Secular Trends and Technological Progress

Robin Döttling[1] and Enrico Perotti [*2]

[1]University of Amsterdam and Tinbergen Institute
[2]University of Amsterdam, CEPR and Tinbergen Institute

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Abstract

Technological progress enhancing the productivity of skills and intangible capital can account for long term financial trends since 1980. As creating intangibles requires commitment of human capital rather than physical investment, firms need less external finance. As intangible capital become more productive, innovators gain a rising income share. The general equilibrium effect is a falling credit demand, consistent with falling trends in both tangible investment and interest rates. Another effect is a boost to asset valuation and rising credit demand to fund house purchases. The combination of rising house prices and increasing inequality raises household leverage and default risk.

While demographics, capital flows and trade also contribute to a savings glut and changes in factor productivity, only a strong technological shift towards intangibles can account for all major trends, including income polarization and a reallocation of credit from productive to asset financing.

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

JEL classifications. D33, E22, G32, J24

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1. Introduction

This paper proposes a growth model describing the general equilibrium impact of technological change on long term financial trends such as interest rates, asset prices and the allocation of credit. It suggests that the transition to a knowledge-based economy and the associated shift from physical to intangible capital is a primary cause for the rising excess savings over productive investment in advanced economies, presented in the "secular stagnation" hypothesis (Summers, 2014; Eichengreen, 2015). Falling interest rates and rising long term asset values can be interpreted as a direct consequence of this gradual process. Critically, the approach also allows to interpret the growing share of income gained by innovators, the progressive reallocation of credit from productive to asset financing uses (primarily for housing) and the rise in household leverage.

Information technology is widely recognized as a main cause for the rising productivity of high-skill workers, leading to a steady increase in wage inequality and skill premia (e.g. see Autor et al., 1998, 2003). On the capital front it has led to an increasing ratio of intangible to tangible investment (Corrado and Hulten, 2010a), as figure 1 documents.

Our focus is to understand the consequences of this transition. A key economic insight is that intangible capital is mostly the result of human capital investment which, unlike tangible capital, cannot be purchased by firms.[1] The transition to intangible investment thus requires less external funding, as compensation to motivate and retain creative employees takes place over time as output is realized. Indeed, the evidence is that firms that invest more in intangibles have lower or even negative net leverage. This shift is often explained by poor pledgeability of intangible assets (Bates et al., 2009; Falato et al., 2013).

This paper suggests that a declining corporate demand appears a more likely explanation than tighter financial constraints. More generally, it proposes that technological progress underlying the evolution of corporate assets offers an interpretation for major financial and economic trends since 1980, such as secular stagnation, credit reallocation and rising asset

[1] Hart and Moore (1994) offer the classic analysis on the inalienability of human capital.

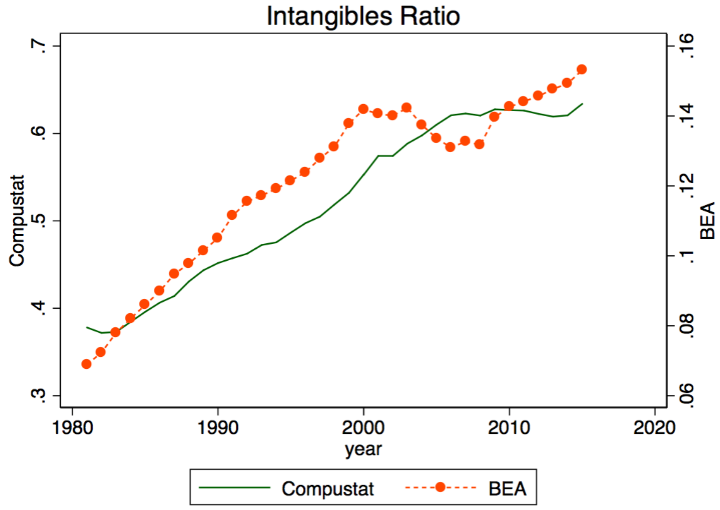

Figure 1: Evolution of the intangible capital ratio since 1980.

The intangibles ratio is defined as the ratio of intangible capital to total capital. The Compustat ratio is computed using the measure of intangible capital of Peters and Taylor (2017). In the BEA data the intangibles ratio is defined as intellectual property products (IPP) over total fixed assets in the NIPA tables.

valuations.

We consider an overlapping generation (OLG) growth model with several productive factors. In its general formulation of production, physical capital is complementary with manual labor while intangible capital is complementary with high-skill labor. As physical capital is fully pledgeable, firms can scale up investment to the point where its marginal productivity equals the cost of borrowing. In contrast, intangible capital is developed by innovative employees, who capture part of its returns. The OLG setup describes life-cycle savings behavior, where land serves as both durable consumption good and as a store of value. Young households save by investing in financial claims and housing, and consume when old.

Our benchmark view of technological change is a steady increase in the relative productivity of intangible capital and skilled labor. Over time intangibles become more productive, so intangible investment rises relative to phsyical investment. This has two effects. Firms expand

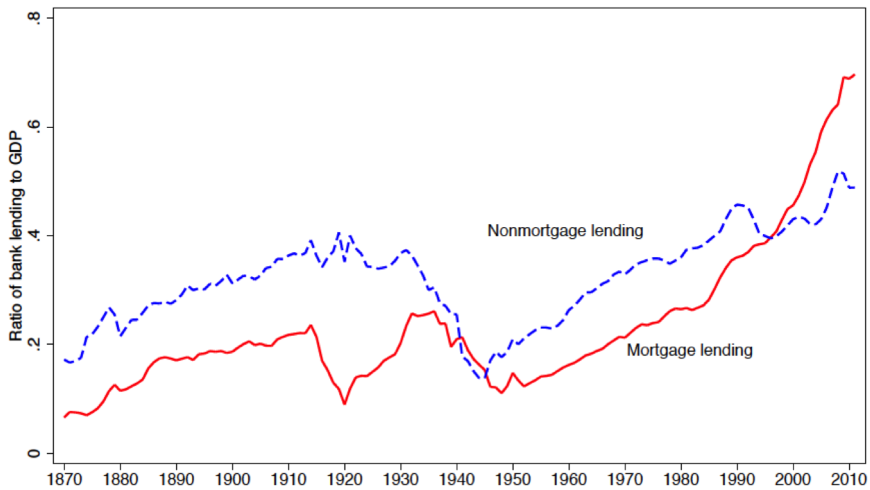

Figure 2: Mortgage and commercial credit in OECD countries (Jordà et al., 2016)

their share of intangible assets by engaging skilled human capital while reducing their external funding. To ensure commitment and retention of skilled human capital, firms comepnsate it by deferred compensation, paid when output is produced (Hart and Moore, 1994; Oyer and Schaefer, 2005; Döttling et al., 2017). As a result of employee coinvestment and delayed compensation, firms need less investment funding. A second effect of the technological shift is that a growing capital share is assigned to innovators. While some intangible value is appropriated by firms and thus incorporated in equity prices, overall the shift reduces the supply of available saving instruments. The general equilibrium consequence is a progressive decline in real interest rates, a trend in place since the early 1980s that persisted throughout the credit boom.

Finally, the growth in savings in excess of productive demand is redirected to fund tangible assets such as real estate or mortgages secured by houses. As land is in fixed supply, this trend boosts house prices (Knoll et al., 2017).

A major productivity shift that implies a rising wage inequality also leads to rising household leverage as the mortgage debt to income ratio rises for unskilled workers. A combined impact of technology on capital and labor markets thus boosts both demand and supply of mortgage credit. In combination with falling demand from firms, this process explains a

declining stock of productive credit relative to mortgage credit across all OECD countries (Jordà et al., 2016, see figure 2).

We compare this hypothesis with alternative views of the growth process consistent with secular stagnation and other historical trends. Other formulations of technological change include a rise in capital productivity, an increasing rate of innovation, more productive intangibles and a higher level of education. Commonly listed non-technological drivers include trade, capital flows and demographics.

Under the general production function in model, only a strongly redistributive process of factor productivity growth since 1980 is analytically consistent with labor and financial trends. Critically, growth over this period has been associated with both falling interest rates and a drop in tangible investment, as well as in corporate net borrowing. Lower rates imply cheaper funding and should boost investment. To account for both a drop in the price and quantity of corporate investment and funding does require a structural decline in firm demand. More precisely, a fall in the ratio of physical investment to GDP in a period of economic growth suggests a major drop in its absolute productivity at the productive frontier (Acemoglu and Autor, 2011).[2]

A savings glut is in part the result of growing capital flows from emerging markets as well as demographic change. However, neither could be the primary growth driver, as none is consistent with the drop in investment, the evolution in corporate capital structure and relative wages. An increase in education level or the cost of creating intangible capital can account for a rise in the absolute productivity and supply of intangible investment, but cannot explain falling funding demand by firms in a period of falling interest rates.

To validate our interpretation of the growth process, we offer a simple quantitative exercise using US data since 1980. The model's long term framing is clearly not suitable for a calibration with high frequency data, so our goal is to match the direction and scale of all major economic trends.

[2] As we focus on production in OECD countries, this shift also reflects some relocation of production to lower income countries.

We calibrate the starting point of the model as an initial steady state in 1980. We next derive the implied evolution of individual growth drivers by matching the observed growth of the intangible-tangible ratio and overall output over the following 35 years. Finally, we evaluate the implied evolution of the main economic variables under each alternative driver. Our postulated shift in relative capital productivity appears not only analytically consistent with the observed trends, but also the best predictor for their historical evolution in the model calibration.

A redistributive productivity trend implied by matching the evolution of intangibles and output growth can generate all observed trends, and replicates well the fall in interest rates and borrowing by firms. Once information on foreign capital inflows and rising levels of education is incorporated, it also matches well the evolution of mortgage credit, while land and stock prices are broadly consistent though higher than in the actual series. Overall, the trends generated from our simple model fit the data surprisingly well.

It is clearly quite hard to validate empirically such a broad framework. As a simple empirical measurement of the direct effect implied by the model, we present cross-country evidence of a significant correlation between adoption of technological progress and the growth of mortgage credit in OECD countries. While these simple regression results offer some comfort, they do not imply causal identification for which more careful work is needed.

One of the theoretical implication worth highlighting is a steady rise in mortgage leverage for lower income households, the result of concomitant trends in capital and labor markets. As a result, even a constant house valuation risk produces a rising mortgage default rate. As in a neoclassical setup without financial constraints the economy is dynamically efficient, there is no case for a policy intervention. Tight loan-to-value (LTV) limits for mortgage loans would have a major impact on house prices, while redirecting savings to production by subsidizing physical investment. While resulting in higher labor wages and growth, this policy induces a large intergenerational transfer so would not be Pareto-improving. Tighter restrictions on mortgage credit may only be justified in the presence of a strong externality associated with financial stability.

While the model formulation for production is quite general, our results require some reasonable assumptions. We assume a low elasticity of savings to real interest rates and an inelastic supply of housing. While higher prices may lead to more dense housing, population growth and urban congestion have countervailing effects.[3] Less essential is the assumption of an exogenous supply of skilled labor. Endogenizing education dampens the effect on relative wages and inequality, as our calibration shows, but implies quite different trends in skill premia and credit allocation.

Most critical for our result is a limited supply elasticity of intangibles, which ensures that innovator rewards rise over time. If all returns to innovation could be competed away there would be no rise in excess savings. While this seems a plausible assumption, whether the rate of innovation can be ramped up is a critical question in the debate on long term growth (Gordon, 2012). Ultimately, any redistributive effect in a growth model results from different supply and demand elasticities, an important empirical issue.

The rest of the paper is organized as follows. Section 2 discusses related literature, and section 3 describes the model and its equilibrium. Section 4 discusses the secular trends we seek to explain, and lists different potential drivers behind them. Subsequently, section 5 derives analytically our main result that among parsimonious drivers only a strongly redistributive form of technological progress towards new technologies is consistent with all major trends. Section 6 follows with a quantification exercise, and offers further empirical evidence in line with our results. Finally, section 7 introduces mortgage default risk and studies policy responses, and section 8 concludes.

2. Related literature

The paper describes how changes in factor productivity affect the allocation of income within both the labor and capital income share, offering a neoclassical benchmark for rising inequality

[3] The Economist magazine (2015) stressed how technological progress favored urban locations, where real estate prices climb under strict zoning rules.

(though it is not set up to describe changes in wealth distribution (Piketty, 2014)). It suggests a key role of a rising income share of innovators (Smith et al., 2017; Koh et al., 2016), is consistent with a rising profit share (Barkai, 2016) and an increasing wealth share for real estate (Rognlie, 2015). The model suggests the growing productivity of intangible capital is also a key driver for a rising savings surplus. The creation of intangible capital is largely driven by human capital investment. Unlike physical capital, human capital cannot be purchased (Hart and Moore, 1994). As it needs to be rewarded over time, firms can delay and thus self finance its compensation. Research on employee compensation recognizes that short term contracts cannot reward complex tasks. A leading survey states "..the most common means of rewarding white-collar workers for effort is by promotion" (Pendergast, 1999). Skilled human capital receives direct and indirect claims on future profits via career advancement, share and option grants. While in reality firms partially co-invest in intangible assets, a close examination reveals that most R&D and organizational capital expenditures reflect skilled labor compensation (Corrado and Hulten, 2010a). Even corporate brand equity may be quite vulnerable to the departure of key employees (Rajan and Zingales, 2001).

The rise of intangible capital has also been related to the falling net leverage and increasing cash hoardings (Falato et al., 2013). Empirical evidence suggests that firms with significant intangibles maintain more internal resources to avoid becoming constrained, in the process contributing to the savings glut (Döttling et al., 2017). Our approach adds to the traditional view that intangibles need to be internally financed because by their nature cannot be pledged to investors, suggesting that the critical contractual issue is not verifiability allowed by tangibility, but appropriability.

A fact consistent with a falling corporate demand for external finance is that the nonfinancial corporate sector in most developed countries (with the exception fo France and Italy) has progressively become a net lender (Gruber, 2015). This has led to concerns that new technology may results in tighter financial constraints for firms Falato et al. (2013), Giglio and Severo (2012) and Caggese and Perez-Orive (2017). Yet recent evidence suggests that firms with more intangible capital do not appear ex ante constrained, as they have higher

free cash flow and do not pay out less to their shareholders (Döttling et al., 2017). This is consistent with a rising human capital co-investment by skilled employees. Gutiérrez and Philippon (2016) find no support for rising financial frictions and evidence of industry effects associated with globalization, competition and short termism. Alexander and Eberly (2016) and Döttling et al. (2017) also find that both in the US and Europe weak investment is associated with the growing role of intangible capital.

On aggregate, US listed firms have rising net equity ouflows, even since the crisis (Lazonick, 2015; Gruber, 2015). Thus overall the rise of intangible investment appears associated with lower funding needs (a lower credit demand) rather than more binding financial constraints (a tighter credit supply), a result consistent with record low borrowing rates.

A rising productivity of innovative human capital leads to an increasing income share for innovators, either as start up entrepreneurs or top employees with significant outside options (Oyer and Schaefer, 2005; Eisfeldt and Papanikolaou, 2014). As intangible value accrues directly to its creators, it does not need to be funded by intermediaries or capital markets. The net effect is a reduction in the supply of investables, and savings in excess of investment that investors can appropriate.

Recent work shows a significant effect on asset pricing of shocks to the allocation of intangible value between firms and employees (Eisfeldt and Papanikolaou, 2013) or across investors (Garlenau and Panageas, 2017). Eisfeldt and Papanikolaou (2013) develop the core idea that key talent appropriates a large fraction of intangible value, and show how technological shocks alter the outside option of key employees. Garlenau and Panageas (2017) study how disruptive entry of new firms create unhedgeable investment risk, boosting demand for safe assets and depressing interest rates, explaining a rising wealth share for innovators. Smith et al. (2017) show how private business income accounts for most of the rise of top incomes since 2000, especially active owner-managers of mid-market firms in skill-intensive and unconcentrated industries. The key role of the owner-innovators is revealed by profit declines after a premature death of the owner.

A related literature studies the effect of information technology on the relative productivity

of skilled labor to explain rising wage inequality since 1980 (e.g. see Katz and Murphy, 1992; Autor et al., 1998, 2003). The increasing gap is in part due to a reduction in absolute real wages for low educated workers in developed economies, a trend that cannot be explained by a simple rise in the absolute productivity of intangibles and skilled human capital. The assumption that skilled labor benefits most from new knowledge is consistent with Mankiw et al. (1995). Acemoglu and Autor (2011) and other authors interpret it as the outcome of automation of physical tasks. We show similarly that only strongly redistributive form of technological progress can replicate all observed trends, in particular falling quantity of price of corporate borrowing. Another likely cause is a spreading of technology to emerging countries, leading to relocation of physical production.

Our model seeks to understand the impact of technological progress on both labor and capital in general equilibrium. A general CES production function allows to compare how different growth factors can account for the main trends, in particular the rise of excess savings over productive investment. In his assessment of secular stagnation, Eichengreen (2015) finds a fall in the relative price of investment goods a more explanation than a drop in investment opportunities (see also Karabarbounis and Neiman, 2013; Sajedi and Thwaites, 2016). Our setup can accommodate this interpretation, as redistributive progress leads to a fall in the productivity-adjusted cost of physical equipment.[4] Our empirical validation has focused on showing how a redistributive technological shift represents the best parsimonious explanation for the combination of observed economic trends. The model thus offers a technological explanation for the rise in house prices, mortgage credit and default rates, reflecting falling interest rates and household leverage as the general equilibrium effect of capital and labor market trends.[5] The rise in mortgage lending, household debt and default in the US has been interpreted by country-specific factors, such as populist pressure (Rajan, 2010) or large capital

[4]This implies less demand for and a lower cost of physical equipment, so that the total productivity-adjusted cost of each unit of capital falls.

[5]As asset bubbles may well occur in equilibrium in an overlapping generation framework, the model is consistent with speculative fluctuations around the trend.

inflows. Yet the share of mortgage to total credit has risen rapidly in all OECD countries Jordà et al. (2016), and we show that its rise is related to the national adoption of intangible investment. Dell'Ariccia et al. (2017) show how as firms increase intangibles, their creditor banks shifts to more real estate funding.

3. Model Setup

This section describes the baseline model environment, solves the individual agents optimization problems, and describes the equilibrium.

Time Overlapping generations live for two periods. Time starts at $t = 0$ and goes on to infinity. There is an initial generation $t = -1$.

Goods There are two consumption goods, corn and land.[6] 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 and L_t are land holdings at the end of period t.[7] The function $v(L)$ with $v'(L) > 0$, $v''(L) < 0$ captures the utility households achieve from living in their house. 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. We assume that high-skill labor is relatively scarce, ensuring that high-skill workers have a higher income than low-skill workers.

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

[7] This formulation of household preferences ensures that long-term interest rates are not pinned down by the household's discount factor (via an Euler equation), but instead by the relative supply of savings vehicles versus household savings.

Assumption 1.

$$\frac{\phi}{(1-\phi)} < \frac{\eta}{1-\eta}$$

The initial old generation is endowed with all the land $\bar{L}$.

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 $F(K_t, H_t, l_t, h_t)$ thus equals

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

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

The evolution of production over time may be due to different growth drivers. The main technological factors are A, η and α. Demographic and trade factors may also change labor or savings supply. Intangible supply depends also on innovative effort, as described below.

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).

Intangible Capital In general, the creation of intangible capital requires co-investment by the firm and its creative employees. We assume here for simplicity that all intangible value is generated by the commitment of skilled human capital. This allows us to highlight a key characteristic of innovation, namely that its reliance on high-skill human capital implies that a large part of the return to intangible capital is appropriated by innovators rather than

investors.[8]

A fraction ε of high-skill households have innovative talent. They can exert effort at a quadratic cost $C(I_{H,t}) = \frac{\beta}{2} I_{H,t}^2$ when young to create intangible capital next period. Here β reflects the ease of innovating, and as it evolves over time it may be a major growth driver. Note that the assumption implies a lower supply elasticity of innovation, while physical capital is easily scalable. As a result, new intangible capital may earn some rents.

A second critical feature of intangibles concerns their financing. The general view is that they are hard to fund externally, as their value cannot be easily pledged. Our insight is that intangibles do not require much external financing even when their future value is both observable and verifiable. As the commitment of human capital cannot be contracted ex ante because of the inalienability of human capital (Hart and Moore, 1994), most intangibles cannot be purchased by firms. We assume innovators can leave at the end of the period with a fraction ω of intangible assets, and sell them next period to other firms for its full value. This credible threat makes it impossible for investors to capture the value of intangibles unless innovators are retained inside the firm.

In order to ensure retention, the firm must offer innovators deferred compensation that vests once production is realized at $t + 1$. This has two effects. First, innovators capture a significant fraction of intangible value, with firms receiving a share $(1 - \omega)$. Second, firms do not become constrained even though some assets cannot be pledged, as they can self finance the cost of human capital by delayed compensation.

Financial Contracts As in the basic setup there is no risk, equity and debt are equivalent. For illustration we refer to external financing as borrowing when backed by land or by physical capital. We refer to external equity as claims backed by the fraction $1-\omega$ of intangible capital that firms can appropriate, and so in principle may be assigned to investors. Households can thus invest in 1 unit of shares, which pays all profits as dividends. In equilibrium, net profits

[8] In (Döttling et al., 2017) firms also co-invest in intangibles, and need to rely more on internal financing to avoid becoming financially constrained.

equal the appropriable revenues from intangible capital creation. Our results do not depend on this interpretation of the firm's capital structure. While consistent with the corporate finance literature, it is not a direct outcome of the model. It may arise endogenously in a model with a tax advantage for debt, in which firm income from intangible capital is a poor source of debt collateral.

3.1. Households

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 a possible price appreciation. As they only consume at $t+1$, they save all other income for retirement. Next to housing, households can buy shares S_t, which pay a dividend and can be sold to subsequent generations. They also invest a net amount of D_t in capital markets, which is either directed at corporate or mortgage debt. 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 ($y_{t+1}^i = 0$), innovators receive capital income from the intangible capital they created, $y_{t+1}^i > 0$.

The maximization problem of a household is:

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

The first two constraints are budget conditions for young and old respectively, while the third rules out negative consumption. As the budget constraints are binding, households choose their housing demand by the first order condition w.r.t. L_t,

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

The price of housing reflects the discounted potential house price appreciation plus its utility value. The relevant discount rate is either the mortgage interest (for a borrower) or the opportunity cost of investing (for a lender), which in a competitive equilibrium is equal to r_{t+1}.

Note that housing demand is independent of income, as mortgages enable all households to consume the same amount of housing.[9] So the role of mortgage credit is to allocate land efficiently, equalizing the marginal utility of housing across agents with heterogeneous income.

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

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

Investments in debt instruments follow 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 an income high enough to buy their house and invest the remainder in shares and corporate debt. In contrast, those with $y_t^i < p_t L_t + f_t S_t$ need to borrow.

We focus on equilibria in which all households can afford to buy shares out of their income and only borrow against their house, implying $y_t^i > f_t S_t$. In this setup households with $D_t^i < 0$ take out a mortgage loan provided by surplus households. In the absence of risk, the intermediation process is not explicitly modelled.

3.2. Physical Capital and Labor

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

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

As investment in physical capital is financed by debt, credit demand is always equal to K_t. Firm equity will also have positive value, since dividends can be written as

$$d_t = F(K_t, H_t, l_t, h_t) - w_t l_t - q_t h_t - (1 + r_t) K_t - \omega R_t H_t.$$

Here $\omega R_t H_t$ denotes the return to intangible capital appropriated by innovators, where R_t is determined below. Under perfect competition, workers and suppliers of funding for physical

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

capital are compensated according to their marginal productivity, $w_t = F_{l,t}$ and $q_t = F_{h,t}$. Since physical capital is fully eligible as collateral, firms are financially unconstrained and can always scale up tangible investment until:

$$1 + r_t = F_{K,t}. \tag{5}$$

3.3. Creation of Intangibles

A fraction of high-skill employees can exert effort to produce intangible capital for the next period. Competitive firms are willing to pay $R_t = F_{H,t}$ per unit of intangible capital, reflecting its productive value. Since the productive use of intangible capital requires the commitment of creative human capital, innovators have a credible threat that enables them to capture some value created.[10] Firms need to match this outside option by adequate deferred compensation equal to $\omega R_t H_t$. That is, innovators capture a fraction ω of the return to the intangibles they created.

Exerting effort innovators incur the cost $C(I_{H,t}) = \frac{\beta}{2} I_{H,t}$. They will scale up investment in intangibles until

$$\omega R_t = \beta I_{H,t-1}. \tag{6}$$

As a result of a sharply increasing cost of innovation, new intangible capital earns positive rents, unlike physical capital. Firms appropriate a fraction $1 - \omega$ of intangible value, which (conditional on successful retention) are verifiable and can be promised to investors. Since production function has constant returns to scale, dividends are given by

$$d_t = (1 - \omega) R_t H_t.$$

Note that the firm is never financially constrained over intangible investment, since it can self-finance its formation by deferred equity to innovators that vest once intangible capital produce output.

[10] In an alternative formulation, innovators create start up firms and sell intangible capital to other firms.

3.4. Equilibrium

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

Total net savings by households equal labor income earned by the young generation minus their house purchases $w_t\tilde{l} + q_t\tilde{h} - p_t\bar{L}$. Net savings are invested in corporate debt $D_t = K_{t+1}$ and equities f_t. Using that $w_t\tilde{l}+q_t\tilde{h} = (1-\alpha)Y_t$, financial market clearing can thus be written as

$$(1 - \alpha)Y_t = p_t\bar{L} + f_t + D_t, \tag{7}$$

where the LHS is the savings supply (labor income saved for retirement) while the RHS are all assets that can carry savings over time, namely housing, corporate debt backed by physical capital investment, and equity backed by the return on intangibles captured by firms.

3.5. Steady State

Our goal is to study the long-term impact of different drivers behind the growth process in our model. To that end, it is useful to briefly consider how the relative importance of intangible capital affects the steady state allocation in our model.

From financial market clearing (7) it is clear that households save a constant fraction $(1-\alpha)$ of income. Our main focus is how these savings are allocated to the three savings vehicles in our model. In steady state, share prices and house prices can be written as

$$f = \frac{(1-\omega)RH}{r}, \tag{8}$$

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

Both these long-term assets increase in value as interest rates fall. The value of intangibles is another determinant of share prices.

As the relative role of intangible capital in the economy grows, firms demand relatively less external finance in the form of corporate debt, which is backed by physical capital. Some of the excess savings are absorbed by share prices, which rise in value as the return on intangibles

increases. However, as investors only appropriate a fraction $(1-\omega)$ of the return to intangibles, innovators receive a rising share of total income. As an increasing share of the capital stock is not investable, excess savings push down interest rates and boost land prices.

4. Secular trends

We now analyze alternative formulations of the growth process to assess what factors can best explain the evolution of economic trends since the 1980s. After identifying the main trends, we analyze analytically and quantitatively individual growth factors. Our main focus is on technological progress, but we also consider globalization and social trends such as demographics and rising education levels.

While some factors can account for some subset of trends, we find that only a strongly redistributive form of technological progress can drive the combination of overall growth, falling investment and interest rates. This set of core results in turn can produce all other trends. After showing this result analytically, we evaluate empirically this interpretation by a quantification exercise.

4.1. Major secular trends

This section lists major economic trends over the past 35 years, that a broadly specified growth model should be able to explain.

Falling real interest rates Real rates have gradually fallen across advanced economies since the early 1980s (King and Low, 2014). For the U.S. we compute the real interest rate as the 10 year treasury yield minus inflation.[11] From a peak above 8% in the early 1980s, US real rates have steadily been declining, to a level around 0% in recent years.

[11] Both series are downloaded from FRED.

Rising intangible relative to tangible investment Corporate investment in intangible assets has risen while physical investment has declined (Corrado and Hulten, 2010b).[12]

We compute the ratio of intangible to total capital for the US economy aggregating firm-level data from Compustat, combined with the measure of intangible capital of Peters and Taylor (2017).[13] We also compute the intangibles ratio from national accounts using data from the BEA's NIPA tables.

Figure 1 in the introduction plots the estimated intangible ratio from these two sources. The Compustat intangibles ratio is on a higher level, since the approach by Peters and Taylor (2017) capitalizes more spending flows than the BEA. For example, the BEA measure does not capitalize any SG&A spending that contributes to a firm's organizational structure. Importantly for us, there is a clear upward trend in both series, highlighting the growing role of intangible capital across data sources. In our model, this trend is represented by a growing value of H relative to K.

Decreasing corporate net borrowing US corporations have been reducing their net borrowing and repurchasing more shares than they issued. The left panel of figure 3 replicates the drop in corporate net leverage of Compustat firms in Bates et al. (2009), next to own calculations showing how the decrease is concentrated among firms with the most intangible assets.[14] Among others, Lazonick (2015) shows how U.S. firms experienced net equity

[12]Intangible capital is here defined as the capitalization of expert human capital invested in corporate knowledge, organizational capability, computerized information and internal software.

[13]This approach capitalizes R&D and some SG&A expenses, as they represent investments in knowledge capital, organizational structure, and brand equity. We then define the aggregate intangible ratio as the ratio of aggregate intangible capital relative to aggregate total (physical plus intangible) capital. Physical capital is defined as property plant and equipment (PPENT). Computing this metric, we restrict the sample to firms with non-missing and at least \$1m in total assets. We also exclude financial firms (SIC codes 6000 - 6999) and utilities (SIC codes 4900 - 4999).

[14]The figure plots average total debt (DLTT + DLC) net of cash holdings (CHE) scaled by assets (AT) for Compustat firms. HINT firms are in the highest tercile of the intangibles ratio distribution in a given year, while LINT are in the lowest tercile.

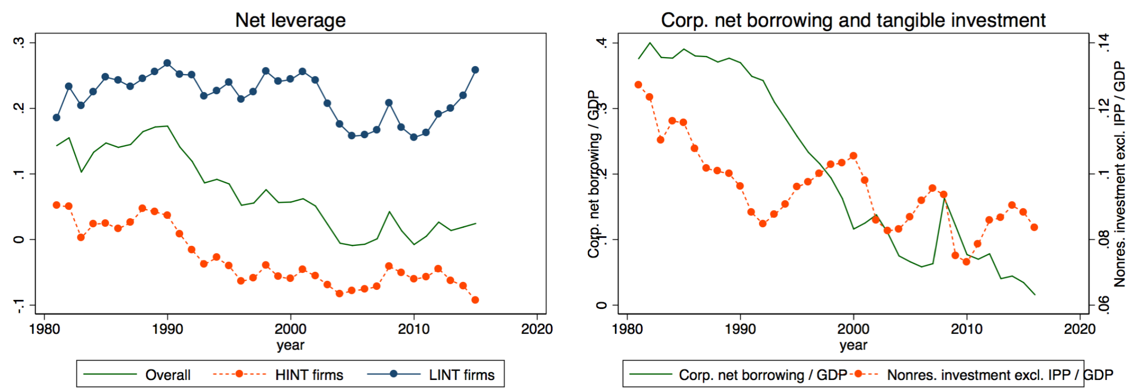

Figure 3: Net leverage and borrowing by non-financial corporations

outflows since 1980, even after the recent crisis.

This overall decrease in external financing by corporations is further confirmed by data on net borrowing of US non-financial businesses from the Flow of Funds, scaled by nominal GDP.[15] This series is plotted in the right panel of figure 3, and displays an even sharper downward trend. This is puzzling as a fall in real rates reduces the marginal cost of tangible investment and borrowing.

Note that consistently with the corporate finance literature, we interpret external financing for tangible investment K as debt. For comparison, the right panel of figure 3 also plots BEA data on non-residential, non-IPP investment relative to GDP, which can also represent K/Y in our model. Both series exhibit an overall downward trend. Therefore, technological progress should be able to account for a falling $\frac{K}{Y}$ in our model.

Mortgage credit growth In contrast to falling corporate credit, mortgage credit has shown a steady rise relative to GDP, as figure 4 shows using data from the Flow of Funds.[16] While

[15]This series is defined as total liabilities minus total financial assets.

[16]The left panel plots aggregate home mortgage credit by households. This series is derived from the Flow of Funds and defined as the total amount of home mortgage debt outstanding by households and nonprofit organizations, divided by nominal GDP. The right panel plots land values computed by (Davis and Heathcote, 2007), divided by nominal GDP. The red dashed line plots the trend components with an HP filter with smoothing parameter 1600.

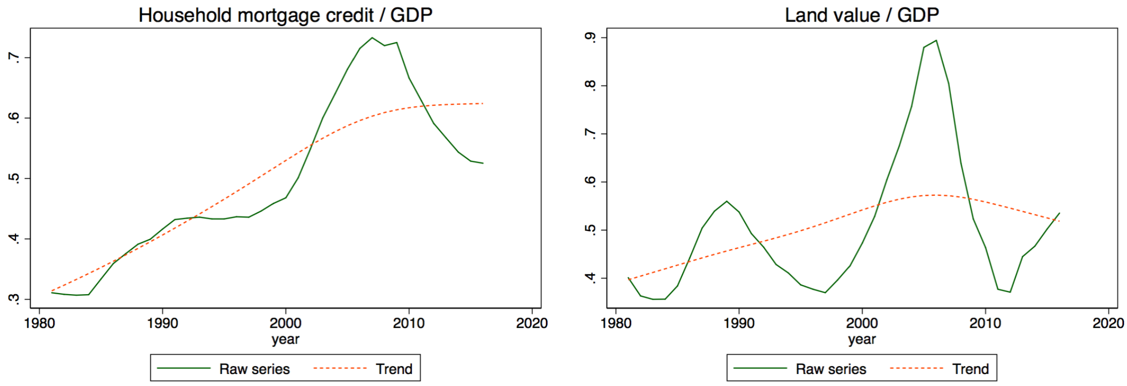

Figure 4: Mortgage credit and land values to GDP

the real estate credit bubble of the 2000s played a role, the figure shows a clear secular growth.

Several authors have pointed to US specific factors for the real estate credit boom, yet Jordà et al. (2016) show how all advanced economies experienced strong mortgage credit growth relative to corporate credit, a shift correlated to the rise of intangible capital (Dell'Ariccia et al., 2017). Such a global trend suggests a generalized reallocation of credit correlated with a common long term growth factor. In our model this trends is represented by growth of $\frac{m}{Y}$.

Rise of land values Knoll et al. (2017) show that real house prices across advanced economies were largely stable from 1870 until the mid 20th century when they started rising strongly. This growth appears largely driven by rising valuations of land, a natural resource in fixed supply.

The right panel of figure 4 shows the aggregate value of US land scaled by GDP, estimated by subtracting from house prices the cost of structures (Davis and Heathcote, 2007). While the bubble in the 2000s is even more visible here, there is an overall upward trend. The value of scarce land in desirable locations has probably risen much more than average. This trend is represented by growth of $\frac{p}{Y}$ in our model.

Stock market capitalization World Bank data shows US stock market capitalization over GDP rising from 50% in 1980 to levels between 100% and 150% since the 2000s. Give the

evidence on large net equity outflows, this suggests a significant revaluation effect driven by lower rates and rising profits. In the model this value is measured by $\frac{f}{Y}$, the value of outstanding shares relative to income.

Rising wage inequality Survey data from the US Bureau of Labor Statistics show a sharp increase in relative earnings of workers with at least a Bachelor degree since 1980. This skill premium trend has been interpreted as the result of skill-biased technological change complementary with high cognitive skills that replaces low skill functions (Acemoglu and Autor, 2011). It is represented by an increase in $\frac{q}{w}$ in the context of our model.

This list defines a set of trends that we seek to explain in the context of our model, $\mathcal{T} = \left\{ r \downarrow, \frac{H}{H+K} \uparrow, \frac{K}{Y} \downarrow, \frac{m}{Y} \uparrow, \frac{p}{Y} \uparrow, \frac{f}{Y} \uparrow, \frac{q}{w} \downarrow \right\}$.

4.2. Key growth drivers

What parsimonious description of the growth progress can at best reproduce these secular trends? Our general production function suggests some technological explanations. A uniform growth effect driven by a rising common productivity factor A as in the classic Solow model benefits all factors of production indiscriminatingly, and is inconsistent with the growing role of intangible capital and high-skill workers.

Accordingly, we focus on intangible-biased growth drivers, and only adjust the common technological progress component A in our quantitative exercise to match the overall level of growth.

- An IT-induced reduction in the cost of producing intangible capital (a fall in β) is a natural growth driver. It boosts the supply of intangible capital relative to physical investment, and leads to higher rewards for complementary factors such as skilled labor. A higher intangible capital creation also implies more total income accruing to innovators. This form of progress is weakly redistributive, as it benefits indirectly also physical factors through their complementarity.

- A more redistributive shift would interpret technological progress as a strong rise in the productivity of intangible capital and skilled labor relative to physical capital and labor at the technological frontier. Such a rise in η leads to aggregate income growth provided there is sufficient skilled labor supply. In this formulation, the absolute productivity of some factors in the optimal productive combination (1) may actually fall over time, consistent with the notion that new technologies replace physical labor at the technological frontier (Acemoglu and Autor, 2011).[17]

Given the evidence on a growing role of intangible capital, our focus is on technological growth drivers. However, economic trends certainly reflect multiple causes, and we also consider other relevant factors. We list here the drivers that we can directly study in our model:

- The share of university educated workers has risen steadily in recent decades. More skilled labor may explain a growing supply of intangible capital. This process is described by an exogenous increase of ϕ, the fraction of skilled labor.

- Piketty (2014) highlights a historical fall in the labor share since the 1970s. This is a redistributive factor that may explain some observed changes in the income distribution. In our model it can be the results of a rising technological importance of capital α in our model.

- A rising ω would reflect an increased bargaining power for innovators over corporations. This factor may boost intangible capital and reduce the investment opportunities available to the public.

- A savings glut with significant capital inflows from abroad may have contributed to the rise of housing prices and mortgage credit in the US. To study capital inflows in our model, suppose foreigners invest a fraction x_t of GDP in domestic financial claims. As they live abroad, foreigners do not gain utility from housing, so holding land directly

[17] As we discuss later, this effect is reinforced by globalization of production as the result of knowledge spillovers.

yields only the price appreciation. Thus, foreigners only invest in financial assets. Given capital inflows x_t the market clearing condition becomes

$$(1 - \alpha + x_t)Y_t = p_t\bar{L} + K_{t+1} + f_t. \tag{10}$$

This list defines a set of growth drivers that have a direct representation in our model, $\mathcal{G} = \{\eta, \beta, \phi, \alpha, \omega, x\}$, that may potentially explain the secular trends $\mathcal{T}$.

Other drivers that have been highlighted in the literature can also be interpreted in the context of our model. Demographic changes such as aging have a similar effect on savings supply. In a model with a richer live-cycle structure, a gradual increase in longevity would lead to a rise in savings. In a reduced form, we can capture this effect as an exogenous increase in savings x, in a similar way as foreign capital inflows.

Globalization is most certainly a first order factor in recent economic evolution. Its redistributive effect represents, next to technological change, a second cause for a shift of factor productivity at the technological frontier in developed countries. Relocation of tangible investment contributes an additional channel for a fall in real labor wages next to automation of manual tasks. Ideally, one would want to study this driver in an explicit multi-country setup. In a reduced form, a combination of technology progress in advanced economies and knowledge spillovers to emerging countries is consistent with a progressive rise in η, if we interpret our production function as that of advanced economies.

Similarly, the falling price of capital goods can be seen in the light of the growing role of intangibles, as these require less physical investment by corporations.

Lastly, as our model does not have a role for competition, it cannot address the effect of rising concentration since the 2000s. This is likely another important driver (Gutiérrez and Philippon, 2016) that we cannot study however.

5. Analytical comparison of growth drivers

This section studies analytically how the growth drivers $\mathcal{G}$ listed above predict the evolution of secular trends $\mathcal{T}$ in the context of our model. Our approach is to study the effect of individual

drivers on the economy's long-run allocation. This comparative static exercise assumes an initial steady state around 1980, and a final steady state around 2015. Section 6 complements this approach by calibrating the model and calculating the combined effect of different factors across steady states. At this point we also simulate the perfect-foresight path between the two long-run allocations.

5.1. Analytical results

For our analytical results we restrict attention to the Cobb-Douglas case (the limiting case once $\rho \to 0$, see appendix A for the general CES case). We start with a simple observation:

Observation. *To individually explain all secular trends $\mathcal{T}$ simultaneously, any growth driver must be able to explain falling corporate borrowing and physical investment $\frac{D}{Y} = \frac{K}{Y}$, along with falling interest rates r.*

This observation conveys a simple intuition. Any driver behind the observed trends must explain a simultaneous drop in the quantity and price of external finance.

Falling corporate net borrowing and interest rates are directly manifested in the data. Moreover, in the model the financial market clearing condition (7) shows clearly that a rising $\frac{K}{Y}$ requires either $\frac{p}{Y}$ or $\frac{f}{Y}$ to be decreasing, directly contradicting their observed trend.

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

This observation mirrors the insight in the labor literature that rising wage inequality coupled with an increase in high-skill employment must be the result of growing demand for skilled workers (e.g. Autor et al., 1998).

After this useful insight we can state our main result:

Theorem. *Among all growth drivers in the set $\mathcal{G}$, only a strongly redistributional form of technological progress (defined as an increase of η) can produce simultaneously all the observed trends $\mathcal{T}$.*

To see this result, consider the steady-state value of the real interest rate:

$$r = \alpha(1-\eta)\frac{Y}{K}, \tag{11}$$

As observed above, both $\frac{K}{Y}$ and r need to drop to explain all secular trends. In (11) the interest rate is equal to the marginal product of physical capital. The key insight of proposition 5.1 is that by (11), falling interest rates can only be the result of 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 rather suggest it has increased (e.g. Dorn et al., 2017). Hence, rising η survives as the only candidate that may individually drive all secular trends.

All other growth drivers in the model can be consistent with falling $\frac{K}{Y}$ only if interest rates increase. Moreover, with falling $\frac{p}{Y}$, also mortgage credit to GDP rises unless η falls. To see this, restate the steady state value of $\frac{m}{Y}$ in the case of positive mortgage credit demand as

$$\frac{m}{Y} = (1-\phi)\frac{p}{Y}\bar{L} - (1-\alpha)(1-\eta). \tag{12}$$

Clearly, with falling $\frac{p}{Y}$, a rising share of mortgage credit requires a rising η and/or a rising α, but the second case is not consistent with falling interest rates.

In conclusion, the analytical results rule out all candidates for the key growth factor except a rising η, through the effect of an evolving investment composition on capital markets.

Intuitively, physical capital can always be scaled up to the point where its marginal productivity equals the cost of external finance. Hence, the combination of falling rates and borrowing, i.e. a fall both in price and quantity of credit, requires a declining demand for external finance from within firms.

5.2. Strongly redistributive technological progress

Under what conditions can a rising η indeed generate all observed trends? While it is not possible to pin down precise conditions in terms of the model's parameters, we show in the appendix that rising η generates all secular trends if parameters are chosen such that

(i) η results in positive, but not too strong output growth, and

(ii) ω is sufficiently large.

While a rising η implies directly a decreasing relative productivity of K, by general complementarity all factors benefit from overall output growth. Provided the effect of η on growth is not too strong the direct effect dominates, resulting in a falling equilibrium ratio of $\frac{K}{Y}$.

When rising η results in falling $\frac{K}{Y}$, firms demand less external financing, and excess savings are absorbed by land and share prices. As long as ω is not too large, most of the returns to innovation are captured by human capital, and hence do not constitute a savings vehicle for the general public. As a result, the growth in stock prices is limited and land values rise to absorb some of the slack savings.[18]

To summarize, strongly redistributive technological progress shifts firm investment to intangible capital, inducing a fall in their external financing needs. As long as overall growth is not too strong, firms decrease their leverage despite falling interest rates. It also results in increasing house and share prices, a rising ratio of mortgage to productive credit and more wage inequality.

6. Calibration and Empirical Validation

We now run a quantitative exercise on our model to see how well different drivers can explain the observed trends in U.S. data. To that end, we calibrate our economy to 1980 and change individual drivers to match the evolution of the intangible-tangible ratio over time. We then compare the evolution of unmatched endogenous variables to the data, to see how well individual drivers explain those trends.

While our model is not suited for a full-blown quantitative assessment of different drivers, this exercise still allows us to get a sense of the magnitude of the effects. It also allows us to elaborate in more detail why drivers other than η fail.

While a redistributive technological shift η emerges as the best growth driver able to explain individually the evolution of investment, economic trends certainly reflect multiple causes.

[18] If ω were small most intangible value is reflected in shares, absorbing savings.

Accordingly, we also use our calibration to assess the joint effect of multiple drivers. While capital inflows and rising education levels can help explain the magnitude of trends, a shift towards intangibles still emerges as a necessary driver to explain why corporations borrow less in the light of low interest rates.

6.1. Calibration to 1980

Throughout we use the functional form $v(L) = \ln(L)$, and need to calibrate parameters $\alpha, \bar{L}, A, \phi, \rho, \eta, \beta, \tilde{h}$ and $\tilde{l}$. Some parameters can be directly drawn from actual data. For ϕ we use the percent of the population with a Bachelor degree or higher in 1980, reported to be 17% in the census data. We set $\alpha = 0.33$, a standard value in the literature in line with the share of income going to capital. To calibrate ρ we use the elasticity of substitution between high-skill and low-skill workers. In the SBTC literature this elasticity is measured to be between 1.4 and 2 (Acemoglu and Autor, 2011), so we set ρ to get an elasticity at the center of this range at 1.7. In line with the discussion in section 5.2, we set ω to a high value such that human capital appropriates most of the returns to intangibles, $\omega = 0.95$. We normalize $\bar{L} = 1$ and set $A = 1$.

This leaves us with the free parameters η, β, $\tilde{h}$ and $\tilde{l}$.[19] We set these parameters to match data moments around 1980. All of these parameters impact the relative usage of physical vs intangible capital, as well as mortgage credit and house prices. Accordingly, we jointly set these parameters to target the aggregate intangibles ratio from Compustat (shown in figure 1), represented by $\frac{H}{H+K} = 0.38$ in the model. We also target mortgage credit over GDP, $\frac{m}{Y} = 0.28$, and land values over GDP to $\frac{p}{Y} = 0.43$.

As in the model these moments cannot be expressed in closed form we pick a parameter combination that minimizes the sum of squared distances between model and data moments, with a higher weight the intangibles ratio (since this is our main variable of interest). The resulting parameter values are $\eta = 0.845$ and,$\beta = 3.105$. The values of labor hours are $\tilde{l} = 19.211$, corresponding to an aggregate number of $l = 15.945$, and $\tilde{h} = 143.75$, implying

[19] Note that only the ratio $\beta = \tilde{\beta}/\varepsilon$ is identified, not the individual parameters.

$h = 24.438$. The model succeeds in matching the intangible ratio quite precisely (0.377 vs 0.376 in the data), and delivers a realistic level of land values over GDP (0.399 vs 0.432) and mortgage credit over GDP (0.311 vs 0.280).

Under this calibration, the level of $\frac{K}{Y}$ is equal to 0.173, which lies between the mean net leverage of Compustat firms (0.193), and the level of nonresidential investment excl. IPP over GDP from the BEA (0.121). Other non-matched endogenous variables such as the level of interest rates and stock market capitalization are not as close to their actual levels. Our focus is to evaluate how well the model predicts their relative change in observed trends.

6.2. Individual Drivers and Why They Fail

Given the calibration to 1980, our approach is to gradually change individual growth drivers over time, and see how well they can replicate the observed trends. In a first experiment, we adopt the parsimonious approach from our analytical results and change each technological growth driver individually. The goal is to match the evolution of the intangibles ratio over time. Other trends are not targeted, and we simply compare how well the model-implied trends match those observed in the data.

The results of this exercise are reported in table 1. The top panel reports the relative change of the different moments of interest between 1980 and 2015. The lower panel compares the trends in the data to those implied by the model, under different individual drivers.

The first row confirms that strongly redistributive growth η generates the right sign for all trends (red numbers indicate that the model-implied change differs from that observed in the data). A falling cost of producing intangibles β also results in a growing intangibles ratio and falling interest rates (second row). However, by general complementarity physical factors benefit too, such that the drop in interest rates is accompanied by an increase in K/Y. As $\frac{K}{Y}$ grows and more funding flows to businesses, both mortgage credit and land values drop relative to GDP, contradicting the trends observed in the data.

A rising income share of capital α can also replicate the observed increase in intangibles (third column). However, it is the result of falling savings supply from young workers. Ac-

Data

	Intangible Ratio	Real rate	Net borrowing / GDP	Mortgages / GDP	Land price / GDP	Stock market cap / GDP
Δ 1980 - 2015	65.82%	-72.27%	-86.20%	86.23%	37.12%	201.11%

Model

	H/(H+K)	r	K/Y	m/Y	p/Y	f/Y
$\eta\uparrow$	65.21%	-17.84%	-61.67%	51.98%	19.71%	36.30%
$\beta\downarrow$	65.24%	-31.11%	29.05%	-18.38%	-16.43%	47.98%
$\alpha\uparrow$	65.13%	113.52%	-39.88%	-8.31%	-14.42%	-30.73%
$\omega\downarrow$	24.23%	92.22%	-50.20%	-49.52%	-37.40%	515.80%
$x\uparrow$	-28.82%	-34.59%	61.96%	64.22%	48.61%	51.29%
$\phi\uparrow$	-20.07%	-25.00%	16.41%	-28.61%	-10.29%	36.29%

Table 1: Relative changes across steady states implied by individual growth drivers.

cordingly, an increase in α results in higher interest rates, contradicting the data.

Adjusting the income share going to innovators ω we are unable to match the observed increase in the intangibles ratio. In fact, intangibles only rise if we *decrease* ω, and even then we manage to generate a growth of at most 24% (by letting ω drop to 0.41). This may seem a bit unintuitive, since innovators should exert more effort as they capture a larger fraction of the returns going to intangibles. The reason that falling ω generates an increase in the intangibles ratio is that it boosts share prices, absorbing savings that would otherwise fund physical investment.

Our remaining drivers are capital inflows from abroad x and rising education levels ϕ. Since we can directly observe how these two evolve in the data, we follow a slightly different approach. Rather than trying to adjust them so as to fit the rise in intangibles, we change these two drivers according to their directly observed evolution in the data.

From 1980 to the mid-1990s the US current account was relatively balanced, while large foreign inflows start in the end of the 1990s. In line with the data, we let x grow from 0 to

Data

	Intangible Ratio	Real GDP	Real rate	Net borrowing / GDP	Mortgages / GDP	Land price / GDP	Market cap / GDP
Δ 1980 - 2015	65.82%	140.82%	-72.27%	-86.20%	86.23%	37.12%	201.11%

Model

	H/(H+K)	Y	r	K/Y	m/Y	p/Y	f/Y
$\eta + A, \phi, x$	64.98%	140.78%	-75.04%	-74.52%	89.38%	66.42%	366.30%
$\beta + A, \phi, x$	65.14%	140.88%	-64.14%	107.33%	6.17%	15.78%	47.98%
$\alpha + A, \phi, x$	63.61%	-48.84%	31.28%	-14.55%	49.48%	48.90%	14.82%
$\omega + A, \phi, x$	51.90%	-40.12%	43.81%	-46.99%	5.87%	16.12%	727.73%

Table 2: Relative changes across steady states implied by combination of growth drivers.

0.35 in the final steady state. While a savings glut pushes down interest rates, by itself it cannot explain why foreign funding did not flow to corporations to fund physical investment.

Finally, we adjust the fraction of high-skill households from $\phi = 0.17$ in 1980, to $\phi = 0.3$ in 2015, in line with the evolution of the fraction of the U.S. population with a Bachelor degree or higher. Higher incomes increase the savings supply, which pushes down interest rates but also flows to firms and investment in physical capital.

6.3. The Combined Effect of Different Drivers

While a redistributive technological shift η emerges as the only growth driver able to explain on its own falling borrowing by corporations with falling interest rates, economic trends certainly reflect multiple causes. We now assess the effect of drivers that seem to be able to generate an increase in the intangibles ratio (η, β, α and ω), in combination with foreign capital inflows and education. That is, next to changing the individual driver, we adjust capital inflows x and education ϕ as observed in the data. Moreover, we adjust A so as to match the actual growth of output from 1980 to 2015.

Table 2 reports the results of this exercise. Strongly redistributive growth η and a falling cost of intangibles β do well at matching the observed growth in the intangible ratio and output. Adjusting ω and α we are not even able to generate an increase in output along rising intangibles.

Combining falling β with other drivers also helps get the sign of more of the trends right. However, K/Y still falls in the light of lower interest rates, as physical factors benefit by general complementarity. Hence, growing η still emerges as the driver best suited to generate the observed trends.

Comparing table 1 to table 2 shows that allowing for capital inflows and rising education levels bring the magnitude of the trends generated by rising η closer to their actual evolution in the data. As capital inflows push up house prices, they help in particular to produce higher land values and mortgage borrowing.

This is further illustrated in figure 5, which compares the model-generated trends to the data, by plotting the simulated perfect-foresight path between the 1980 and 2015 steady states.[20] The dashed line plots the endogenous evolution of the respective variables when we only change η over time, and match the evolution of the intangibles ratio.[21] The dashed-dotted line plots the time path when η is adjusted in combination with A, x and ϕ, and output growth is targeted.

Comparing the model-implied timepath to the data, a clear picture emerges. Rising η accounts well for the overall trend in the series, in particular when matching actual output growth and accounting for capital inflows and education. While the growth of intangible capital flattens in the late 1990s, foreign inflows help especially to boost the magnitude of the growth in mortgage credit and house prices since this period. Still, technological change is a necessary driver in the background, explaining why the foreign capital did not flow to corporations.

[20] When indicated, data series are normalized by their mean level across the years 1978-1983, and model series by their initial steady state.

[21] We let η grow faster until 2000, since the growth of intangibles flattens somewhat thereafter (see figure 1).

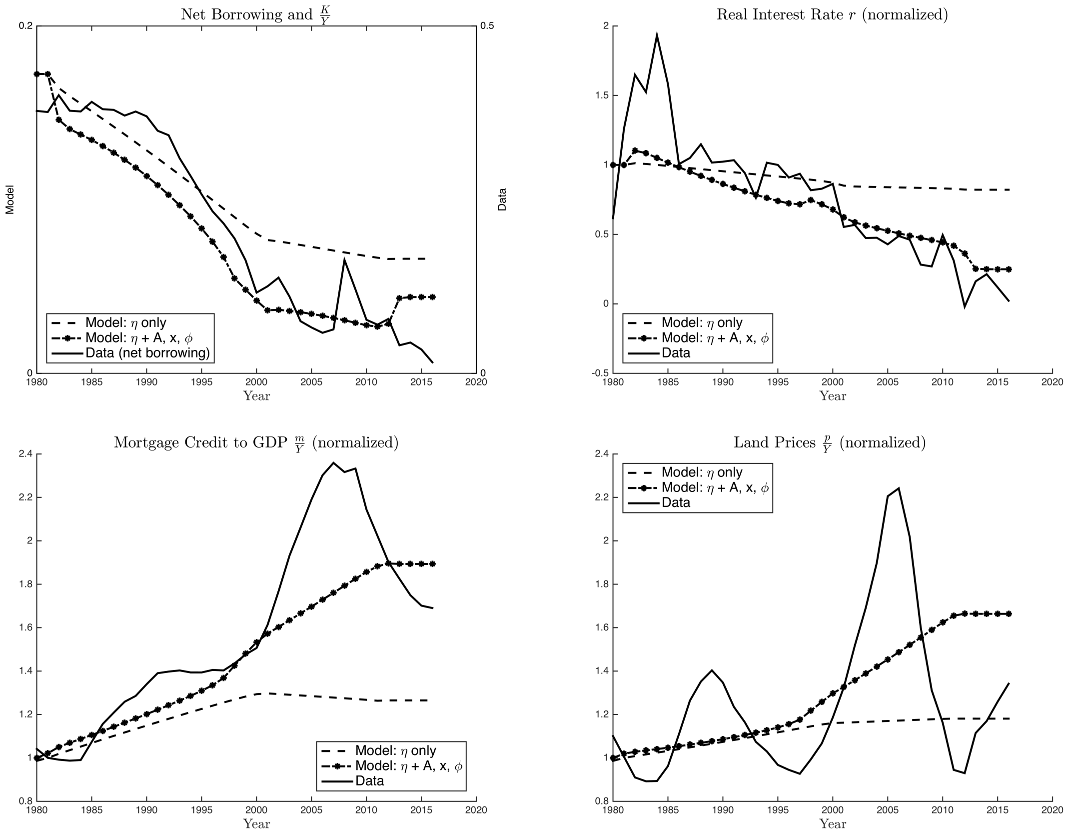

Figure 5: Simulated perfect-foresight time path compared to actual series.

Actual series are naturally more volatile since our long term approach cannot match oscillations around trends. This is particularly visible in the land price and mortgage credit series during the real estate bubble in the 2000s. Overall, given our simple model and given that we do not match any trends other than the intangibles ratio and output growth, the model-generated series are relatively close to the underlying trend in the data.

6.4. Cross-country evidence

According to the model, excess savings driven by intangible use by firms boost mortgage credit over GDP. We further examine this empirical relationship in a panel of OECD countries, seeking to explain the share of mortgage credit to total credit calculated by Jordà et al. (2016).

Table 3: Cross country evidence on mortgage credit and intangible investment

Mortgage Ratio is the ratio of mortgage to total credit. *Intangibles Ratio* is the ratio of intangibles to total assets. Reported t-statistics based on errors clustered at the firm level. ***, **, * indicate significance at 1%, 5%, and 10% level. All independent variables are lagged one year.

	(1)	(2)	(3)	(4)
	Mortgage Ratio	Mortgage Ratio	Mortgage Ratio	Mortgage Ratio
Intangibles Ratio (INTAN-Invest)	0.777***	0.706***		
	(5.00)	(4.05)		
Intangibles Ratio (Compustat)			0.299***	0.432***
			(3.29)	(3.34)
Log GDP per capita		0.00360		-0.870
		(0.04)		(-1.70)
Current Account		0.00175		0.00928
		(0.40)		(1.37)
Year Fixed Effects	No	Yes	No	Yes
Observations	263	263	264	264
Adjusted R^2	0.402	0.392	0.152	0.270

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

We use the intangible capital measures based on National Accounts, available through the INTAN-Invest project (see Corrado et al., 2012). As an alternative measure we use Compustat Global firm data, estimating intangibles by capitalizing R&D and SG&A expenditures as in Döttling et al. (2017) and Peters and Taylor (2016).[22]

Table 3 presents the results of fixed effect and pooled OLS regressions using the two intangible ratio measures, GDP per capita as a general control and capital inflows to include net

[22]For details see Döttling et al. (2017). Compustat Global data coverage is from 1989 to 2015, the INTAN-Invest series from 1995 to 2010. These measures are strongly correlated, with an average of 0.82.

external savings. Including time fixed effects maintains the significance of the results.

In all specifications, a higher intangibles ratio is significantly associated with more mortgage credit. Its impact is economically significant, as each percentage point increase in the intangibles ratio increases the ratio of mortgage to total credit by between 0.3 and 0.78 percentage points.

Overall, cross-country correlations are consistent with the conjecture that a rising usage of intangibles results in reduced corporate demand for credit and a re-allocation of funding to existing assets such as real estate. The results mirror the US evidence in Dell'Ariccia et al. (2017), that higher usage of intangible capital by firms induces banks to shift away from productive, towards mortgage lending.

7. Rising default rates and policy issues

A growing scale of mortgage credit may have consequences for financial stability (Jordà et al., 2015), as it increases the chance that the high debt burden will be unsustainable. As a consequence, policy debate has centered on how to control mortgage credit risk. To assess this issue we introduce some time-invariant uncertainty in house prices.

Our key result is that in a redistributive growth process, low-skill households need to increase their loan to income ratio to acquire housing. Over time, this endogenous rise in household leverage produces more frequent mortgage defaults, even with a constant risk factor.

Suppose that after yielding utility to their owner, but before it is sold to the next generation, agent i's house value receives a temporary shock ξ_t^i with zero mean that alters its value. In appendix D we solve the modified model, presenting a "weather shock" that may damage houses. In this interpretation houses hit by a negative shock require repairs and therefore trade at a discount, $p_t^i = p_t(1-\xi_t^i)$, defining a threshold

$$\hat{\xi}_t^i = 1 - \frac{p_{t-1}}{p_t} LTV_{t-1}^i$$

such that for realizations of $\xi_t^i > \hat{\xi}_t^i$ household i defaults on her mortgage. Here $LTV_{t-1}^i \equiv \frac{(1+r_t)(-D_{t-1}^i)}{p_{t-1}L_{t-1}^i}$ is defined as the loan-to-value (LTV) ratio of a home buyer.

As shown in the appendix, a stationary shock leaves the equilibrium allocation unchanged. As a result we immediately have the following corollary:

Corollary 1. *Define* $\chi_t \equiv 1 - G(\hat{\xi}_t^l)$ *as the aggregate default of low-skill workers. Technological progress that results in rising mortgage credit relative to GDP also produces increasing steady-state default among low-skill workers* ($\frac{d\chi}{d\eta} \geq 0$)

As technological progress increases income inequality and house prices, low-skill workers end up with higher LTV-ratios, lowering the threshold $\hat{\xi}^l$. Thus even for a given distribution of shocks, default occurs more frequently.

While rising mortgage default rates were a main cause for the 2008 financial crisis, in our current formulation any default is just an ex-post transfer with no aggregate welfare loss. As lenders are compensated by a higher interest rate, there is no inefficiency that needs to be addressed by a Pareto-improving policy intervention, since the economy is dynamically efficient. If however mortgage defaults caused a financial externality, e.g. through fire sales (Lorenzoni, 2008) or aggregate demand externalities (Korinek and Simsek, 2016), stronger policy intervention over time may be warranted, for example through tightening loan-to-value ratios.

Such a policy has interesting side effects for the long run allocation in our model. Restraining the borrowing of young home buyers restricts their ability to bid up the price of land, reducing house prices while pushing interest rates even lower. As the released savings are redirected towards physical investment, in general equilibrium both output and wages grow via the indirect subsidy to production. The trade off is that the old generation suffers a capital loss, and the stock of housing is allocated less efficiently. Interestingly, the policy benefits most those for whom the borrowing constraint becomes binding. Young low-skill workers gain through smaller transfers to older generations and a higher capital stock - a consequence of lower equilibrium land prices.[23]

This result mirrors Deaton and Laroque (2001), who show that introducing land in a base-

[23]We derive these results formally and they are available upon request.

line OLG growth model eliminates the "Golden Rule" steady state that maximizes long-run consumption. As land absorbs savings, there is generally an under-accumulation of productive capital. Our model highlights that this effect may be stronger in a knowledge economy where capital is becoming more intangible-intensive over time.

8. Conclusion

This paper offers a neoclassical growth model where technological change can account for the growing excess of savings over productive investment sometimes dubbed as "secular stagnation".

While skill-biased technological progress is known to explain the evolution of relative wages, our framework extends it to derive concomitant trends in credit allocation and asset prices. A boost to the productivity of intangible investment increases the value captured by innovators who invest their own human capital, resulting in a fall in corporate demand for finance. The savings glut progressively lowers interest rates, leading to repricing of long term assets such as houses and shares.

The model can endogenize popular explanations for a persistent period of low investment, such as a drop in investment opportunities and a fall in the relative price of investment goods. As Cochrane (1994) highlights, evolution in corporate investment may reflect other economic forces besides technological improvements. The model is able to incorporate also nontechnological factors, such as the effect of globalization on labor supply and the relocation of production. The savings surplus is certainly affected by savings supply shocks driven by demographic changes and capital outflows from emerging markets, although such nontechnological factors cannot explain all economic trends (Eichengreen, 2015). In particular, the contemporaneous drop in interest rates and tangible investment requires a drop in credit demand rather than a boost to credit supply.

Our redistributive growth model is aimed specifically at explaining the evidence on developed countries rather than describing a global production function. Thus the evolution

of relative factor productivity is reinforced by globalization, where advanced economies specialize in high intangible industries while some physical production is relocated to emerging markets. This shift in comparative advantage may reflect a gradual knowledge spillover that induces developed economies to specialize in innovative products to maintain growth. The process has redistributive effects on physical and skilled labor as well as on the allocation of intangible capital return between innovators and investors.

Critically, excess savings arise because savers cannot co-invest in the private development of intangible capital (Hart and Moore, 1994). Innovative entrepreneurs are nowadays largely self financed, as they need only modest upfront investment and can fund skilled human capital investment via deferred compensation and equity grants. Anecdotal evidence suggests that a large fraction of value created by innovative firms accrues to founders and employees, and these firms maintain a steady share dilution rate via equity grants to employees. The fall in investable and falling rates induces a shift to other long term investment such as housing. Rognlie (2015) confirms that surging house prices account for a rising fraction of the capital share of aggregate income.

In conclusion, our framing enables to assess what form of technological progress can best account for major secular trends. While in the classic Solow growth model (Solow, 1956) progress boosts equally all factors' productivity, IT has clearly favored some factors. Our evidence suggests that the trends cannot be explained simply by a rise in the productivity of intangibles. Only a highly redistributive reallocation of productivity can account for the observed trends, in particular with the combination of a steady fall in physical investment, falling interest rates and labor wages in a context of aggregate growth (Acemoglu and Autor, 2011).

Overall, more insight is needed on the evolution of capital in a knowledge economy. We have here highlighted the consequences of the special nature of intangible capital, where a large share of its return must be assigned to innovative human capital that creates it. On the other hand, while innovators may be richly rewarded, the knowledge they create is non excludable. As it becomes available to others it contributes to the spread of knowledge, with

additional redistributive effects in a global economy.

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Appendix A General case

In the more general CES case (not restricted to Cobb-Douglas), the steady-state interest rate (11) can be expressed as

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

$$\frac{q}{w} = \frac{\eta}{1-\eta}\left(\frac{H}{K}\right)^{\alpha\rho}\left(\frac{\tilde{l}}{\tilde{h}}\right)^{1-(1-\alpha)\rho} \tag{A.2}$$

Other conditions such as market clearing (7), and steady state mortgage credit to GDP (12) remain the same.

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, A and l. A decrease in A or 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 implausible driver behind the relevant secular trends.

Note that in the CES case income inequality depends on the ratio $\frac{H}{K}$. The growth of intangibles may therefore give an additional boost to inequality. Consequently, modeling technological change other than growth in η may also produce rising income inequality.

Appendix B Strongly redistributive growth

This appendix elicits that when a rise in η results in positive but not too extreme growth $\frac{1}{1-\eta} \geq \frac{dY}{d\eta} \geq 0$. As a first step we collect the relevant equations and evaluate them in steady state. The model's core is defined by (1), (5), (6), (3), (3.1) and (7).

The steady-state equilibrium for the variables r, R, K, H, f, p and Y is defined by the fol-

lowing equations, together with the production function (1):

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

$$R = \alpha\eta\frac{Y}{H} \tag{B.2}$$

$$H = \frac{\omega}{\beta}R \tag{B.3}$$

$$f = \frac{(1-\omega)RH}{r} \tag{B.4}$$

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

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

We start by showing that an increase in η results in falling $\frac{K}{Y}$ if growth is not too strong, i.e. if $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$

Using (B.1) and (B.2) in (B.6), and solving for $\frac{K}{Y}$ yields the following expression:

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

Taking a derivative w.r.t. η and evaluating when $d\left(\frac{K}{Y}\right)/d\eta \leq 0$ yields the following condition:

$$\frac{dY/d\eta}{Y} \leq \frac{1}{1+\eta}\left[1+\frac{(1-\omega)(1+2\eta)\alpha Y}{v'(\bar{L})\bar{L}}\right]$$

Since $\omega \leq 1$ this condition is always satisfied if $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$, showing that it is a necessary condition for $d\left(\frac{K}{Y}\right)/d\eta \leq 0$.

We next show that when $\omega \to 1$, and $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$ holds, an increase in η can generate all observed trends, here again summarized for convenience: (i) $\frac{dr}{d\eta} \geq 0$, (ii) $\frac{d\frac{q}{w}}{d\eta} \geq 0$, (iii) $\frac{d\frac{H}{K}}{d\eta} \geq 0$, (iv) $\frac{d\frac{K}{Y}}{d\eta} \leq 0$, (v) $\frac{d\frac{f}{Y}}{d\eta} \geq 0$, (vi) $\frac{d\frac{m}{Y}}{d\eta} \geq 0$, (vii) $\frac{d\frac{p}{Y}}{d\eta} \geq 0$

Rising $\frac{H}{K}$ (iii) directly follows from rising η, as an increase in η directly boosts the productivity of H relative to K. Consequently, it must be that innovators want to create more H relative to the usage of K by firms. By (A.2) it must then be that $\frac{q}{w}$ always increases in η, showing trend (ii).

We already showed above that when $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$, $\frac{K}{Y}$ falls, as required for trend (iv). We now proceed showing that from falling $\frac{K}{Y}$ all other trends follow.

By (B.4), when $\omega \to 1$, $f \to 0$. Using this, the market clearing condition (B.6) can be written as

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

Since the left hand side is a constant and the right hand side is both increasing in $\frac{p}{Y}$ and $\frac{K}{Y}$, it must be that when $\frac{K}{Y}$ falls, $\frac{p}{Y}$ increases, in line with trend (vi).

Observe that by (B.5), rising $\frac{p}{Y}$ must mean that rY falls. But since technological progress results in output growth ($\frac{dY}{d\eta} \geq 0$), this can only be if interest rates fall, as in trend (i).

Furthermore, with $\frac{p}{Y}$ and η rising, by (12) it must also be that mortgage credit $\frac{m}{Y}$ is rising, consistent with trend (vii).

Finally, too see that share valuations rise, write them as

$$\frac{f}{Y} = (1-\omega)\frac{\alpha\eta}{r}. \tag{B.7}$$

Clearly, with falling rates, an increase in η must result in rising share values. This completes the proof for all trends (i) - (vii).

Appendix C Steady state changes

Table C extends table 1 from the main text, and reports the changes in steady state value of the intangibles ratio, output, stock market capitalization to GDP and wage inequality. The unrealistically strong increase in wage inequality likely owes to the fact that all mortgage credit is from rich to poor households. In a richer life-cycle growth in mortgage credit relies less on rising inequality in incomes.

Table 4: Matched and implied changes across steady states.

Intangibles Ratio $\frac{H}{H+K}$

	1980	1995	2015	Δ 1980 - 2015
Data	0.377	0.487	0.625	65.82%
Model: η only	0.378	0.487	0.625	65.21%
Model: $\eta + A, \phi, x$	0.378	0.484	0.624	64.98%
Model: β only	0.378	0.487	0.625	65.24%
Model: $\beta + A, \phi, x$	0.378	0.489	0.625	65.14%

GDP (normalized) Y

	1980	1995	2015	Δ 1980 - 2015
Data	1.000	1.572	2.408	140.82%
Model: η only	1.000	1.006	1.017	1.68%
Model: $\eta + A, \phi, x$	1.000	1.604	2.408	140.78%
Model: β only	1.000	1.281	1.737	73.72%
Model: $\beta + A, \phi, x$	1.000	1.575	2.409	140.88%

Stock Market Cap to GDP $\frac{f}{Y}$

	1980	1995	2015	Δ 1980 - 2015
Data: series	0.424	0.934	1.375	224.17%
Model: η only	0.493	0.589	0.672	36.30%
Model: $\eta + A, \phi, x$	0.493	1.550	2.298	366.30%
Model: β only	0.493	0.591	0.729	47.98%
Model: $\beta + A, \phi, x$	0.493	1.102	1.436	191.40%

Wage Inequality $\frac{q}{w}$

	1980	1995	2015	Δ 1980 - 2015
Data: series	1.739	2.380	2.481	42.63%
Model: η only	3.733	6.759	13.184	253.18%
Model: $\eta + A, \phi, x$	3.733	10.274	34.133	814.41%
Model: β only	3.733	3.966	4.279	14.64%
Model: $\beta + A, \phi, x$	3.733	2.326	2.507	-32.83%

Appendix D The model with default

We now introduce some idiosyncratic risk to allow for the possibility of default. Suppose that after yielding utility to their owner, but before it is sold to the next generation, agent i's house receives a temporary "bad weather shock" ξ_t^i, with a CDF $G(\xi)$ with support $[-1, 1]$ and zero mean.

The weather shock is drawn every period, and its effects are thus temporary. Realizations of $\xi_t < 0$ mean the house stands in a neighborhood that temporarily experiences particularly good weather, yielding their owner some additional utility $-p_t\xi_t$ per unit of land. In contrast, realizations of $\xi_t > 0$ are bad weather shocks that damage the house. A damaged house will not yield any utility to the next owner unless it is repaired at cost $p_t\xi_t$ per unit of land. As the cost has to be ultimately borne by the seller, a damaged house trades at a discount such that $p_t^i = p_t(1 - \xi_t^i)$.

As a result of the shocks, households with very larger shocks default. In particular, default occurs if $-(1 + r_{t+1})s_t^i \geq p_{t+1}^i L_t^i$, defining a threshold

$$\begin{aligned}\hat{\xi}_t^i &= 1 - \frac{(1 + r_t)(-s_{t-1}^i)}{p_t L_{t-1}^i} \\ &= 1 - \frac{p_{t-1}}{p_t} LTV_{t-1}^i\end{aligned}$$

such that for realizations of $\xi_t^i > \hat{\xi}_t^i$ a household defaults on her mortgage, and where $LTV_{t-1}^i \equiv \frac{(1+r_t)(-s_{t-1}^i)}{p_{t-1}L_{t-1}^i}$ is defined as the loan-to-value ratio of a home buyer. Note that default can only occur if $\hat{\xi}_t^i < 1$, i.e. if $\hat{\xi}_t^i$ is within the support of ξ_t^i. As a result, whenever i is a borrower $(s_{t-1}^i \leq 0)$, she may default.

To compensate lenders for the possibility of default, borrowers pay a higher rate. We assume that savers pool their mortgage lending through an intermediary that just breaks even and pays lenders the riskless rate r_t. The household maximization is analogous to (2). In particular, denoting the risky rate by rr_t^i the maximization problem of household i in the

model with default becomes

$$\max_{c^i_{t+1},L^i_t,s^i_t} \mathbb{E}_t U(c^i_{t+1}, L^i_t) = \mathbb{E}_t c^i_{t+1} + v(L^i_t)$$

$$s.t. \qquad s^i_t \leq y^i_t - p_t L^i_t$$

$$c^i_{t+1} \leq \max\left\{y^i_{t+1} + p_{t+1}(1+\xi^i_{t+1}L^i_t + (1+rr^i_{t+1})s^i_t, 0\right\}$$

$$c^i_{t+1}, L^i_t \geq 0$$

where the max-function in the $t+1$ budget constraint reflects that households are protected by limited liability. The probability of default is $[1 - G(\hat{\xi}^i_t)]$, so that expected consumption at $t+1$ can be written as

$$\mathbb{E}_t c_{t+1} = G(\hat{\xi}^i_{t+1})\left\{p_{t+1}(1 + \mathbb{E}_t[\xi^i_{t+1}|\xi^i_{t+1} \leq \hat{\xi}^i_{t+1}])L^i_t + (1+rr^i_{t+1})s^i_t\right\}$$

Now, the break even condition for the intermediary on borrower i is

$$-(1+r_{t+1})s^i_t = -G(\hat{\xi}^i_{t+1})(1+rr^i_t)s^i_t + (1 - G(\hat{\xi}^i_t))p_{t+1}(1 + \mathbb{E}_t[\xi^i_{t+1}|\xi^i_{t+1} > \hat{\xi}^i_{t+1}])L^i_t.$$

Plugging this condition into $\mathbb{E}_t c_{t+1}$ the objective function can be written as follows

$$\mathbb{E}_t U(c^i_{t+1}, L^i_t) = y^i_{t+1} + p_{t+1}L^i_t + (1+r_{t+1})(y^i_t - p_t L^i_t) + v(L^i_t)$$

The household problem boils down to choosing L^i_t to maximize $\mathbb{E}_t U(c^i_{t+1}, L^i_t)$. Differentiating w.r.t L^i_t results in the first order condition and thus demand for land (**??**). It follows that the allocation in the model with default is equivalent to the model without default. However, now households with $\xi^i_t > \hat{\xi}^i_t$ default.