Secular Trends and Technological Progress

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Abstract

Technological progress enhancing the productivity of intangible capital can account for several long term financial trends since 1980. Critically, creating intangibles requires the commitment of human capital rather than physical investment, so firms need less external finance. In general equilibrium, a falling credit demand can explain reduced tangible investment along with falling interest rates. Excess savings boost asset valuations and flow to other assets such as real estate. Rising house prices combined with increasing wage inequality increase mortgage credit demand, household leverage and default risk. While demographics, trade and capital flows may have a strong impact on savings glut and factor productivity, only a major productivity shift to intangibles can account for all major trends, including rising income inequality.

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 (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). However, recent evidence suggests a declining corporate demand for external funding rather than tighter constraints, as innovative firms do not appear financially constrained. [2]

We analyse this productive evolution by a very general CES production function where

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

[2] Döttling et al. (2017b) document how firms with more intangibles have lower investment and external funding needs while maintaining their payout rate, as they can fund their human capital by a greater use of deferred compensation.

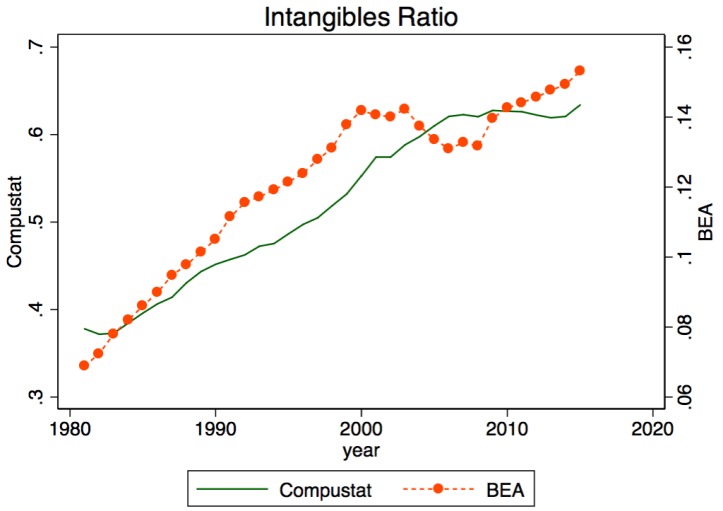


Figure 1: Evolution of the intangible capital ratio since 1980.

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.

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 through the effort of some key innovative employees, who capture part of its returns. Saving behavior is described in an OLG setup 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. As a result, firms expand their share of intangible assets while reducing their external funding, as human capital is rewarded only when output is produced to ensure its commitment and retention (Hart and Moore, 1994; Oyer and Schaefer, 2005; Döttling et al., 2017b).

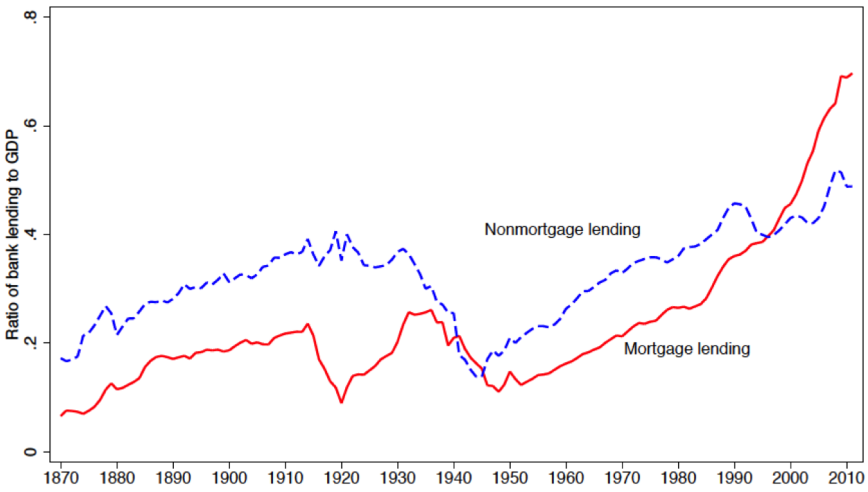


Figure 2: Mortgage and commercial credit in OECD countries (Jordà et al., 2016)

As over time intangibles become more productive, a growing capital share needs to be assigned to innovators. While some intangible value is appropriated by firms and thus incorporated in equity prices, overall the shift reduces the supply of saving instruments. Over time the general equilibrium consequence is a progressive decline in real interest rates, a trend in place since the early 1980s and persisted throughout the credit boom.

The growth in excess savings 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 final effect is rising mortgage debt to income ratios, as unskilled labor income does not rise in line with house prices. A combined impact of technology on capital and labor markets thus boosts both demand and supply of mortgage credit. This may explain the declining stock of productive credit relative to mortgage credit across all OECD countries (Jordà et al., 2016, see figure 2).

We compare our hypothesis with alternative views of the growth process and secular stagnation, including different formulations of technological change as well as non-technological drivers such as trade and demographics. We show analytically that only a process of strong shifts in factor productivity can explain labor and financial trends since 1980. Growth over

this period has been associated with both falling interest rates and a drop in conventional (tangible) investment and corporate net borrowing. Lower rates per se should imply cheaper funding and boost demand for physical investment. To account for both a drop in the price and quantity of corporate funding thus requires a structural decline in firm demand. More precisely, a fall in the ratio of physical investment to GDP in a period of economic growth requires a disruptive form of technological change, where new technologies replace other factors at the productive frontier (Acemoglu and Autor, 2011).

We rule out a classic Solow residual version where overall factor productivity increases the productivity of all factors. Uniform growth would indiscriminately benefit tangible capital and low skill labor as much as new technologies. Growing capital flows from emerging markets or demographic change may account for a "savings glut" and a steady drop in interest rates as well as the growth of house prices and mortgage credit. However, it cannot be the primary growth driver as it is not consistent with the drop in investment, nor 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 combination with dropping interest rates.

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

Our approach is to calibrate the model to an initial steady state around 1980, and compare how changes in individual factors generate an implied path for the main economic variables over the following 35 years. Doing so, we match the observed growth of the intangible-tangible ratio and overall output, and assess how well alternative growth drivers can replicate other, non-matched long term trends.

A gradual shift in relative capital productivity appears not only analytically consistent with observed trends, but also best predicts the evolution of the data in our calibration.

When we account for foreign capital inflows and rising levels of education, it generates a realistic fall in interest rates and borrowing by firms, and a growth in mortgage credit in line with its trend in the data. The increase in land and stock prices increases are also broadly consistent, though the magnitude of the growth is a bit higher than in the data. Overall, the trends generated from our simple model fit the data surprisingly well, especially given that we only match the evolution of intangibles and overall output growth.

Finally, we offer consistent cross-country evidence of a significant correlation between adoption of technological progress and the growth of mortgage credit in OECD countries. While these result offer some comfort, they do not imply causal identification for which more careful work is needed.

One of the theoretical implication is a steady rise in mortgage leverage for lower income households, such that even a constant house value risk produces a rising mortgage default rate. Yet as in a neoclassical setup without financial constraints the economy is dynamically efficient, there is no case for policy. 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 over time may only be justified when its stability benefits are sufficiently strong.

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 are countervailing factors.[3] Less essential is its assumption on an exogenous supply of skilled labor. Endogenizing education would dampen the effect on relative wages and inequality, as our calibration shows, but does not alter the overall framework.

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

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

Our neoclassical growth model offers a productivity benchmark for the debate on rising inequality (Piketty, 2014). One contribution is a close modelling of how technological progress alters the allocation of income within both the labor and capital income share, with general equilibrium implications affecting asset values and credit allocation. Although the model is not set up to describe changes in the distribution of wealth, its results are consistent with an increasing role in the income share accruing to real estate (Rognlie, 2015) and intellectual property products (Koh et al., 2016).

A key driver of evolution in the model is the growing income share of creative human capital associated with the growing role of intangible capital. Unlike physical capital, human capital cannot be purchased (Hart and Moore, 1994), and often needs to be rewarded via deferred compensation (unvested equity grants and career promises, Oyer and Schaefer (2005)).

Research on employee compensation recognizes the inadequacy of short term contracts for rewarding complex, long term 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 profits via deferred compensation, career advancement, share and option grants (Eisfeldt and Papanikolaou, 2013, 2014).

The rise of intangible capital has also been related to the falling net leverage and increasing cash hoardings. 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., 2017b). This is consistent with a rising human capital co-investment by skilled employees that does not require external financing. 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. (2017a) also find that both in the US and Europe weak investment is associated with the growing role of intangible capital.

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). 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 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. Another likely cause is a spreading of technology to emerging countries, leading to relocation of physical production.

Our contribution is to bring together the insights from both the labor and finance literature, to understand the combined impact of technological progress 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. Eichengreen (2015) compares two productive factors, and finds a fall in the relative price of investment goods a more explanation than a drop in investment opportunities (see also Thwaites, 2014). Both these hypotheses are consistent with our redistributive form of technological progress, as it leads to a fall in the productivity-adjusted cost of physical capital as well as a fall in the supply of investable assets.

The rise in US mortgage lending has been interpreted with 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). Closely related to our approach is the evidence in Dell'Ariccia et al. (2017) that as firms increase intangibles, their own creditor banks shifts to more real estate funding. 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 asset bubbles may well occur in equilibrium in an overlapping generation framework, the model is consistent with speculative fluctuations around the trend.

3. The model

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.[4] There is a fixed amount of land $\bar{L}$ that is infinitely durable and does not depreciate. Denote by p_t the relative price of land in terms of corn at t.

Agents Each generation consists of a unit mass of households indexed by i. Household i of generation t has utility function $U(c^i_{t+1}, L^i_t) = c^i_{t+1} + v(L^i_t)$, where c^i_{t+1} denotes i's consumption of corn and L^i_t its land holdings at the end of period t. The function $v(L)$ with $v'(L) > 0$, $v''(L) < 0$ captures the utility households achieve from living in their house. 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. 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:

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

Here A_t is a parameter of overall productivity, while η measures the relative productivity of intangible capital and high-skill labor. An exogenous growth of η over time will be one of the main technological growth drivers we consider.

The firm can invest $I_{K,t}$ units of corn at t to install $K_{t+1} = I_{K,t}$ units of physical capital that can be used in production at $t+1$, producing $K_{t+1} + Y_{t+1}$ units of corn. Intangible capital is created by some high skill workers with innovative talent. Both types of capital fully depreciate after production, and the firm starts with an initial stock (K_0, H_0).

Intangible capital We assume that intangible investment only requires the commitment of skilled human capital over time. A fraction ε of high-skill households have an innovative

[4] We do not distinguish between houses and the underlying land and use the two terms interchangeably.

talent and can exert effort when young to create H_{t+1} units of intangible capital next period. We assume a convex cost of effort $C_t(H_{t+1})$ at time t, and specifically the functional form $C_t(H_{t+1}) = \frac{\tilde{\beta}}{2} H_{t+1}^2$, where $\tilde{\beta}$ scales the cost of innovative effort. A fall in $\tilde{\beta}$ is another growth driver we will consider in later sections. This assumption reflects the lower supply elasticity of innovative investment relative to existing capital, which is easily reproducible.[5]

The development of intangibles requires that human capital remains committed for its full implementation. An innovator could leave a firm and redeploy a fraction ω of the intangibles created in an own venture or another firm. This credible threat makes it hard for outside investors to capture the value of intangibles. However, firms do not become constrained because they can self finance their commitment to human capital by offering delayed compensation.

Financial contracts In our basic setting there is no risk, so equity and debt are equivalent. However, for illustration we refer to external financing as borrowing when backed by land or by physical capital.

We refer to external equity as a claim backed by the fraction $1 - \omega$ of revenues from intangible capital that firms can appropriate.

Finally, we assume that high-skill labor is relatively scarce, ensuring that high-skill workers have a higher income than low-skill workers. This assumption guarantees that in equilibrium high-skill workers are not borrowing.

Assumption 1.

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

3.1. Households

Households supply their labor endowment inelastically to the representative firm, generating income $y_t^i \in \{w_t \tilde{l}, q_t \tilde{h}\}$ when young, where w_t denote wages for manual workers and q_t wages of

[5] In our setup innovators are talented employees who create intangibles inside existing firms. An alternative formulation is as entrepreneurs whose firms produce new intangible capital for existing firms.

high-skill workers. As households only consume at $t+1$ they save all income for retirement. They can buy a house and sell it to the next generation when they are old, earning some utility plus a possible price appreciation. They can also invest in the financial market, where savings s_t^i are either invested in corporate or mortgage debt, or in corporate equities. While most households have no income when old ($y_{t+1}^i = 0$), innovators receive income from the intangible capital they created, $y_{t+1}^i > 0$.

Let s_t^i denote net financial savings. We will refer to households with $s_t^i \geq 0$ as lenders and those with $s_t^i < 0$ as borrowers. The maximization problem of a household is:

$$\begin{aligned} \max_{c_{t+1}^i, L_t^i, s_t^i} \; & U(c_{t+1}^i, L_t^i) = c_{t+1}^i + v(L_t^i) \\ s.t. \quad & s_t^i \leq y_t^i - p_t L_t^i \\ & c_{t+1}^i \leq y_{t+1}^i + p_{t+1} L_t^i + (1 + r_{t+1}) s_t^i \\ & c_{t+1}^i, L_t^i \geq 0 \end{aligned} \tag{2}$$

As the budget constraints are binding, households choose their housing demand by the first order condition

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

In equilibrium, the potential house price appreciation plus its utility (LHS) has to equal either the mortgage interest (RHS, for a borrower) or the opportunity cost of investing (RHS, for a lender). Thus the optimal demand for land is:

$$L_t^i = v'^{-1}\left((1 + r_{t+1}) p_t - p_{t+1}\right), \tag{3}$$

Note that housing demand is independent of income, as all workers have the same demand for housing.[6]

The role of mortgage credit is to allocate land efficiently to equalize the marginal utility from housing across agents. Financial savings follow as a residual $s_t^i = y_t^i - p_t L_t^*$. Households with $y_t^i \geq p_t L_t^*$ have an income high enough to buy their house and invest some in the financial market. In contrast, those with $y_t^i < p_t L_t^*$ take out a mortgage.

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

As land has both a consumption and a storage use, mortgage credit serves to separate the two uses. Agents with low incomes sell claims on their houses, providing a saving vehicle while enjoying their consumption value.

3.2. Physical capital and labor

The representative firm maximizes profits employing the four input factors physical capital K_t, intangible capital H_t, low-skill labor l_t and high-skill labor h_t.

Under perfect competition, workers and suppliers of funding for physical capital are compensated according to their marginal productivity. Since physical capital is fully eligible as collateral, firms can always finance tangible investments externally. The firm scales up tangible investment until:

$$r_t = Y_{K,t}. \tag{4}$$

We will refer to funding of tangible capital as debt (so corporate demand for credit is $d_t = I_{K,t} = K_{t+1}$), while we term as equity the corporate claim issued against the firm share of the value of intangible capital. This distinction is consistent with the corporate finance literature but are arbitrary in the model. As there is no risk, there is no meaningful distinction between forms of external finance. Here we simply adopt the terminology as a convention.

3.3. Creation of intangibles

High-skill innovative workers can exert effort to produce intangible capital for the next period. Producing H_{t+1} units of intangible capital has a cost of effort $C(H_{t+1})$, and intangibles are valued at $R_{t+1} = Y_{H,t+1}$ per unit, equal to their marginal productivity. This investment of creative human capital produces a *future* value, and requires human capital investment in the firm.

Since the realization of intangible capital requires the commitment of creative human capital, the innovator retains a credible threat to redeploy her human capital elsewhere. We assume that a fraction ω of intangible value $H_{t+1}R_{t+1}$ may be taken outside the firm. To

capture some value from the creation of intangible capital, the firm needs to offer adequate deferred compensation to match this outside option.

This implies that innovators will scale up their investment in intangibles until $\omega R_{t+1} = C'(H_{t+1})$. Using our functional form assumption, and that a fraction $\phi\varepsilon$ of households are innovators, the aggregate investment in intangible capital is

$$H_{t+1} = \frac{\phi\omega}{\beta} R_{t+1}, \tag{5}$$

where $\beta \equiv \tilde{\beta}/\varepsilon$.

Some profits cannot be promised to investors at t. The residual fraction $1-\omega$ of intangible value accrues to the firm and can be promised to outside equity. Note that the firm is never financially constrained over intangible investment, since it can self finance its formation by deferred equity grants to innovators that vest as intangible capital is created.

Let the ex-dividend share price at time t be f_t. After production the net profit $(1-\omega)R_t H_t$ can be paid out as a dividend.[7] Shares must generate the market return r_{t+1} available on corporate and mortgage debt, so at any point in time their value is:

$$f_t = \frac{f_{t+1} + (1-\omega)R_{t+1}H_{t+1}}{1+r_{t+1}} \tag{6}$$

3.4. Equilibrium

Market clearing in the land market requires that $\int_0^1 L_t^i di = \bar{L}$. Using (3) leads to the land market equilibrium:

$$p_t = \frac{p_{t+1} + v'(\bar{L})}{1+r_{t+1}}. \tag{7}$$

Plugging this price in (3) implies that $L_t^i = \bar{L}$ for all i. As demand for housing does not depend on wealth, all agents consume the same amount. Total net financial savings by households equal labor income earned by the young generation minus their house purchases

[7] Here shareholders are indifferent between retaining or paying out profits. Any retained earnings will reduce the amount of corporate debt issued to fund tangible investment and thus have no effect on net corporate demand for external finance.

$\int_0^1 s_t^i di = w_t \tilde{l} + q_t \tilde{h} - p_t \bar{L}$. Savings can be 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

$$(1-\alpha) Y_t = p_t \bar{L} + f_t + K_{t+1}, \tag{8}$$

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.

Given the parameters of the model, the equilibrium is defined by equations (1), (4), (5), (6), (7) and (8).

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.[8] 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 while physical investment has declined (Corrado and Hulten, 2010b).[9]

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).[10] We also compute the intangibles ratio from national accounts using data from the BEA.

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 intangi-

[8] Both series are downloaded from FRED.

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

[10] 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).

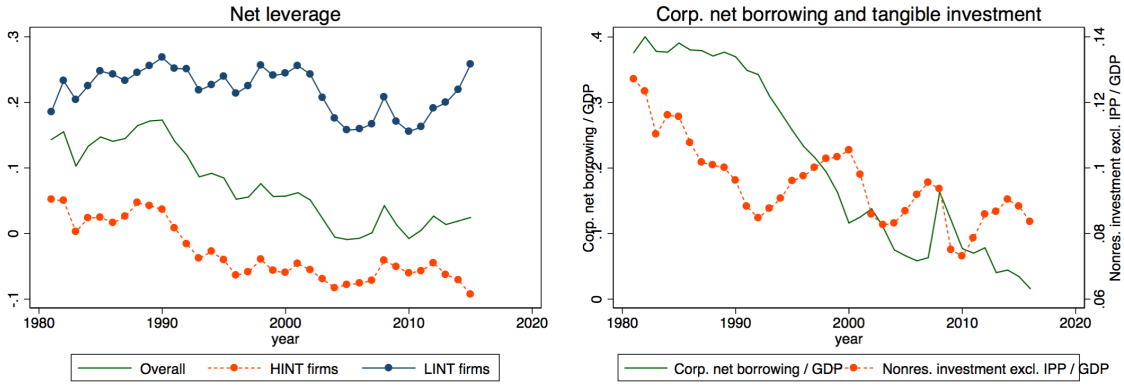


Figure 3: Net leverage and borrowing by non-financial corporations

ble assets.[11] 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 corporations is further confirmed by data on net borrowing of US non-financial businesses from the Flow of Funds, scaled by nominal GDP.[12] 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.

Note that consistently with the corporate finance literature, we interpret external financing for tangible investment $\frac{K}{Y}$ as debt. For comparison, the right panel of figure 3 also plots non-residential, non-IPP investment relative to GDP, calculated using data from the BEA. Both series exhibit an overall downward trend. Therefore, technological change process 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.[13] While

[11] 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.

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

[13] 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

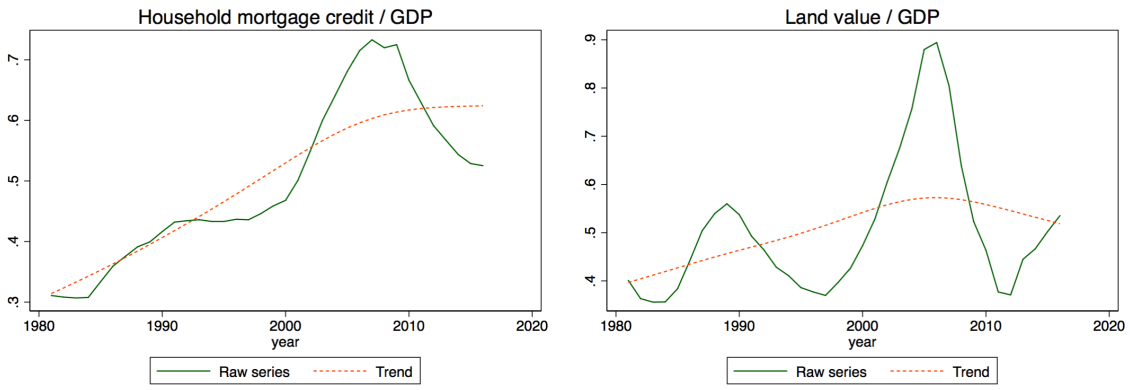


Figure 4: Mortgage credit and land values to GDP

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 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.

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.

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.

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 consider intangible-biased growth drivers, adjusting 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).[14]

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 these drivers here and study their impact analytically in the following section. Section 5.3 discusses in more detail how well these drivers can individually explain the trends in the context of 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 an historical rise in the capital share since the 1970s. This is a redistributive factor that may explain some observed changes in the income distribution. It is represented by a rise in 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.

- Globalization has had a major effect on the location of production in recent decades, led by the integration of China in the global economy. This driver can contribute to the replacement of old technologies in advanced economies.

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

5. Analytical comparison of growth drivers

This section looks analytically how the growth drivers listed above predict the evolution of secular trends 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 studying the combined effect of different factors in a calibrated example.

5.1. Analytical results

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

Lemma 1. *To explain all secular trends simultaneously, any growth driver must be able to simultaneously explain falling corporate borrowing $\frac{d}{Y} = \frac{K}{Y}$ and falling interest rates r.*

This lemma 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 (8) 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.

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

After this useful insight we can state our main result:

Proposition 1. *Only a strongly redistributional form of technological progress (defined as an increase of η) can produce simultaneously all the observed trends.*

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

$$r = \alpha(1-\eta)\frac{Y}{K}, \tag{9}$$

By lemma 1 both $\frac{K}{Y}$ and r need to drop to explain all secular trends. In (9) the interest rate is equal to the marginal product of physical capital. The key insight of proposition 1 is that by (9), 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).

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. We can restate the steady state value of $\frac{m}{Y}$ in the case of positive mortgage credit demand as

$$\frac{m}{Y} = (1-\phi)\frac{p}{Y}\bar{L} - (1-\alpha)(1-\eta). \tag{10}$$

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 moderate 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 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.[15]

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.

5.3. Non-technological drivers

While a redistributive technological shift emerges as the best growth driver able to explain individually the evolution of investment, economic trends certainly reflect multiple causes. Before considering the combined effect of technological progress with capital inflows and rising education, we discuss in more detail why alternative, non-technological growth drivers fail to explain the trends as parsimonious drivers.

Increased education level A rising share of university educated workers can be described by an exogenous increase of the fraction of high skilled labor ϕ in our model

While this driver may explain a growing supply of intangible capital, an expansion of the supply of skilled workers would also result in a drop in the skill premium and an indirect boost to the productivity of physical factors, both inconsistent with the observed trends.

Capital inflows into developed economies Bernanke (2005) warned about a global savings glut driven by outflows from emerging economies. Net flows to developed countries became positive around 1998, peaked during the mortgage credit boom and remained sustained ever

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

since.

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, reducing interest rates. Given capital inflows x_t the market clearing condition becomes

$$(1 - \alpha + x_t)Y_t = p_t\bar{L} + K_{t+1} + f_t. \tag{11}$$

Demographic changes such as aging have a similar effect on savings. In a model with a richer live-cycle structure, a gradual increase in longevity would lead to a rise in savings, also leading to a drop in interest rates and a rise in house prices.

Whatever its source, any exogenous boost to savings does lead to a decline in interest rates and a rise in the price of all long term assets, such as houses and corporate equity. However, ceteris paribus firms would also use more funding and invest more in tangible capital, increasing labor relative to skilled wages. While changes in savings supply have certainly been significant, they cannot represent the key driver of the observed trends.

Increasing bargaining power of innovators A rising ω would reflect an increased share for innovators, e.g. as a result of falling barriers to entry in innovative sectors. This would contribute to a fall in investable claims and depress interest rates, but also support tangible investment through complementarity, much like a falling β. This channel could also result in decreasing a stock market valuations, as investors price a lower share of intangible value captured by firms.

Falling labor share A clearly redistributive growth factor would be a rise in α, the capital share of income at the technological frontier. Piketty (2014) highlights an historical rise in the capital share since the 1970s. In a neoclassical setup, such a shift may reflect differential productivity growth, consistent with the evidence on labor wages (Acemoglu and Autor,

2011). However, this explanation is not consistent with falling interest rates nor a declining tangible investment.

Growing international trade Globalization has had a major effect on the location of production in recent decades, with China starting to play a significant role rather late in our sample. This process is probably best studied with an explicit trade model with knowledge spillovers, an endeavor beyond the scope of our growth model that focuses on the production frontier in advanced economies. However, it can be introduced in our context in reduced form. The simplest formulation is to describe it as a increase in the supply of unskilled labor abroad, as emerging countries progressively adopt current technology. This relocation process reduces domestic tangible investment in advanced countries while boosting it in emerging countries.

A main objection to this formulation is that such a trend is incompatible with falling interest rates. It also cannot by itself account for absolute gains to skilled labor and more generally to positive growth in developed countries.

Yet 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. A combination of technology progress in advanced economies and knowledge spillovers to emerging countries is thus consistent with a progressive rise in η.

6. Calibration and empirical validation

The model's analytical results suggest that a strongly re-distributive form of technological progress is best suited to explain the secular trends since 1980. We now run a quantitative exercise on our model to see how well changes in the technological drivers η and β can explain the observed trends in U.S. data, while taking other evolving factors into account. The approach is not intended as a fully fledged calibration, for which our long term model on

low frequency changes is not suited.

We first calibrate the parameters of the model to 1980 economic conditions, and then gradually change growth drivers to match the evolution of the intangible-tangible ratio observed in the data. The resulting evolution of endogenous variables in the model is compared to the actual series in the data.

6.1. Calibration to 1980

Throughout we use the functional form $v(L) = \ln(L)$, with fixed parameters for $\alpha, \bar{L}, A, \phi, \rho, \tilde{h}$ 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. 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 $\omega = 0.95$. We normalize $\bar{L} = 1$ and set $A = 1$.

This leaves us with the free parameters η, β, $\tilde{h}$ and $\tilde{l}$.[16] 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. The aggregate intangibles ratio from Compustat (shown in figure 1) is matched to the ratio $\frac{H}{H+K}$ in the model. Mortgage credit over GDP is matched to $\frac{m}{Y}$, and land values over GDP to $\frac{p}{Y}$.

As in the model these moments cannot be expressed in closed form we calculate the steady state for a large grid, and pick a parameter combination that results in levels close to the data.[17] 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

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

[17] We do so minimizing the sum of squared distances between model and data, putting a higher weight on the intangibles ratio. The resulting parameter values are $\eta = 0.845$ and,$\tilde{\beta} = 3.105$. 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 $h = 24.438$.

credit over GDP (0.311 vs 0.280).

Under this calibration, the level of $\frac{K}{Y}$ is equal to 0.173, which is also in line with the data. It 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). Unsurprisingly, 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. How well can technological drivers explain the secular trends?

Given the calibration to 1980, our approach is to gradually change growth drivers over time, and see how well they can replicate the observed trends. We calculate the variables of interest across steady states, and also plot a simulated time path.

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.

In a second experiment, we change the technological growth drivers simultaneously with A, ϕ, and x. Changing A allows to target the magnitude of output growth in the data. Section 5.2 highlights the relevance of generating a realistic level of growth. Through its positive overall effect on income, technological progress can benefit factors that do not gain directly.

To account for capital inflows we increase x_t in line with the evolution of the net international investment position of the US and adopt the market clearing condition (11). From 1980 to the mid-1990s the US current account was relatively balanced, while large foreign inflows start towards the end of the 1990s. In line with the data, we let x_t grow linearly from 0 to 0.05 in the mid-1990s, and then more steeply to 0.35 in the final steady state.

We also adjust the fraction of high-skill households from $\phi = 0.17$ in 1980, to $\phi = 0.3$ in the 2010s, in line with the fraction of people with a Bachelor degree or higher in the US.

Table 1: Implied changes across steady states.

Net Borrowing to GDP $\frac{K}{Y}$

	1980	1995	2015	Δ 1980 - 2015
Data: net borrowing / GDP	0.373	0.260	0.052	-86.20%
Data: nores. investment excl. IPP / GDP	0.121	0.094	0.084	-30.56%
Model: η only	0.172	0.114	0.066	-61.67%
Model: $\eta + A, \phi, x$	0.172	0.094	0.044	-74.52%
Model: β only	0.172	0.195	0.222	29.05%
Model: $\beta + A, \phi, x$	0.172	0.219	0.357	107.33%

Real Interest Rate r

	1980	1995	2015	Δ 1980 - 2015
Data: series	0.059	0.042	0.016	-72.27%
Data: HP-filtered trend	0.050	0.041	0.006	-88.46%
Model: η only	0.285	0.255	0.234	-17.84%
Model: $\eta + A, \phi, x$	0.285	0.157	0.071	-75.04%
Model: β only	0.285	0.240	0.196	-31.11%
Model: $\beta + A, \phi, x$	0.285	0.194	0.102	-64.14%

Mortgage Credit to GDP $\frac{m}{Y}$

	1980	1995	2015	Δ 1980 - 2015
Data: series	0.311	0.435	0.579	86.23%
Data: HP-filtered trend	0.311	0.466	0.622	100.69%
Model: η only	0.272	0.354	0.414	51.98%
Model: $\eta + A, \phi, x$	0.272	0.369	0.516	89.38%
Model: β only	0.272	0.251	0.222	-18.38%
Model: $\beta + A, \phi, x$	0.272	0.234	0.289	6.17%

Land Values to GDP $\frac{p}{Y}$

	1980	1995	2015	Δ 1980 - 2015
Data: series	0.399	0.394	0.464	16.30%
Data: HP-filtered trend	0.393	0.499	0.532	35.43%
Model: η only	0.448	0.497	0.537	19.71%
Model: $\eta + A, \phi, x$	0.448	0.517	0.746	66.42%
Model: β only	0.448	0.416	0.375	-16.43%
Model: $\beta + A, \phi, x$	0.448	0.417	0.519	15.78%

As reported in appendix C, the evolution of the intangible ratio, as well as output growth (in the second experiment), are matched quite precisely.

Table 1 reports the implied level and changes of the endogenous series $\frac{K}{Y}$, r, $\frac{m}{Y}$ and $\frac{p}{Y}$.[18] The first three columns report the resulting steady state values, assuming the model is in a stationary state around 1980, 1995 and 2015, respectively.[19] The fourth column calculates the percentage change from the initial 1980 to the final 2015 value.

We compare the results from our model to the corresponding data series. A rising η by itself generates the right sign for all of the trends (including income inequality and stock market capitalization, see appendix).

A weakly redistributive technological progress (falling β) also results in lower interest rates. However, falling interest rates are associated with rising $\frac{K}{Y}$, as highlighted in proposition 1. 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.

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.

Combining falling β with capital inflows, mortgage credit and land values grow modestly. However, this configuration of the growth process still generates rising $\frac{K}{Y}$ and falling wage inequality $\frac{q}{w}$ (see appendix), contradicting the data.

To further illustrate how the model-generated trends compare to the data, we plot the simulated timepath between the 1980 and 2015 steady states in figure 5.[20] The dashed line plots the endogenous evolution of the respective variables when we change only 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.

[18] See appenidx C for $\frac{H}{H+K}, Y, \frac{f}{Y}$ and $\frac{q}{w}$.

[19] The targeted values are the mean intangibles ratio across 1978-1982, 1993-1997, and 2011-2016 respectively.

[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).

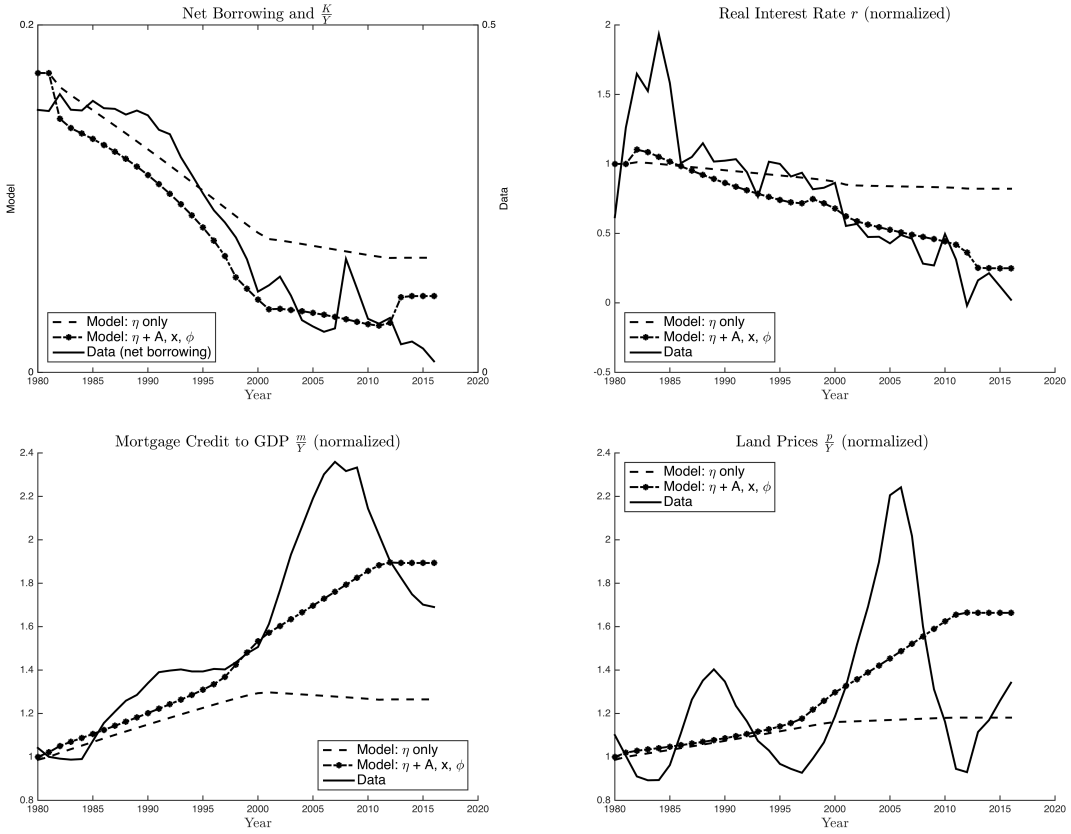


Figure 5: Simulated time path compared to actual series.

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 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 quite close to the underlying trend in the data.

6.3. Cross-country evidence

Here we examine the empirical relationship between mortgage credit and intangible investment in a panel of OECD countries, seeking to explain the share of mortgage credit to total credit from Jordà et al. (2016). According to the model, excess savings driven by intangible use by firms boost this ratio.

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. (2017b) and Peters and Taylor (2016).[22]

Table 2 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 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.

[22]For details see Döttling et al. (2017b). 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.

Table 2: 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)	(5)
	Mortgage Ratio	Mortgage Ratio	Mortgage Ratio	Mortgage Ratio	Mortgage Ratio
Intangibles Ratio (INTAN-Invest)	0.777***	0.706***			0.554**
	(5.00)	(4.05)			(2.55)
Intangibles Ratio (Compustat)			0.299***	0.432***	
			(3.29)	(3.34)	
Log GDP per capita		0.00360		-0.870	0.255**
		(0.04)		(-1.70)	(2.22)
Current Account		0.00175		0.00928	-0.00399
		(0.40)		(1.37)	(-1.40)
Year Fixed Effects	No	Yes	No	Yes	No
Country Fixed Effects	No	No	No	No	Yes
Observations	263	263	264	264	263
Adjusted R^2	0.402	0.392	0.152	0.270	0.516

t statistics in parentheses

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

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 $LTV_{t-1}^i \equiv \frac{(1+r_t)(-s_{t-1}^i)}{p_{t-1}L_{t-1}^i}$ 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 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 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,

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

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 (9) 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 (8), and steady state mortgage credit to GDP (10) 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), (4), (5), (6), (7) and (8).

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):

$$r = \frac{\alpha}{1+\eta}\frac{Y}{K} \tag{B.1}$$

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

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

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

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

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

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 (10) 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 3: 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 (3). 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.