices in OECD countries (Knoll et al., 2017).

Rising innovator share Suggestive evidence points to a strong rise in the innovator share of capital income (Smith et al., 2019), affecting the nature and allocation of undiversifiable risk (Garlenau and Panageas, 2017). As firms rely increasingly on intangible capital, skilled human capital and innovators benefit vastly (Eisfeldt et al., 2019), capturing a rising share of returns and altering the asset pricing kernel (Kogan et al., 2020).

Eisfeldt et al. (2019) show a remarkable rise in the share of employee compensation paid as deferred share compensation rather than wage income (see Figure 5), suggesting a gradual shift from paying for skilled service to rewarding human capital investment contributing to capital accumulation.

3. Model

This section describes the model environment, derives its equilibrium and the main results.

Time Time is discrete and runs from $t = 0$ to infinity. Overlapping generations live for two periods.

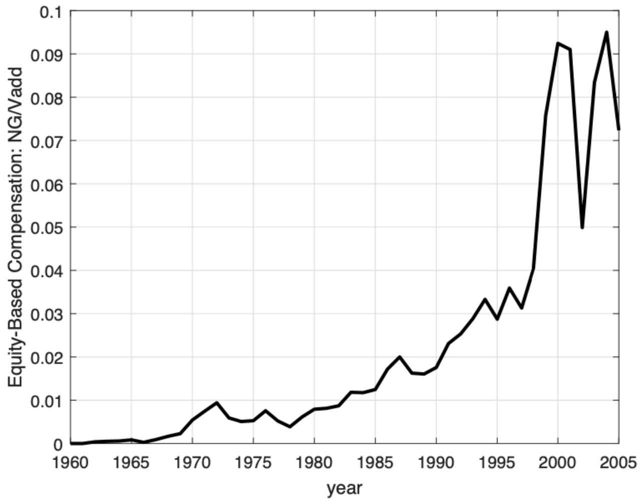

Figure 5: Employee equity compensation over value added from Eisfeldt et al. (2019).

Goods There are two consumption goods, corn and land.[5] There is a fixed amount of land $\bar{L}$, infinitely durable as it does not depreciate. We denote by p_t the relative price of land in terms of corn.

Households Each generation consists of a unit mass of households. Households have a quasi-linear utility function $U(c_{t+1}, L_t) = c_{t+1} + v(L_t)$, where c_{t+1} denotes consumption of corn when old, and L_t are land holdings at the end of period t. The function $v(L)$ with $v'(L) > 0$, $v''(L) < 0$ captures the utility households achieve from living in their house. The initial old generation is endowed with all initial assets, such as firm shares and land. A fraction ϕ of households ($i = h$) is born with high human capital and offers $\tilde{h}$ units of high-skill labor, while the rest ($i = l$) provides $\tilde{l}$ units of manual labor. Both types of labor endowments are supplied inelastically.

[5]We do not distinguish between houses and land, and will use the terms interchangeably.

Representative Firm There is an infinitely-lived representative firm in a competitive market, set up in the initial period with a mandate for value maximization. It has access to a nested CES production technology that uses as inputs physical capital K_t, highly complementary with manual labor l_t, as well as intangible capital H_t, complementary with high-skill labor h_t. Aggregate output thus equals

$$F(K_t, H_t, l_t, h_t) = \left[\eta(H_t^\alpha h_t^{1-\alpha})^\rho + (1-\eta)(K_t^\alpha l_t^{1-\alpha})^\rho\right]^{\frac{1}{\rho}} . \tag{1}$$

where η measures the relative productivity of intangible capital and high-skill labor versus physical inputs, α is the capital share, and ρ is related to the elasticity of substitution between physical and intangible factors.

The firm can invest $I_{K,t}$ units of corn at t to install $K_{t+1} = I_{K,t}$ units of physical capital, to be used in production at $t+1$. In contrast, intangible capital is created by innovative skilled workers. Both types of capital fully depreciate after production, and the firm starts with an initial stock (K_0, H_0). Households trade shares in the representative firm at the endogenous price f_t, which quantity is normalized to 1.

Intangible Capital The creation of intangible capital requires co-investment by the firm and its creative employees. Here we assume all intangible value is generated by a subset of skilled innovators at no monetary cost.[6] A fraction ε of high-skill workers can exert effort at a non-pecuniary utility cost of $C(I_{H,t}) = \frac{\psi}{2} I_{H,t}^2$, to create intangible capital $H_{t+1} = I_{H,t}$ next period.

Intangible capital creation requires creators to commit their human capital until production

[6] In reality firms need to fund some intangible investment spending, such as advertisements, patent purchases and basic salaries. See Döttling et al. (2020) for a model in which firms need to incur some investment cost in intangible capital.

next period. As human capital is inalienable (Hart and Moore, 1994), a wage paid today does not restrict the ability of innovators to leave before production, taking a fraction ω of intangible capital. Thus firms need to offer deferred compensation that grants innovators a fraction ω of intangible value. As the value of innovation increases, the innovator share rises.

Financial Claims All firm profits are verifiable, so the inalienability of innovative human capital is the only contractual friction. No claims may be issued at t against intangible value appropriated by innovators at $t+1$ (as opposed to the share captured by the firm).

In the basic setup there is no uncertainty nor other frictions, so firm equity and debt are equivalent. For illustration we refer to external financing as borrowing when backed by land or by physical capital, and as external equity for claims backed by the fraction $(1-\omega)$ of intangible capital that firms can appropriate and assign to investors. Households can thus invest in shares and corporate debt. As compensation to human capital is deferred, firms do not become financially constrained as their future return is fully pledgeable. Firms pay out all profits as dividends denoted d_t, though our results do not depend on their payout policy.

Labor and capital supply Households supply their labor endowment inelastically to the representative firm, receiving income when young. Labor income is $y_t^i \in \{w_t\tilde{l}, q_t\tilde{h}\}$ where w_t denote wages for manual workers and q_t are wages of high-skill workers. Households can buy a house L_t for own use, and sell it to the next generation when they are old, earning some utility plus any price appreciation. As households only consume in retirement at $t+1$, they use all wage income for house purchases and retirement savings.[7]

Next to housing, households can buy shares at a price f_t and corporate or mortgage debt

[7]The simplifying assumption rules out any savings response as rate change, as it is indeed the case empirically, but is not critical to our results.

D_t. We refer to households with $D_t \geq 0$ as lenders, and $D_t < 0$ as borrowers. While most households have no income when old ($y^i_{t+1} = 0$), innovators receive capital income from the intangible capital they created, $y^i_{t+1} > 0$.

3.1. Household choice

The maximization problem of a household is:

$$\begin{aligned} &\max_{c_{t+1}, L_t, S_t, D_t} U(c_{t+1}, L_t) = c_{t+1} + v(L_t) \\ s.t. \quad & p_t L_t + f_t S_t + D_t \leq y^i_t \\ & c_{t+1} \leq y^i_{t+1} + p_{t+1} L_t + (f_{t+1} + d_{t+1}) S_t + (1 + r_{t+1}) D_t \\ & c_{t+1}, L_t, S_t \geq 0 \end{aligned} \tag{2}$$

The first two constraints reflect budget conditions for young and old respectively. At the optimum the budget constraints are binding, so housing demand is given by the first order condition w.r.t. L_t,

$$p_t = \frac{p_{t+1} + v'(L^i_t)}{1 + r_{t+1}}.$$

The price of housing reflects the discounted future house price plus its utility value. The relevant discount rate is either the borrowing interest rate (for a borrower) or the opportunity cost of investing (for a lender). In a competitive equilibrium they both equal r_{t+1}.

Note that housing demand is independent of income, as borrowing enables all households to consume the optimal amount of housing.[8] Hence, we interpret borrowing as taking out a mortgage, which allows equalizing the marginal utility of housing across agents with heterogeneous income.

[8] We consider borrowing constraints in the extension on mortgage default.

The first order condition w.r.t. S_t yields a pricing equation for shares:

$$f_t = \frac{f_{t+1} + d_t}{1 + r_{t+1}}. \tag{3}$$

Investments in capital markets follows as a residual $D_t^i = y_t^i - f_t S_t - p_t L_t$. Households with $y_t^i \geq p_t L_t + f_t S_t$ have enough income to buy their house and invest the remainder. In contrast, those with $y_t^i < p_t L_t + f_t S_t$ need a mortgage loan.

3.2. Firm Investment Choice

Firms employ labor l_t and h_t, and invest in physical capital K_t, so as to maximize the infinite stream of dividends d_t:

$$\max_{K_t, l_t, h_t} \sum_{t=0}^{\infty} d_t \tag{4}$$

To finance physical investment firms raise $D_t^f = I_{K,t}$ on capital markets, and pay the equilibrium interest rate r_t. Since innovators capture a fraction ω of intangible value, dividends can be written as

$$d_t = F(K_t, H_t, l_t, h_t) - w_t l_t - q_t h_t - [I_{K,t} - D_t^f] - (1 + r_t) D_{t-1}^f - \omega R_{H,t} H_t.$$

Under perfect competition, workers and suppliers of funding for physical capital are compensated according to their marginal productivity, $w_t = F_{l,t}$ and $q_t = F_{h,t}$. Since firms are financially unconstrained they can always scale up tangible investment until $1 + r_t = F_{K,t}$

Creation of Intangibles Innovators invest in the creation of intangible capital. In the second period they can leave to re-deploy a fraction ω of their intangible capital at a competitor firm. Their ex-post compensation needs to match this outside option of value $\omega R_{H,t+1} H_{t+1}$. This compensation must be paid after production takes place, where $R_{H,t}$ is the value of intangible capital. Under perfect competition, $R_{H,t} = F_{H,t}$. Innovators incur an effort cost

$C(I_{H,t}) = \frac{\psi}{2}(I_{H,t})^2$, to create $H_{t+1} = I_{H,t}$ units of intangibles at $t+1$, so they scale up their intangible creation until

$$\omega R_{H,t} = \psi I_{H,t-1}. \tag{5}$$

As the ratio H/K rises, so does the innovator capital share.

The firm is never financially constrained, since tangible assets can be funded at the interest rate while intangible capital investment by innovators is self-financed via deferred compensation. Under constant returns to scale, competitively supplied factors are compensated according to their marginal productivity. Competitive firms earn profits on the fraction $(1-\omega)$ of intangible value they can appropriate:

$$d_t = (1-\omega)R_{H,t}H_t.$$

For illustrative purposes we refer to external funding for tangible capital as debt, though in our setup it is equivalent to equity as there is no risk.

3.3. Equilibrium

A competitive equilibrium is defined as an allocation $\left\{c_t^h, c_t^l, L_t^h, L_t^l, D_t^h, D_t^l, D_t^f, K_t, H_t\right\}_{t=0}^{t=\infty}$ and prices $\{w_t, q_t, R_{H,t}, R_{K,t}, r_t, f_t\}_{t=0}^{t=\infty}$, such that given prices

- households maximize their utility (2),
- innovators choose intangible investment (5),
- final good producers maximize dividends (4),

and land and capital markets clear.

Market clearing in the land market requires $\int_0^1 L_t^i di = \bar{L}$. Since land can be fully pledged, mortgages allow for an efficient homogeneous allocation of land, with $L_t^i = \bar{L}$ for both high-skill and manual workers.

In the capital market, total net savings by households equal labor income earned by the young generation minus their house purchases, $D_t = w_t\tilde{l} + q_t\tilde{h} - p_t\bar{L}$. Net savings are invested in debt $D_t^f = K_t$ and stocks f_t. Using that $w_t(1-\phi)\tilde{l} + q_t\phi\tilde{h} = (1-\alpha)Y_t$, financial market clearing can be written as

$$(1-\alpha)Y_t = p_t\bar{L} + D_t^f + f_t, \tag{6}$$

Thus total savings supply equals the supply of investable assets, namely housing, corporate debt and equity. Lower income households use mortgage debt to buy their house, borrowing from higher income household.

A technological shift to intangibles has an effect on the evolution of credit demand and financial prices. In our context of inelastic savings from labor income are directed to retirement savings, and may be allocated to net investable assets. These include housing corporate debt and equity. In steady state their value can be written as

$$f = \frac{(1-\omega)RH}{r}, \tag{7}$$

$$p = \frac{v'(\bar{L})}{r}, \tag{8}$$

$$D^f = K. \tag{9}$$

Total investable assets for net savers include mortgage debt, whose value in steady state is given by:

$$m \equiv \max\left\{0, (1-\phi)(pL + fS - w\tilde{l})\right\}.$$

4. Redistributive Growth

We consider now the general equilibrium effects of technology-driven redistributive growth, defined by a steady rise in the relative productivity of intangible factors η. The first step is to define under what conditions such a productivity shift leads to growth and at the same time a re-allocation away from physical capital. Then we consider its impact on key macroeconomic trends. We report here all results derived in Appendix A. Throughout we focus on comparative statics across steady states, in line with out focus on long-term trends. We adopt the nested formulation of Cobb-Douglas production (as $\rho \to 0$), while other trends are discussed in Section 4.1 and the general CES case in Appendix B.

First, the ratio of intangible to physical capital K/H rises directly with the relative productivity shift in the production function (1). As a results, rising η increases income inequality $\frac{q}{w} = \frac{\eta}{1-\eta}\frac{\tilde{l}(1-\phi)}{\tilde{h}\phi}$. The reason is that skilled wages rise more than physical wages, which under modest overall growth may in fact decline.

Second, a rise in η is consistent with aggregate output growth as long as the supply of skilled labor is sufficient.[9] Throughout we focus on the case in which η results in growth.

The key for η to replicate other long-term trends is that it results in a falling ratio of K/Y, in line with the documented trend of falling CAPEX over GDP in Section 2. This result is not obvious since, by general factor complementarity, aggregate growth also stimulates demand for physical investment. As long as the effect of η on growth is not too strong, the direct negative effect on factor productivity dominates, resulting in a falling equilibrium ratio of $\frac{K}{Y}$:

Lemma 1. *As long as $\frac{dY}{d\eta}$ does not exceed a threshold defined in Appendix A, rising η results*

[9] While we abstract from education choices in the model, a rising skill premium can ensure adequate incentives to develop skilled human capital to ensure this condition is met.

in falling $\frac{K}{Y}$*:*

$$d\left(\frac{K}{Y}\right)/d\eta \leq 0$$

As a result of falling K/Y, firm demand for productive financing falls. The financial market clearing condition (6) illustrates the effect of a falling K/Y on the equilibrium allocation of savings. As retirement savings are inelastic to rates, the direct effect of a lower K/Y is a boost in house and/or share prices as alternative savings vehicles:

$$(1-\alpha) = \frac{p}{Y}\bar{L} + \frac{f}{Y} + \frac{K}{Y}.$$

As firms rely on a rising share of intangible capital, over time they need less external finance. Rising intangible value incorporated in share prices (reflecting the firm share $(1-\omega)$) absorbs only a fraction of their capital value, see Eq. (7). In contrast, the capital share ω accruing to innovators ex post is not investable. Thus, a critical effect of rising human capital is a savings surplus that pushes down interest rates, ensuring that excess wealth over investment needs is stored in higher long-term asset values. As long as ω is sufficiently large, excess savings reduce interest rates and are re-directed towards housing:

Proposition 1. *Suppose rising* η *results in growth (*Y *increases) that satisfies the condition described in Lemma 1, so* K/Y *falls. As long as* ω *is not too small, a rising* η *results in falling interest rates* r*,*

$$dr/d\eta \leq 0,$$

rising house prices relative to income p/Y*, rising share prices relative to income* f/Y*, and rising mortgage credit relative to income,* m/Y*.*

When ω is large, most intangible value is not investable, so excess savings are not fully absorbed by higher share prices. In this case, η is able to explain the signs of all major trends documented in Section 2.

That house prices rise when interest rates fall is immediate from Eq. (8), given land is in fixed supply. Steady state share prices can be written as

$$\frac{f}{Y} = (1-\omega)\frac{\alpha\eta}{r}. \tag{10}$$

Firm equity value increases in η via a direct effect of an increase in intangible value captured in share prices, and indirectly by lower interest rates.

In combination with falling labor wages, the effect is a rising demand for mortgage credit, which can be accommodated by rising net savings. The steady state value of a positive mortgage demand is:

$$\frac{m}{Y} = (1-\phi)\frac{p}{Y}\bar{L} - (1-\alpha)(1-\eta). \tag{11}$$

Clearly, with $\frac{p}{Y}$ rising, higher η results in more mortgage credit.

To summarize, as long as output growth is positive but not too strong, and ω is sufficiently large, K/Y and r indeed both fall in response to rising η. The key analytical result is that under these conditions, a rising η can predict the direction of all major trends described in Section 2.

A structural shift in the relative productivity of intangible versus physical assets also suggests an interpretation for a recent shift in the distribution of capital income, analoguous to the effect of automation driving a rising skill premium and even a decline in absolute labor wages. Changes in the capital income share are here due to a reduced need to fund tangible assets by capital market investors, combined with a rising value creation and capture by innovating entrepreneurs and firms. As a result, outside investors receive a declining share of aggregate capital income. In a steady state equilibrium, the return on intangible capital captured by innovators (scaled by GDP) can be written as

$$\frac{\omega H R_H}{Y} = \omega\alpha\eta,$$

This value clearly rises as η increases, driven by the uncontractible nature of intangible capital. This result mirrors evidence in Eisfeldt et al. (2019) and Smith et al. (2019) that suggest that part of the measured rise in capital incomes is actually compensation for innovative high-skill human capital.

In conclusion, a technological shift leading to falling productivity of capital assets that can be funded externally offers a consistent and parsimonious interpretation for the combination of falling interest rates and physical investment.

4.1. Alternative Growth Drivers

In our general formulation of production with four factors, a rise in η is a parsimonious explanation consistent with the cited economic trends in developed countries since 1980. Clearly, many other factors have shaped the growth process since 1980. We discuss here how other growth drivers proposed in the literature contribute to some of the observed trends, but cannot individually account for the full set.

Growth factors in our setup may be generically classified as changes in factor supply (e.g., increased global labor supply, more educated workers, greater ease of innovation, a rise in life expectancy and capital flows) and factor productivity (rise in educational level, tangible and/or intangible capital productivity). Our framing is less appropriate to discuss the role of increasing market concentration, so we discuss this contributing factor separately. Similarly, a rising globalization of physical production in emerging markets.

We anticipate here an intuitive result in our setting, derived by considering the steady-state value of the real interest rate as the balance between funding supply and demand (see

Appendix B for the general CES case):

$$1 + r = \alpha(1 - \eta)\frac{Y}{K} \tag{12}$$

This condition indicates that a structural shift consistent with falling interest rates requires a rising ratio $\frac{K}{Y}$, unless η rises or α falls. A falling income share going to capital α is not supported by the data, which suggest it has increased (e.g. Dorn et al., 2017).[10] Thus, in this setting, a rising η survives as the only candidate that may individually drive a combined drop in both K/Y and r.[11]

Intuitively, the general insight is that, for both the price and quantity of external finance to drop, firm demand needs to fall. An alternative may be rising financial constraints on the firm side. However, evidence points to weak investment funding demand (Justiniano et al., 2019; Döttling et al., 2020).

Greater ease of innovation Steady IT progress may lead to an improvement in the rate of innovation, reducing its cost. This would lead to an expansion in the supply of intangible capital and thus its use (Corrado et al., 2009). Such a shift is consistent with evidence on the falling cost of (productivity-adjusted) physical capital equipment, reflecting a greater IT content. In our setup this driver may be seen as a fall in β. By itself, greater ease to create intangibles cannot account for the rise in innovator rents, so it still requires a rise in their absolute productivity. This form of progress may be seen as weakly redistributive, and would imply that physical factors benefit indirectly through their complementarity. A rise in the supply of intangible capital directly implies benefits for complementary factors such as skilled

[10] Note that most empirical estimates for α cannot easily separate income by skilled workers versus innovators.

[11] In Döttling and Perotti (2019) we offer a rough quantitative matching of observed trends by a rising η over 1980-2015, while showing that no other growth driver alone can match even the signs of these trends.

labor, and a greater income share accruing to innovators. In equilibrium it would also induce some growth in K/Y, thus increasing funding needs by firms. This contradicts the trends on CAPX and external financing documented in Figure 3.

Savings glut A savings glut may arise as a result of significant capital inflows from emerging markets into developed countries. Safety-seeking inflows certainly have contributed to the rise of housing prices and mortgage credit in the US, just as in Europe (Spain, Ireland, Netherlands) large housing booms resulted from foreign funding flows.

A simple treatment of capital inflows in our model would have foreigners invest some amount in domestic financial claims. As foreigners do not gain utility from housing, they would only invest in financial assets including mortgage credit. The effect of greater saving supply would be a decline in interest rates and an asset price boost.

Aggregate savings may also rise because of demographic changes such as rising population or longevity (Eggertsson et al., 2018), though the effect should be reversed in time (Goodhart and Pradhan, 2017).

Thus, savings-boosting factors reducing interest rates certainly contributed to recent economic evolution. However, they cannot account for the combination of falling price and volume of investment financing.

Falling labor share Dorn et al. (2017) highlight a historical rise in the capital share since the 1970s. This may be described by a rising technological importance of capital α.

By construction, a value shift to capital does not explain the evolution of its composition. It would boost total investment and funding needs by firms, as well as lower savings from young workers. Accordingly, an increase in α would result in higher interest rates, inconsistent with the data.

Our approach seeks a neoclassical benchmark on how productivity can explain observed shift in income distribution, so it abstracts from political considerations driving wealth inequality (such as advanced by Piketty (2014)).

Increasing education The share of university-educated workers has risen steadily in recent decades, perhaps an endogenous response to rising skill premia. This process can be described by an exogenous increase of ϕ, the fraction of skilled labor.

Such an increase in the supply of skilled labor directly enhances the supply of intangible capital, as well as savings supply. Similarly to capital inflows and demographic change, this driver would push down interest rates but also stimulate firm investment in physical capital due to complementarity.

Rising innovator share Modern IT technology is less firm-specific than past technological platforms, which were often fully proprietary. Its rise has arguably enhanced the ability of innovators to transfer useful knowledge across firms (Saxenian, 1994), and indeed many innovative firms were spawn from entrepreneuers leaving established firms. An increased bargaining power for innovators over corporations may be described as a rise in ω.

This shift clearly boosts incentive to produce intangible capital. However, a boost to their supply would reduce pure innovative rents while inducing more investment in complementary physical capital, in contrast to the evidence.

Rising concentration Our setup with a representative firm cannot model changes in the level of competition, which may introduce dynamic inefficiency (Eggertsson et al., 2018). Rising concentration since 2000, especially in the US, is consistent with a rising profit share and equity valuations (Gutiérrez and Philippon, 2017), though its effect on interest rates, credit allocation and skilled wages is not obvious. Aghion et al. (2019) shows how technological change may enables greater scale and scope, concentrating capital rents for innovators.

Globalization Trade globalization is a first-order factor in recent economic evolution. Technological diffusion has supported massive relocation of tangible investment to emerging economies, where it boosted labor income. In our closed economy setup, a combination of technology progress in advanced economies and knowledge spillovers to emerging countries is an alternative interpretation of a progressive rise in η in the efficient production frontier of advanced economies.

4.2. Key Assumptions

Our results are driven by the characteristics of human capital in intangible creation, as well as on specific plausible assumptions whose accuracy is an important empirical issue. We discuss them in relation to the existing literature.

Factor displacing technology Our redistributive growth conjecture is related to the labor literature on the effect of technological change (e.g. Katz and Murphy, 1992; Autor et al., 1998, 2003). The leading explanation is that automation directly substitute labor (Acemoglu and Autor, 2011). A milder formulation where only intangible productivity rises can account for a rising skill premium but not for the observed fall in absolute labor wages. Our generalized redistributive shift explains a rise in the innovator share relative to passive investors' returns and the change in capital composition.

In his assessment of secular stagnation, Eichengreen (2015) favors technological explanations over a structural decline in demand (see also Karabarbounis and Neiman, 2013;

Sajedi and Thwaites, 2016), pointing to a steady fall in the relative (productivity-adjusted) price of investment goods to explain reduced funding needs. This trend is consistent with a view of more productive technology incorporated in physical equipment, which reduces its productivity-adjusted cost and encourages physical labor substitution.

Inelastic savings An imbalance of savings over investment funding needs may arise in our setup as retirement savings are inelastic to interest rates, a well documented phenomenon (Blinder and Deaton, 1985; Matthew Canzoneri and Diba, 2007). All results would survive under positive but weak elasticity. The key contribution to the rise in excess savings is due to the inability by innovators to sell forward their future income, because of the inalienability of human capital.

Direct micro evidence for our interpretation is offered by Dell'Ariccia et al. (2018), who show that as US firms shift toward intangible investment, their local banks expand real estate lending. Krishnamurthy and Vissing-Jorgensen (2015) and Mian et al. (2017) show that credit supply shocks boost leveraged asset purchases rather than productive investment.

Inelastic supply A reasonable standard assumption is a limited elasticity of durable non-productive assets such as housing. While higher land prices may lead to more dense housing, population growth and urban congestion have countervailing effects.

While the model assumes a fixed supply of skilled labor, it is easy to endogenize a response driven by educational choices. Its effect would be to dampen the effect of a technological shift on intangible value, but not alter its effects. On the other hand, it is possible to interpret a reduced productivity of physical labor in developed countries in part as the result of a vast increase in world labor supply that depressed comparative advantage of domestic labor, compounding the direct effect of automation substituting physical tasks.

Our most critical assumption is an inelastic supply of innovation, which enables the creation of quasi rents during a technological transition. Innovative intangible capital cannot be scaled up easily, so technology enables innovators to earn rising rewards. This effect requires that innovator rents are not easily competed away, else there would be no rise in excess savings.

Inalienable human capital In our framing intangible capital is created by a subset of innovative high-skill workers, who contribute to reduced investable assets because they are not able to sell ex ante a claim on the return to their human capital. The inability of innovators to borrow against their future income is a common assumption in labor economics as it reflects moral hazard as well as the inherent fredom of workers to change jobs (Hart and Moore, 1994; Eisfeldt and Papanikolaou, 2013).

Presumably because of the underlying commitment problem, human capital receives the bulk of its reward in deferred form via IPOs and share grants (Oyer and Schaefer, 2005; Eisfeldt et al., 2019) and progressive career advancement (Pendergast, 1999), just as academic human capital investment is rewarded by doctoral degree and delayed tenure.

Firms also co-invest in intangible assets such as patents, R&D and organizational capital (Eisfeldt and Papanikolaou, 2013; Döttling et al., 2020). Firms capture some intangible value in their equity value, but the human capital share appears large and able to affect stock returns (Eisfeldt and Papanikolaou, 2014).

Kogan et al. (2020) show how increasing value capture by innovators increases non hedgeable risk for outside shareholders, and may depress share prices. Döttling et al. (2020) shows how the optimal financing and compensation of intangible investment may require innovating firms to become net lenders so as to minimize risk for unvested claims, thus adding to the savings glut.

Rising inequality Our approach models income polarization as driven by productivity, a variation of the original interpretation by Pareto (1897) or the assortative matching view by Kremer (1993). Evidence on a rising profit share may be explained by higher intangible capital productivity (Barkai, 2016), or rising concentration due to technological change and weak antitrust rules (Gutirrez and Philippon, 2017; Aghion et al., 2019), though the evidence is less clear outside the US (Döttling et al., 2017). By itself, a rise in traditionally defined capital share excluding human capital cannot replicate the observed trends, as it would imply a rise in complementary capital investment and thus credit demand.

Our focus is on a rising inequality within the capital share. The setup predicts a falling capital share for passive investors, both because of reduced productivity of investable assets and a falling interest rate. There is abundant evidence of a rise in the income share of innovators (Koh et al., 2016). Smith et al. (2019) show most of the recent rise of top incomes is due to business income for active owner-managers in skill-intensive sectors. A higher profit share in part reflects rising market power for leaders (Gutiérrez and Philippon, 2017; Aghion et al., 2019) and highly disruptive entrants (Garlenau and Panageas, 2017).

Finally, our analysis helps also interpreting a contemporaneous rise in real estate share in total wealth (Rognlie, 2015). A proper model to capture the dynamic of wealth distribution requires modelling a bequest motive. Wealth inequality is even more skewed than income (Piketty, 2014), perhaps reinforced by intergeneration accumulation (Becker and Tomes, 1979).[12]

[12]See Benhabib and Bisin (2017) for a thoughtful review.

5. Policy Discussion and Conclusions

We offer a neoclassical view of redistributive growth, driven by a form of technological change that not just boosts the relative productivity of skilled labor and intangible factors over physical factors, but actually substitutes them. The result is a redistributive shift in factor productivity and capital shares that matches a similar shift documented in the labor share (Acemoglu and Autor, 2011).

Our approach can offer a parsimonious explanation for major long-term trends in developed countries in the last decades. The broader challenge is to contribute to explain a persistent excess of savings over productive investment in a phase of falling interest rates, often defined as "secular stagnation".

A rise in relative factor productivity for intangibles in developed economies certainly reflects a growing specialization in intangible-intensive industries, while some physical production is relocated to emerging markets.

The analytical results suggest that a rising return to intangible capital may produce positive growth that cannot compensate for declining productivity of physical factors. As a result, firms reduce physical investment and leverage despite their falling cost. The resulting savings surplus is stored in increasing house and share prices, while more credit flows to mortgage credit to meet a rising demand.

A natural question is whether a growing volume of mortgage credit and rising household leverage may compromise financial stability (Jordà et al., 2015). Such a redistributive growth path produces a rising ratio of house prices to unskilled labor income, and will cause more frequent defaults even with a time-invariant house price risk.

A policy limiting loan-to-value ratios would reduce house prices (as they are in fixed supply), household leverage and mortgage defaults. This intervention also reduces interests rates, thus redirecting savings to physical investment by indirectly subsidizing its cost. An LTV limit thus benefits most those for whom the borrowing constraint becomes binding (unskilled labor), by restricting their ability to bid up house prices as well as by higher wages driven by the subsidy to physical investment.

As the economy is dynamically efficient, mortgage defaults produce ex-post transfers with no aggregate welfare loss. The general equilibrium effects of a LTV policy are smaller intra-generational transfers due to capital losses by the old generation on their house sale.

These considerations mirror Deaton and Laroque (2001), who show how introducing land in an OLG growth model absorbs savings, so that there is generally an under-accumulation of capital. It also relates to empirical evidence in Chakraborty et al. (2018), who find that the housing boom in the 2000s crowded out real investment. Our model highlights that such effects may be stronger in a knowledge economy where technology leads to an excess of savings over investment.

Finally, our long-term approach offers a clear interpretation of major trends in labor, capital and asset markets in terms of technological change and the changing role of human capital. Its empirical relevance should be its consistence with a large set of long term trends. Ultimately, a redistributive growth interpretation needs to be validated by more granular empirical work on its specific channels. Closely related evidence is offered by Dell'Ariccia et al. (2018), who show that as U.S. firms increase their share of intangibles, their creditor banks shift to more real estate funding.

Overall, this paper offers some novel insight on the evolution of income distribution in a knowledge economy, suggesting a complex evolution for skilled and unskilled wages as well as capital returns for innovators and savers. Future research may clarify the precise distinction between skilled labor operating intangible assets and innovators creating new ones. More generally, extrapolating the model insight raises concerns, as it would suggest a tendential rise in income and capital concentration along with further redistributive effects. Such an evolution may prove so controversial as to challenge an open globalized economy.

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Appendix A Strongly Redistributive Growth

This appendix elicits that as long as rising η results in positive but not too extreme growth, then it can produce all trends $\mathcal{T} = \left\{r\downarrow, \frac{K}{Y}\downarrow, \frac{m}{Y}\uparrow, \frac{p}{Y}\uparrow, \frac{f}{Y}\uparrow, \frac{q}{w}\uparrow\right\}$. As a first step we collect the relevant equations and evaluate them in steady state. The steady-state equilibrium for the variables r, R_H, K, H, f, p and Y is defined by the following set of equations, together with the production function (1):

$$1 + r = \alpha(1-\eta)\frac{Y}{K} \tag{A.1}$$

$$R_H = \alpha\eta\frac{Y}{H} \tag{A.2}$$

$$H = \frac{\omega}{\psi}R_H \tag{A.3}$$

$$f = \frac{(1-\omega)R_H H}{r} \tag{A.4}$$

$$p = \frac{v'(\bar{L})}{r} \tag{A.5}$$

$$(1-\alpha)Y = p\bar{L} + f + K \tag{A.6}$$

As a first step, Lemma 1 shows under what conditions K/Y falls in response to η.

Proof of Lemma 1 Combine (A.6) with (A.1), (A.2), (A.4) and (A.5), to write the market clearing condition in terms of K/Y, η and Y:

$$(1-\alpha) = \frac{K}{Y} + \frac{v'(\bar{L})\bar{L}\frac{K}{Y}}{Y(\alpha(1-\eta) - \frac{K}{Y})} + \frac{(1-\omega)\alpha\eta\frac{K}{Y}}{\alpha(1-\eta) - \frac{K}{Y}} \tag{A.7}$$

The left-hand side is a constant and let the right-hand side be a function denoted $g(\frac{K}{Y}, \eta, Y)$. Note that $g(.)$ increases in K/Y and η, and decreases in Y.

Now consider how an exogenous increase in η affects equilibrium K/Y. If Y was unaffected by changes in η, since $g(.)$ increases in both K/Y and η, an increase in η would need to result in a fall of K/Y, for Eq. (A.7) to still be satisfied. The counter-veiling force is that Y increases in η, shifting down $g(.)$. But as long as Y does not grow too strongly, K/Y must still fall. I.e., K/Y must fall as long as $\frac{dY}{d\eta}$ does not exceed a threshold implicitly defined by the condition

$$\frac{\partial g(.)}{\partial Y}\frac{dY}{d\eta} \leq \frac{\partial g(.)}{\partial \eta}.$$

□

Next, Proposition 1 shows that rising η additionally results in falling interest rates, as long as output growth is positive.

Proof of Proposition 1 First, from the market clearing condition (A.6), falling $\frac{K}{Y}$ implies rising $\frac{p\bar{L}}{Y} + \frac{f}{Y}$:

$$(1-\alpha) = \frac{p\bar{L}}{Y} + \frac{f}{Y} + \frac{K}{Y}.$$

Intuitively, with K/Y falling, housing and share prices have to increase to absorb excess savings. The ratios $\frac{p}{Y}$ and $\frac{f}{Y}$ are given by

$$\frac{f}{Y} = \frac{(1-\omega)\alpha\eta}{r}, \tag{A.8}$$

$$\frac{p}{Y} = \frac{v'(\bar{L})}{rY}. \tag{A.9}$$

First note that share prices always increase in response to η. To see this, suppose f/Y falls. By Eq. (A.8), this can only be the result of a strong increase in interest rates, i.e., $dr/d\eta > 0$. However, by Eq. (A.9), this would imply falling p/Y, since $dY/d\eta \geq 0$. With both p/Y and f/Y falling, the sum $\frac{p}{Y} + \frac{f}{Y}$ would fall, contradicting market clearing. Thus, share prices must increase. Intuitively, share prices capture some of the value created by the shift to intangibles.

If share prices increase by a lot, it is still theoretically possible that p/Y falls while the sum $\frac{p}{Y} + \frac{f}{Y}$ increases. However, as long as ω is sufficiently large, innovators capture a large part of intangible asset income, so share prices cannot absorb too much value and house prices must increase. This is easiest to see for the limiting case $\omega \to 1$. In this case, $\frac{f}{Y} \to 0$, so house prices must rise to absorb excess savings.

Next, observe that an increase in $\frac{p}{Y}$ implies a drop in rY. As long as $dY/d\eta \geq 0$, it therefore follows that $dr/d\eta \leq 0$. From Eq. (11), it is clear that with $\frac{p}{Y}$ and η rising, it must also be that mortgage credit $\frac{m}{Y}$ rises.

Finally, wage inequality depends on η and the relative supply of skilled and unskilled workers, and increases in response to η:

$$\frac{q}{w} = \frac{\eta}{1-\eta}\left(\frac{\tilde{l}(1-\phi)}{\tilde{h}\phi}\right)$$

This completes the proof for all trends in the set $\mathcal{T}$. □

Appendix B General CES Case

In the more general CES case (not restricted to Cobb-Douglas), the steady-state interest rate (A.1) can be expressed as

$$1 + r = \alpha(1-\eta)\frac{Y^{1-\rho}}{K^{1-\alpha\rho}} l^{(1-\alpha)\rho} \tag{B.1}$$

Relative to the Cobb-Douglas case, the interest rate still depends on $\frac{K}{Y}$, though not linearly. The new parameters that show up are ρ and l. A decrease in l could also explain simultaneously falling $\frac{K}{Y}$ and r. However, this would also lower output, while on average US real GDP has grown by more than 2% a year since the 1980s. The effect of ρ on the secular trends is ambiguous, but changing complementarity between intangible and tangible capital seems an unlikely major driver behind the secular trends. The conclusion that η emerges as the only factor that can by itself explain a simultaneous fall of K/Y and r is thus robust to the general CES case.