DISCUSSION PAPER SERIES

DP12519

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FINANCIAL ECONOMICS and MACROECONOMICS AND GROWTH

ISSN 0265-8003

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Discussion Paper DP12519
Published 19 December 2017
Submitted 19 December 2017

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Abstract

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JEL Classification: N/A

Keywords: Intangible Capital, skill-biased technological change, mortgage credit, Human Capital, excess savings, House Prices

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Acknowledgements
We are grateful to Bj•orn Br•ugemann for many helpful discussions, to Paul Romer, Viral Acharya, Dimitris Papanikolaou, Gregory Thwaites and Eric Bartelsman for valuable comments, Kasper Goosen for research assistance, and seminar participants at Columbia University, NYU, LSE, CREI-UPF, University of Amsterdam, Tinbergen Institute, European Central Bank, Free University Amsterdam, Bank of Finland, DNB and Bank of England. Earlier versions were circulated under the title "Technological Change and the Evolution of Finance".

Secular Trends and Technological Progress

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November 2017

Abstract

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JEL classifications. D33, E22, G32, J24

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1. Introduction

A rising excess of savings over productive investment in advanced economies has defined a phase of "secular stagnation" (Summers, 2014; Eichengreen, 2015). This paper proposes a growth model describing the general equilibrium impact of technological change on long term real and financial trends. It suggests that the transition to a knowledge-based economy and the associated shift from physical to intangible and human capital is a primary cause for excess savings and falling rates. The interpretation is consistent with a growing share of income for innovators, a progressive reallocation of credit from productive to mortgage financing and the rise in household leverage.

Information technology is widely recognized as a main cause for the rising productivity of high-skill workers and the steady rise in wage inequality and skill premia (e.g. see Autor, Katz, and Krueger, 1998; Autor, Levy, and Murnane, 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.

We analyse the consequences of this transition on financial markets. Our key step is to recognize that intangible capital is mostly created by the commitment of creative human capital. While firms hire employees, they cannot purchase their human capital (Hart and Moore, 1994), but must reward them over time as output is realized to ensure their motivation and retention. The transition to intangible investment thus requires less initial investment spending.

It has long been established that firms investing more in intangibles have lower or even negative net leverage (Bates, Kahle, and Stulz, 2009; Falato, Kadyrzhanova, and Sim, 2013). This is usually explained by their poor pledgeability, as intangible assets are deemed hard to verify and extract. Our approach offers a restatement of this intuition in terms of appropriability. Since creative human capital is critical not just to generate but also to operate intangible capital, innovators are able to appropriate a large fraction of its value. Thus even if intangible assets were easily verified, they represent poor collateral for investors because

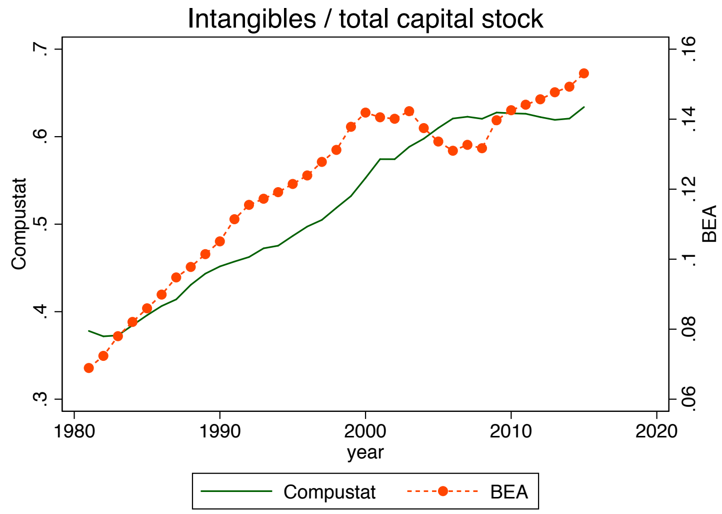

Figure 1: Evolution of the intangible capital ratio since 1980.

Ratio of intangible to total capital. The Compustat ratio uses the intangible capital measure by Peters and Taylor (2017), while the BEA data shows the ratio of intellectual property products (IPP) over total fixed assets.

much of their value is already assigned to the creators or under their control.

The distinct implication of this view is that the technological transition does not lead to increasing financial constraints, since human capital is rewarded gradually over time, such that investments in intangibles are essentially "self-funded" inside firms. The overall result is a reduced share of future revenues accruing to investors. In this view, reduced leverage reflects a drop in credit demand by firms even as interest rates fall, rather than rising financial constraints for which there appears to be little evidence.

We study investment and savings behavior in an overlapping generation (OLG) growth model. We adopt a very general production function under constant elasticity of substitution (CES), where physical capital is complementary with manual labor while intangible capital is complementary with high-skill labor. We introduce land (housing) as serving as both durable consumption good and as a store of value for agents' life-cycle savings. As physical capital is fully pledgeable, firms can scale it up till its marginal productivity equals the cost of borrowing. In contrast, innovative capital cannot be easily scaled up, so intangible capital produces rents that must be shared with innovative employees.

Our benchmark view of technological change is a steady increase in the relative productivity of intangible capital and skilled labor. Over time, the scale of intangible investment rises relative to physical investment. To ensure retention of skilled human capital and avoid the loss of intangible value, firms offer deferred compensation when output is produced (Hart and Moore, 1994; Oyer and Schaefer, 2005; Döttling, Ladika, and Perotti, 2017). As a result, firms need less upfront investment funding.

A second effect of the transition is that innovation rents increase over time. While some intangible value is appropriated by existing firms and incorporated in their share prices, a growing capital share needs to be assigned to innovators. As a result, over time the shift reduces the supply of available saving instruments. The general equilibrium consequence is a progressive decline in real interest rates. Critically, a redistributive innovative process can explaining the puzzling combination of a steady fall in the cost of credit and rising share prices since 1980 with a falling rate of traditional investment.

In equilibrium the rising excess of savings over corporate credit demand is redirected to fund house purchases. As land is in fixed supply, lower rates also boosts house prices (Knoll, Schularick, and Steger, 2017).

There is a final effect of the productivity shift on labor income and capital values, leading to rising household leverage as house prices rise relative to unskilled wages. Thus a growing savings supply is matched by a rising demand for mortgage credit. The process explains a declining stock of productive credit relative to mortgage credit across all OECD countries (Jordà et al., 2016, see figure 2).

While it would be challenging to validate empirically this broad interpretation, we offer a clear analytical result. We show that common alternative views of the growth process cannot by themselves explain major financial trends since the 1980s. We evaluate other technological explanations such as a rise in capital productivity, in the rate of innovation, and in the level of education. Among commonly cited non-technological drivers we consider trade, capital flows

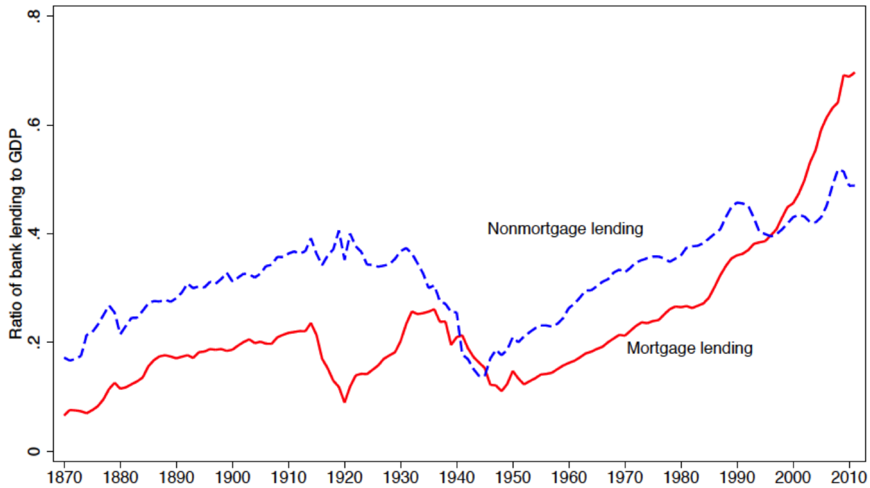

Figure 2: Mortgage and commercial credit in OECD countries (Jordà et al., 2016)

and demographics. The key insight is that recent growth has taken place in an environment of falling interest rates and declining tangible investment and corporate net borrowing. Lower rates per se imply cheaper funding, and should boost investment. To account for both a drop in the price and quantity of tangible investment does require a structural decline in firm demand, reflecting a major drop in its productivity at the productive frontier (Acemoglu and Autor, 2011).[1]

Capital inflows from emerging markets (especially since 1998) and demographic change certainly contributed to a savings glut in many countries. However, neither could be the sole driver, as both are inconsistent with the drop in investment, the evolution in corporate capital structure and relative wages. An increase in education level or in the rate of innovation can contribute to a rise in its scale and productivity, but cannot explain trends such as a falling demand for funding in a period of falling interest rates.

It is extremely challenging to validate empirically such a broad framework, and we do not seek to do so. We do offer a simple quantification of our interpretation of the growth process using US data since 1980. The model's long term framing is not suitable to explain

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

variation around trends, so our limited goal is to match the direction and scale of major economic trends. We calibrate the starting point as an initial steady state in 1980, and derive the implied evolution of individual growth drivers by matching the growth of the intangible-tangible ratio and output. A shift in relative capital productivity appears to offer also a better calibration, matching not just the direction but also the scale of major trends.[2]

While our formulation for production is quite general, our results do require specific assumptions. Ultimately, any redistributive effect of growth must result from different supply and demand elasticities, an important empirical issue.

Some assumptions appear empirically reasonable. We assume a low elasticity of savings to real interest rates, a well documented result confirmed in recent years. We assume an inelastic supply of housing. While higher prices may lead to more dense housing, population growth and urban congestion have countervailing effects.

Our simplifying assumption of an exogenous supply of skilled labor is not essential. Endogenizing educational choices would dampens the effect on relative wages, but could not explain the evolution of skill premia and credit allocation.

Our result critically depends on two assumptions. The first is a limited supply elasticity of intangibles, which ensures that innovator rewards rise over time. If all returns to innovation were competed away, there would be no rise in excess savings. While this seems a plausible assumption, the rate of innovation remains an unsolved issue in the debate on long term growth (Gordon, 2012).

The second assumption requires that innovators who stand to gain considerable wealth from their human capital investment cannot borrow against their expected future income and consume when young, reducing the savings surplus. This is a standard assumption in labor economics, reflecting natural moral hazard as well as anti slavery legislation, and relates to the inability to alienate human capital. An additional complicating factor is represented by the extreme uncertainty over the chance of success of innovative ideas, especially in a context

[2] We report a significant cross-country correlation between adoption of intangibles and the growth of mortgage credit across OECD countries, without suggesting any causal identification.

of winner-takes-all competition.

The model predicts a steady rise in mortgage leverage for lower income households, so that even a constant house value risk produces a rising mortgage default rate. However, our neoclassical setup offers no direct policy implications. In the absence of externalities or financial constraints the economy is dynamically efficient. Tight loan-to-value (LTV) limits for mortgage loans would reduce house prices, redirecting savings to production by subsidizing physical investment. While resulting in higher labor wages and output, this policy induces large intra- and intergenerational transfers and would not be Pareto-improving. A public intervention is only justified in the presence of a strong externality associated with financial stability. Analysing this issue would require modelling cyclical fluctuations in credit and house prices beyond the scope of our model.

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

2. Related literature

The paper offers a technological explanation for a rising income share of innovators (Smith, Yagan, Zidar, and Zwick, 2017; Koh, Santaeulàlia-Llopis, and Zheng, 2016). It is consistent with a rising profit share (Barkai, 2016) and an increasing role of real estate in total wealth (Rognlie, 2015), though its neoclassical setup may not be appropriate to fully describe historical changes in wealth distribution (Piketty, 2014).

The key insight is that a growing productivity of intangible capital is also a key driver for a rising savings surplus. Since human capital cannot be purchased nor pledged (Hart and Moore, 1994), it needs to be rewarded over time, and future income pledged to innovators clearly cannot be shared with investors. Complex, innovative tasks cannot be rewarded by short term contracts (Manso, 2011), so skilled human capital receives direct and indirect claims on future profits via gradual vesting of share grants and career advancement (Pendergast, 1999).

While firms partially co-invest in intangible assets, most R&D and organizational capital expenditures reflect skilled labor compensation (Corrado and Hulten, 2010a). Even corporate brand equity critically depend on 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; Döttling et al., 2017). Firms with significant intangibles maintain more internal resources to avoid becoming constrained, in the process contributing to the savings glut (Bates et al., 2009).

Suggestive evidence for a falling corporate demand for external finance comes from aggregate data on positive net lending by the non-financial corporate sector in most developed countries (Gruber, 2015). This has been interpreted in terms of tighter financial constraints in Falato et al. (2013), Giglio and Severo (2012) and Caggese and Perez-Orive (2017). Yet recent evidence on firms with more intangible capital suggest they do not appear constrained. Thanks to their lower total investment spending, these firms have higher free cash flow, and do not pay out less to their shareholders (Döttling et al., 2017). They also have more share grants, consistent with a significant human capital co-investment by skilled employees. Gutiérrez and Philippon (2016) find no support for rising financial frictions, and offer evidence of industry effects associated with globalization, competition and short termism. Alexander and Eberly (2016) and Döttling, Gutiérrez, and Philippon (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 (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 evidence suggests the allocation of intangible value between firms and innovators has a significant impact on share prices (Eisfeldt and Papanikolaou, 2013) and across firms and investors (Garlenau and Panageas, 2017). Eisfeldt and Papanikolaou (2013) show how technological shocks alter the outside option of key employees, enabling some to appropriate a large fraction of intangible value. Garlenau and Panageas (2017) study how disruptive entry of innovative firms create unhedgeable risk, boosting demand for safe assets and depressing interest rates while 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.

A related literature studies the effect of information technology on the relative productivity of skilled labor, and explains 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 unskilled workers in developed economies. Such a trend cannot be explained by a simple rise in the absolute productivity of intangibles and skilled human capital.

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.

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 physical 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.[3] 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.[4] 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 inflows. Yet the share of mortgage to total credit has risen rapidly in all OECD countries Jordà et al. (2016). A simple cross countries analysis presented in the empirical section shows how its rise is correlated with the national rate of adoption of intangible investment. Related evidence is offered by Dell'Ariccia, Kadyrzhanova, Minoiu, and Ratnovski (2017), who show that as firms increase their intangible investment, 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.[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.

[3] 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.

[4] As asset bubbles may well occur in equilibrium in an overlapping generation framework, our model is consistent with speculative fluctuations around a long term trend.

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

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.[6] 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.

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.

[6] 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.

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. Here we assume that all intangible value is generated by a subset of skilled human capital at no monetary cost.[7] 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

[7]One could easily introduce that firms need to contribute a fraction of intangible investment value. Since intangibles are not pledgeable, firms would need to accumulate internal resources to fund these investments, hence not growing the amount of investable claims in the economy. See (Döttling et al., 2017) for a model in which workers and firms co-invest.

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 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:

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

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.[8] 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 shares:

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

Investments in debt instruments follow as a residual $D_t^i = y_t^i - f_tS_t - p_tL_t$. Households with $y_t^i \geq p_tL_t + f_tS_t$ have an income high enough to buy their house and invest the remainder in shares and corporate debt. In contrast, those with $y_t^i < p_tL_t + f_tS_t$ 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 $y_t^i > f_tS_t$. 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.

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

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 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.[9] 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 $C(I_{H,t}) = \frac{\beta}{2} I_{H,t}^2$. They will scale up investment in intangibles until

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

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

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.

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 homogenous allocation of land, $L_t^i = \bar{L}$ 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. The allocation of savings in steady state

To understand how technology impacts financial trends in the model, it is useful to understand its impact on the steady state allocation of savings.

The financial market clearing condition (7) indicates that households save a fraction $(1-\alpha)$ of their income. How are savings allocated? A share is invested in corporate debt backed by tangible investment. There are two other savings vehicles, corporate shares and houses. In steady state their value can be written as

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

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

As the relative role of intangible capital in the economy grows, firms demand relatively less external finance to fund physical investment. Some savings are absorbed by share prices, which rise in value as the return on intangibles increases. However, as firms only appropriate a fraction $(1-\omega)$ of the return to intangibles, innovators receive a rising share of total income. As this increasing share of the capital stock is not investable, excess savings push down interest rates, and all long-term assets increase in value. Thus the evolution of intangible value is an indirect driver of share and house prices, even though its direct effect is to subtract a rising share of income from investment assets.

4. Secular trends

This section analyzes alternative formulations of the growth process to assess what factors can best explain the evolution of economic trends since 1980. After describing the main trends we examine analytically how well they may be explained by individual growth factors. We complement these analytical results with a suggestive quantitative exercise to study the combined impact of different drivers. Technological progress is the natural driver of long term growth, but we also consider social trends such as demographics and rising education levels as well as global capital and trade flows.

Most factors can account for some subset of trends. Our main result is that only a strongly redistributive form of technological progress can by itself drive the observed combination of growth, falling investment and interest rates. We show analytically that this core set in turn produces all other major trends.

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 account for.

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.[10] From a peak above 8% in the early 1980s, US real rates have steadily been declining, to a level around 0% in recent years.

Rising intangible relative to tangible investment Corporate investment in intangible assets has risen even as total investment has declined (Corrado and Hulten, 2010b).[11]

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).[12] 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 higher, since Peters and Taylor (2017) capitalizes more spending flows than the BEA estimates.[13] Whatever the better definition, there is a clear and steady upward trend in both series. In the language of the model, this trend is represented by a growing value of H relative to K.

[10] Both series are downloaded from FRED.

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

[12] 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).

[13] For example, the BEA measure does not capitalize any SG&A spending that contributes to a firm's organizational capital.

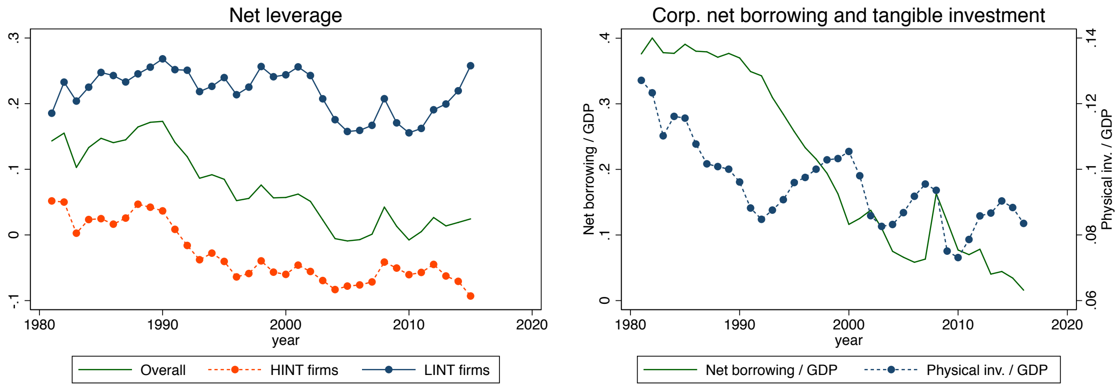

Figure 3: Net leverage and borrowing by non-financial corporations

Decreasing corporate net borrowing US corporations have been reducing their net borrowing, while 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 outflows since 1980, even after the recent crisis.

This overall decrease in external financing by firms 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 in the right panel of figure 3 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 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, the key growth factor should be able to account for a falling $\frac{K}{Y}$ in our model.

[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.

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

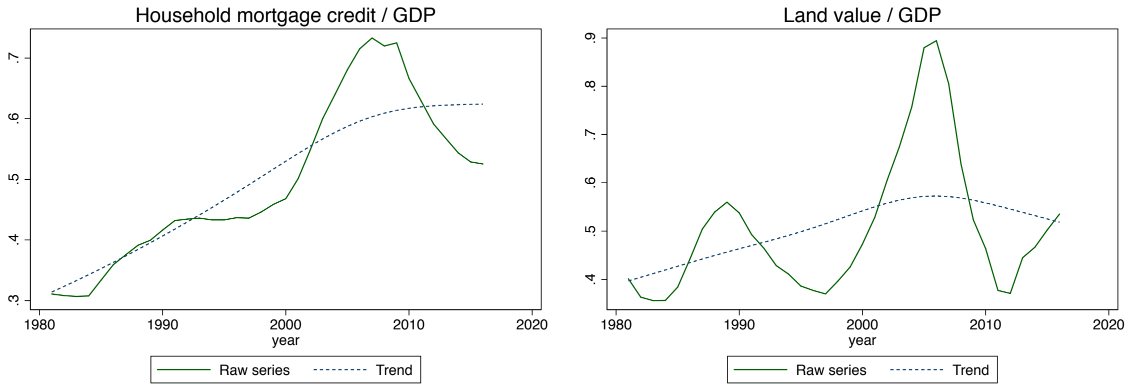

Figure 4: Mortgage credit and land values to GDP

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 the real estate credit bubble of the 2000s played a role, the figure shows a clear secular growth since 1980.

While several authors have highlighted specific US factors for the recent real estate credit boom, Jordà et al. (2016) show how all advanced economies experienced strong mortgage credit growth relative to corporate credit. This shift appears 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. Since 1980 they have started rising strongly in real terms. This growth appears largely driven by rising demand, since land is largely in fixed supply and urban density is constrained by regulation.

[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.

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 scale of net equity outflows, this value reflects 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 would benefit all factors of production equally. Such a growth driver is inconsistent with the growing role of intangible capital and rising skill premium in wages. Hence, we focus on intangible-biased growth drivers.

- An improvement in the rate of innovation, such as 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, 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 physical factors also benefit indirectly 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 (a rise in η). Such progress 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, it is natural to focus on technological growth drivers. However, general economic trends certainly reflect multiple causes, so we evaluate 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.

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

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 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 may have a direct 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 the reduced form of the model, a combination of technology progress in advanced economies and knowledge spillovers to emerging countries is consistent with a progressive rise in η in the efficient production frontier of advanced economies.

Similarly, a falling price of (productivity-adjusted) capital goods can reflect a growing productivity of software and skilled labor employed along physical equipment, while reflecting the lower cost of the physical input.

Lastly, our model cannot easily accommodate changes in the level of competition, so it does not incorporate the effect of rising concentration since the 2000s. This is an important driver of economic evolution (Gutiérrez and Philippon, 2016) and is consistent with a rising profit share and equity valuations, though its effect on interest rates, tangible investment and skilled wages is not obvious.

5. Analytical comparison of growth drivers

This section assesses 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.

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. Physical capital can always be scaled up to the point where its marginal productivity equals the cost of external finance. Any driver behind the observed trends must explain a simultaneous drop in the quantity and price of external finance. A combination of falling quantity and cost of physical capital at the technological frontier suggests a structural decline in its demand.

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 simultaneously produce all observed trends in the set $\mathcal{T}$.*

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

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

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 the theorem 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, Katz, Patterson, Van Reenen, 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, our analytical results show that η is the only growth driver consistent with all long term trends. Of course, the world is complex and not one single driver explains all trends. But this result suggests that a strongly redistributional shift is among the key drivers explaining the weak demand for credit by corporations in an environment of falling interest rates. In section 6 we examine the joint effect of different growth drivers.

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 parameters, we show in the appendix that rising η generates all secular trends if parameters are chosen such that

(i) changes in η result 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. As long as ω is significant, a large fraction of the return to innovation is captured by human capital, and hence does 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.

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

Our analytical results allow us to study the impact of individual drivers. We now calibrate our model and use a numerical solution to (i) understand in more detail why other drivers fail, and (ii) assess the combined impact of multiple drivers. 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, the results indicate that capital inflows and rising education levels help explaining the magnitude of trends. Still, 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 $\tilde{l}$.[18] 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 $\frac{p}{Y} = 0.43$.[19]

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

[19]The resulting parameter values are $\eta = 0.845$ and,$\beta = 3.105$. The values for labor are $\tilde{l} = 19.211$, corre-

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 whether 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. Accordingly, 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

sponding to an aggregate number of $l = 15.945$, and $\tilde{h} = 143.75$, implying $h = 24.438$. 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.

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.

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 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.

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.

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 Joint Effect of Multiple Drivers

While a redistributive technological shift η emerges as the primary growth driver able to explain lower credit demand along with falling interest rates, economic trends reflect multiple causes. We now calibrate the effect of drivers that seem to be able to generate an increase in the intangibles ratio (η, β, α and ω), incorporating information on capital inflows and education levels. In other words, when assessing each individual driver we also adjust capital inflows x and education ϕ as observed in the data. Moreover, we implicitly 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

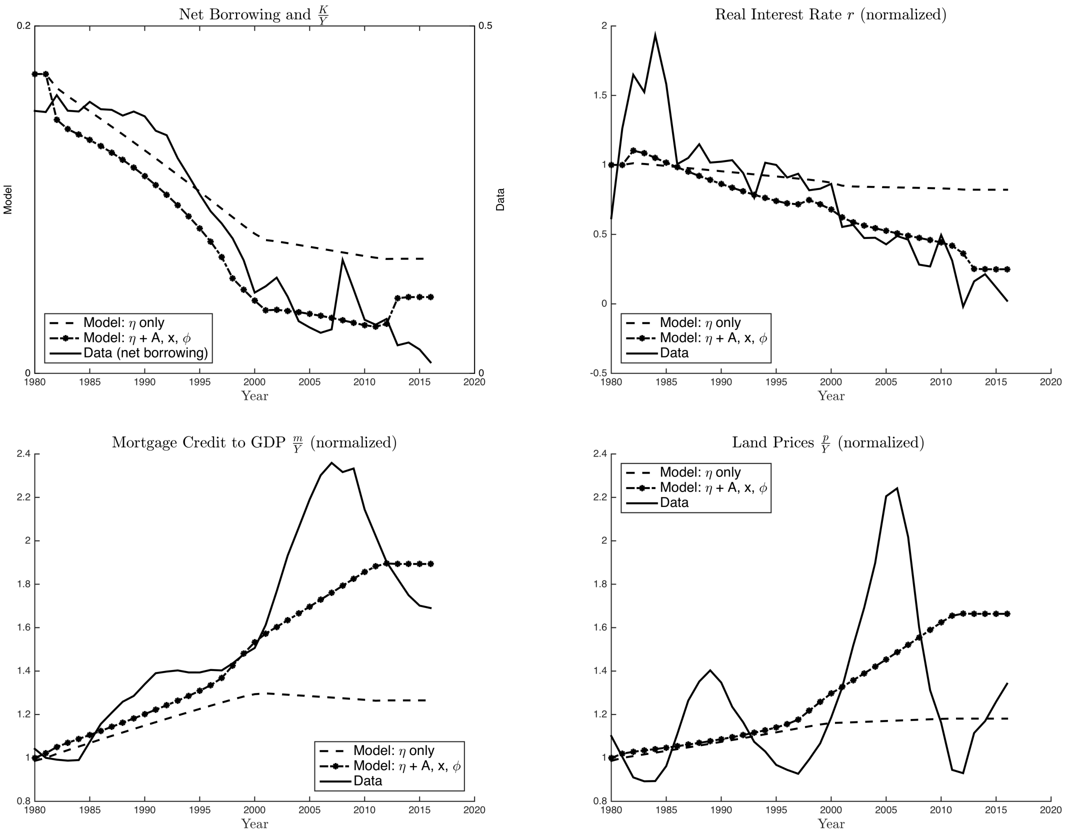

Figure 5: Simulated perfect-foresight time path compared to actual series.

output. Adjusting ω and α cannot even generate an increase in output in a context of rising intangibles.

Combining falling β with additional trends helps get the correct sign for more trends. 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 technological driver best suited to generate 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.

Actual economic series are naturally much more volatile, and 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, as our simple long term model is only calibrated to match the intangibles ratio and output growth, the model-generated series seem 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 account for the evolving national share of mortgage credit to total credit calculated by Jordà et al. (2016) in terms of the national rate of adoption of new technology.

We use the intangible capital measures based on National Accounts, available through the INTAN-Invest project (see Corrado, Haskel, Iommi, and Jona Lasinio, 2012). As an

[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] Note that η grows faster until 2000, then the growth of intangibles flattens somewhat (see figure 1).

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) Mortgage Ratio	(2) Mortgage Ratio	(3) Mortgage Ratio	(4) 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

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

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 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

[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.

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 our 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, Schularick, and Taylor, 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* $\chi_t \equiv 1 - G(\hat{\xi}^l_t)$ *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 baseline 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 produc-

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

tive 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

We offer a neoclassical growth view that may account for the growing excess of savings over productive investment dubbed "secular stagnation". Our broad framework allows to shed light on what type of technological change may have driven these secular trends. While information technology has clearly favored some factors, our analysis and evidence suggests that growth in the last decades cannot be simply explained by a rise in the absolute 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.

While skill-biased technological progress is acknowledged as a key cause of the evolution of relative wages (Acemoglu and Autor, 2011), our framework extends its effect to 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 and increasing household leverage. The model endogenizes 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.

Critically, excess savings arise because savers cannot fully co-invest in the development of intangible capital, whose value largely accrues to innovators (Hart and Moore, 1994). Innovative startups nowadays need only modest upfront investment, relying on co-investment by skilled human capital funded by deferred compensation. Anecdotal evidence suggests that a large fraction of value created by innovative firms accrues to founders and employees. Even once listed, innovative firms remain largely self financed, and maintain a high share dilution rate to fund grants to employees.

Our result on the implied evolution of relative factor productivity in developed economies is certainly reinforced by their growing specialization in high intangible industries, while some physical production is relocated to emerging markets. Next to the direct impact of IT on production and the composition of demand, a shift in comparative advantage probably explains the absolute fall in the productivity of physical inputs.

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 following 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 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

$$\begin{aligned}\max_{c_{t+1}^i, L_t^i, s_t^i} \quad & \mathbb{E}_t U(c_{t+1}^i, L_t^i) = \mathbb{E}_t c_{t+1}^i + v(L_t^i) \\ s.t. \quad & s_t^i \leq y_t^i - p_t L_t^i \\ & c_{t+1}^i \leq \max\left\{y_{t+1}^i + p_{t+1}(1 + \xi_{t+1}^i L_t^i + (1 + rr_{t+1}^i)s_t^i, 0\right\} \\ & c_{t+1}^i, L_t^i \geq 0\end{aligned}$$

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

$$\mathbb{E}_t c_{t+1} = G(\hat{\xi}_{t+1}^i)\left\{p_{t+1}(1 + \mathbb{E}_t[\xi_{t+1}^i | \xi_{t+1}^i \leq \hat{\xi}_{t+1}^i])L_t^i + (1 + rr_{t+1}^i)s_t^i\right\}$$

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

$$-(1 + r_{t+1})s_t^i = -G(\hat{\xi}_{t+1}^i)(1 + rr_t^i)s_t^i + (1 - G(\hat{\xi}_t^i))p_{t+1}(1 + \mathbb{E}_t[\xi_{t+1}^i | \xi_{t+1}^i > \hat{\xi}_{t+1}^i])L_t^i.$$

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

$$\mathbb{E}_t U(c_{t+1}^i, L_t^i) = y_{t+1}^i + p_{t+1} L_t^i + (1 + r_{t+1})(y_t^i - p_t L_t^i) + v(L_t^i)$$

The household problem boils down to choosing L_t^i to maximize $\mathbb{E}_t U(c_{t+1}^i, L_t^i)$. Differentiating w.r.t L_t^i 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 $\xi_t^i > \hat{\xi}_t^i$ default.