On the role of female health for economic development

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Abstract

We analyze the economic consequences for less developed countries of investing in female health. In a theoretical framework, where parents trade off the number of children against investments in their education, we show that better female health speeds up the demographic transition and thereby the takeoff toward sustained economic growth. In contrast, solely male health improvements delay the transition and take-off because ceteris paribus they increase the gender health gap. We illustrate the analytical results numerically for two stylized less developed economies that differ only in the gap between male and female health. According to our results, investing in female health is an important lever for development policies.

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1 Introduction

While the role of gender (in-)equality for the economic-demographic transition has received considerable attention over the past years, the role of female health for economic development has been addressed but is not yet fully understood.[1] Generally, four channels appear to matter: (i) Healthy women are more able to participate productively in the labor market with direct consequences for the level and growth of economic output. (ii) Better health increases the returns to educational investments in girls: this is both through lower morbidity, allowing for greater labor market participation at the intensive margin, and lower mortality, raising labor market participation at the extensive margin (Jayachandran and Lleras-Muney, 2009; Albanesi and Olivetti, 2013). Besides raising productivity in a direct way, health investments also foster female participation in the labor market and may, as a knock-on effect, lower fertility [see (iv) below]. (iii) Better health of mothers may directly affect the health of her children through in-utero effects as well as the mother's ability to breastfeed and nourish her children in other ways. Female health, thereby, improves development prospects through direct intergenerational transmission of human capital. (iv) Better female health may lower fertility and, thus, economic (youth) dependency with a knock-on effect on female labor participation and educational investments. Lower fertility may arise as a direct consequence of improved reproductive health, in the sense of availability of contraceptives (Bailey, 2006). However, it is also triggered indirectly as a response to changes in female opportunity costs of child-rearing and/or in the returns to education and, thus, in consequence to a swing in the quality-quantity trade-off toward the quality of children (e.g. Galor and Weil, 2000; Soares and Falcão, 2008; de la Croix and Vander Donckt, 2010). The general picture that emerges is that by enhancing female labor participation and education, improvements in female health will have a direct impact on economic development. This direct stimulus is then propagated through ensuing reductions in fertility, which in themselves will trigger additional increases in participation and education — a virtuous cycle. This gives rise to the question to what extent improvements in female health may be an important stimulus fostering the take-off onto a sustained economic growth path.

In this paper we examine some of the mechanisms by which improvements in female health can stimulate economic development by studying a dynamic general equilibrium model in which overlapping generations of families choose consumption, the number of children, and educational investments into their children. Education translates into the stock of human capital of the next generation. We integrate the decision-making at the household level into a two sector economy, where effective labor is either combined with a

[1] See for example Galor and Weil (1996), Knowles et al. (2002), Abu-Ghaida and Klasen (2004), Lagerlöf (2005), Iyigun and Walsh (2007), Soares and Falcão (2008), Kimura and Yasui (2010), Schober and Winter-Ebmer (2011), and Rees and Riezman (2012) for the role of gender inequality for economic development. See Field et al. (2009), Jayachandran and Lleras-Muney (2009), de la Croix and Vander Donckt (2010), Agénor et al. (2010), and Albanesi and Olivetti (2013) for the particular effect of female health. An extensive systematic review of the economic and non-economic literature on female health and its role for development is presented in Iversen and Onarheim (2013).

fixed factor in the production of final goods or employed within an education sector. We solve for the dynamic general equilibrium and study the conditions under which the economy switches from a low-growth regime with high fertility and no educational investments into a modern growth regime with declining fertility and increasing educational investments. Note that we do not analyze the historical take-off to sustained long-run growth that is associated with the industrial revolution in nowadays industrialized countries, but that we focus on contemporaneously poor countries that can benefit from technological spillovers from the rest of the world (see the Unified Growth Theory of Galor and Weil, 2000; Galor, 2005, 2011, for an appropriate description of the historical evolution from stagnation to growth).

Our particular focus lies on the role of female health, which for the purpose of our analysis is assumed to affect female productivity and/or participation in the labor market for any given level of education. We motivate this by the finding that while females may face a longer life-span, they are subject to productivity losses due to greater morbidity during their working lives.[2] Some advance toward understanding this female-male health paradox has recently been made by Case and Paxson (2005) who identify the crucial role of differences in the distribution of conditions over the sexes during younger ages, where women suffer to greater extent from (chronic) conditions which are (objectively) associated with higher morbidity. For any given condition, however, males are typically affected more severely, which explains higher rates of male mortality. We examine how the household choices in the two regimes vary with the level of female health, and what are the implications for the macroeconomic outcomes. Specifically, we seek to understand whether better female health contributes to higher rates of economic growth and an earlier transition from stagnation to sustained economic growth. As healthier females have better access to the labor market (and higher earnings) they have a higher opportunity cost of raising children even within the high fertility regime. This tends to enhance economic growth from technology adoption although the distinction may be insubstantive until the take-off. More importantly, higher female health facilitates the economic transition in that it lowers the earnings threshold at which educational investments in children become profitable. These investments then trigger both the educational and demographic transition which are underlying economic development. While this suggests an unambiguously positive role of female health for economic development, there is an offsetting tendency. This is because the greater participation of (healthy) women in the labor market depresses earnings in the low-growth regime and, thereby, the incentive for households to undertake investments into education. We show both analytically and numerically that despite this offsetting effect, female health is unambiguously speeding up economic transition.

We contrast these findings against the impacts of health improvements for males alone and equiproportional health improvements for both sexes. Here, it turns out that by a pure

[2]Indeed, this is evidenced by the fact that young adult women bear a greater burden of years lived in disability (Vos et al., 2012). In addition, the economic burden of disease within the household appears to fall primarily on women, as is evidenced in Bonilla and Rodriguez (1993).

income effect male health improvements tend to increase fertility because they essentially give rise to a lager gender health gap and, thereby, slow down economic growth and the progress toward economic transition. For an equiproportional health improvement for both sexes, we find that economic growth during the low-growth regime remains unaffected, while it rises in the sustained growth regime. Strikingly, this finding mirrors the empirical results by Cervellati and Sunde (2011) who find that health improvements tend to foster growth of per capita income after the demographic transition but typically not prior to it. Furthermore, we find that the transition from low growth to sustained growth is promoted by equiproportional health investments although not to the same extent as in case of solely female health investments. All these analytical results are also confirmed by our numerical analyses.

Altogether this suggests a distinct role for development policies targeted at female rather than male health improvements. While such policies may be based on female disadvantage regarding access to health care to begin with,[3] our analysis suggests an additional rationale on development grounds. However, targeting female health or even redistributing health care from males to females may come at a loss of utility to the overall household. If this is true, this hints at a conflict between the short-term interests of the household and long-run development goals.

By emphasizing the role of female health for economic development, our model bears some resemblance to the theoretical analyses in Jayachandran and Lleras-Muney (2009), Albanesi and Olivetti (2013), de la Croix and Vander Donckt (2010), and Agénor et al. (2010).[4] The first two of these works examine how fertility and educational choices at household level depend on maternal mortality but do not extend this analysis into a macro-economic framework. de la Croix and Vander Donckt (2010) consider the impact of female health, modeled as a greater amount of healthy life-time, on fertility and gender specific educational investments in a collective household model with Nash bargaining. While they are able to conclude that female health contributes toward a (more likely) transition to a low fertility regime with educational investments into both male and female children, their work is based on a rather rudimentary modeling of the macro-economic environment, essentially consisting of an exogenous increase in wages over time. Thus, they are missing out on general equilibrium effects, which are modulating the transition. While our framework features a much simpler modeling of the household (giving rise to similar mechanics, however), its general equilibrium formulation allows a more accurate and more complete analysis of the macro-economic dynamics.[5] Finally, Agénor et al.

[3]See e.g. Deaton (2008) and Molini et al. (2010) for distribution in height and BMI biased against women; Bhalotra (2010) and Baird et al. (2011) for disproportionate mortality of girls in the presence of economic crisis; Bloom et al. (2001) and Self and Grabowski (2012) for evidence on difficulties for women to access health care when lacking autonomy.

[4]While highlighting the importance of female health for economic development, the work by Field et al. (2009) constitutes a micro-econometric analysis of the role of Iodine deficiency on female and male educational performance in a developing country.

[5]While not analyzing explicitly the role of female health but rather the effects of a general increase in longevity, Soares and Falcão (2008) nevertheless highlight a number of similar channels through which health improvements foster the economic-demographic transition by altering female labor supply and

(2010) consider a complex household model within a general equilibrium framework. Their work highlights the role of public infrastructure for accessing health care, thus giving the analysis a different focus. Furthermore, they concentrate on balanced growth paths, whereas we are particularly interested in the transition process.

The remainder of the paper is organized as follows. Section 2 introduces the model, solves for the optimal choices at the household level, and sets out the market equilibrium. Section 3 is devoted to the dynamics and develops our main result regarding the impact of female and male health on the economic transition. Section 5 provides a numerical characterization of the impact of gender-specific health on the development process, while Section 4 considers some policy experiments. Finally, Section 6 shows that our results are robust to collective household decision-making before Section 7 concludes.

2 The model

In this section we develop a simple analytically tractable dynamic general equilibrium model of economic development, featuring differences in male and female health. Time evolves discretely and in generation t the economy is populated by $N_t/2$ couples formed out of a pool of N_t individuals. We assume that one male and one female match randomly after coming of age. Each couple jointly decides on consumption, the number of children, and the educational investments into each child. The last two decisions determine the population growth rate and the individual human capital level, respectively, which then jointly determine the available aggregate human capital stock of the economy in the next generation $t + 1$.

The aggregate human capital stock net of the time that is spent on child rearing can be employed in two sectors: goods production and education. Educational investments of parents determine employment in the education sector, while aggregate consumption determines the employment in final goods production. The only input in the education sector are teachers $L_{t,E}$, while final goods are produced by using workers $L_{t,Y}$, natural resources of fixed supply X, and the technologies available to generation t, denoted by A_t (see Galor and Weil, 2000). It is assumed that less developed countries do not have an R&D sector for the development of new technologies but rather adopt technologies developed in more advanced countries. For a justification of this assumption see Jones (2002), Keller (2002), and Ha and Howitt (2007), who show that the technological frontier of the world is almost exclusively driven by the most developed industrialized countries. Following Benhabib and Spiegel (2005), p. 941 we model the speed of technology adoption as being positively influenced by the technological gap between the less developed countries and the technology leaders and negatively influenced by the gap in human capital. The former can be justified by the notion that the adoption of new technologies is more likely to pay off the larger the additional amount of output that can be produced by using them

fertility. Similar to de la Croix and Vander Donckt (2010) their model, too, remains a partial equilibrium/household level analysis.

(cf. Howitt, 2000; Acemoglu et al., 2006), while the latter can be justified by the notion that the handling of new technologies requires a certain amount of skills (cf. Nelson and Phelps, 1966).

2.1 Household choices

Consider a less developed economy populated by male-female couples who face the following utility function

$$u = \log(c_t) + \gamma \log(n_t) + \delta \log(\bar{e} + e_t), \tag{1}$$

where c_t denotes joint adult consumption, where n_t refers to the number of children, where e_t denotes investment into the education of the offspring, and where $\bar{e}$ represents the education level that children have without any educational investments by their parents (cf. Strulik et al., 2013). The rationale for $\bar{e} > 0$ is that children acquire knowledge during childhood by observing parents and peers. The parameters γ and δ measure the utility-weight of the number of children and their education, respectively. The budget constraint of the couple is given by

$$\xi_m \widehat{w}_t + \xi_f \widehat{w}_t(1 - \psi n_t) = c_t + e_t n_t, \tag{2}$$

where $\widehat{w}_t := w_t h_t$ refers to the wage rate per unit of time, depending on the human capital of adults, h_t, and the wage rate per unit of human capital, w_t; where ξ_m and ξ_f are measures of male and female health, respectively; and where ψ refers to the fraction of time that is required for giving birth to and caring for one child. Thus, household income on the left-hand side of the equation is composed of the husband's and the wive's earnings, both not only increasing in the (common) level of human capital but also in gender-specific health. We assume that in our developing economy men do not contribute to child-care. Thus, female earnings are lowered by the (full) amount of time ψn_t required for bearing and rearing n_t children. This means that the quality-independent child costs are represented by foregone female earnings. By contrast, the quality-dependent child costs are represented by total educational expenditure $e_t n_t$ on the right hand side of Equation (2).

The impact of health on earnings can be understood in two ways: First, ξ_m and ξ_f may represent health-dependent labor participation in the sense that only healthy time can be used for (productive) employment. According to data from the Global Burden of Disease Study, Vos et al. (2012), p. 2184, find that in 1990 males and females aged 30 live about 0.11 and 0.124 life years in disability (YLD), respectively. Normalizing total time to unity, we would then obtain $\xi_m = 1 - YLD_m (= 0.89)$ and $\xi_f = 1 - YLD_f (= 0.876)$.[6] We are making the additional assumption that child-care has to be provided and can be provided regardless of the mother's health status.[7] Given that child-care is provided

[6] Furthermore, there is case-study evidence that the economic burden of disease (in terms of labor lost) at household level primarily falls on females (cf. Bonilla and Rodriguez, 1993).

[7] This, obviously, rules out from our consideration very severe diseases. While we recognize that a

unconditionally, this implies that available working time is $1 - \psi n_t$, of which a share ξ_f is used effectively, whereas a share $1 - \xi_f$ is lost.[8]

Second, ξ_j, $j = f, m$, may represent productivity at the working place, implying that (effective) wage rates are now given by $\xi_j \widehat{w}_t$, whereas male and female participation are given by 1 and $1 - \psi n_t$, respectively. Indeed, there is ample evidence that individual productivity increases in health.[9] While our analysis does not rely on a priori assumptions about the ordering of ξ_m and ξ_f, the literature on the male-female health gap would suggest that $\xi_m \geq \xi_f$.[10] Lower female productivity may arise, for instance, due to Iodine deficiency, a problem encountered in many developing countries, in particular in Sub-Saharan Africa. As Field et al. (2009) find from microeconometric evidence, insufficient Iodine intake during pregnancy lowers cognitive ability and subsequent educational attainment, in particular for girls. Notably this is true even when girls and boys receive the same amount of schooling. In this context, $\xi_m - \xi_f > 0$ could be interpreted in a direct way as the extent to which maternal Iodine deficiency impairs female productivity for a given quantity of education h_t (as would arise from educational spending e_t).

For fertility to be non-negative and not to exceed the amount that would induce females to spend more time on child-care than their available time budget allows, we assume that $\gamma \in (\delta, \xi_f/\xi_m)$ holds. Solving the couple's utility maximization problem then yields optimal consumption

$$c_t = \frac{(\xi_m + \xi_f)\widehat{w}_t}{1+\gamma}, \tag{3}$$

while optimal fertility and optimal human capital investments are given by

$$n_t = \begin{cases} \frac{\gamma(\xi_m+\xi_f)}{\xi_f \psi(1+\gamma)} & \text{for } \widehat{w}_t \leq \frac{\gamma \bar{e}}{\delta \xi_f \psi} \\ \frac{(\gamma-\delta)(\xi_m+\xi_f)\widehat{w}_t}{(1+\gamma)(\xi_f \psi \widehat{w}_t - \bar{e})} & \text{otherwise,} \end{cases} \tag{4}$$

$$e_t = \begin{cases} 0 & \text{for } \widehat{w}_t \leq \frac{\gamma \bar{e}}{\delta \xi_f \psi} \\ \frac{\delta \xi_f \psi \widehat{w}_t - \gamma \bar{e}}{\gamma - \delta} & \text{otherwise.} \end{cases} . \tag{5}$$

At low levels of wages, $\widehat{w}_t \leq \gamma \bar{e}/(\delta \xi_f \psi)$, the couple divides household income between

number of acute infectious diseases may, indeed, debilitate women to the extent they cannot provide childcare, a number of important chronic conditions (anemia, non-fatal malaria, cataract) are such that they are likely to depress female labor supply but not their ability to provide (at least basic) childcare.

[8] One could argue that the provision of child-care imposes a disutility to the woman while in the sick state. It can be checked that adding a term $-\phi(1-\xi_f)\psi n_t$ to the utility function does not change our results qualitatively as long as $\phi \in \left[0, \overline{\phi}\right]$.

[9] See for example Strauss and Thomas (1998), Schultz (2002), Shastry and Weil (2003), Schultz (2005), Bleakley (2007), Weil (2007), Bleakley (2010a), Bleakley (2010b), and Fink and Masiye (2012). The effects also include health impacts during childhood which reflect on adult productivity: Recent work by Bleakley (2007) and Bleakley (2010a) identifies strong direct effects on adult productivity of childhood exposure to hookworms and malaria, respectively. Notably, productivity increases even for a given level of schooling. As Bleakley (2010b) argues, better child health tends to raise, as first order effect, the quality of a given quantity of education, whereas ensuing (optimal) changes to the quantity of education only give rise to second-order effects.

[10] This is also suggested by the literature on female disadvantage in regard to health and health-care referenced in the introduction.

consumption c_t and fertility n_t alone, while educational investments e_t are zero. The reason is that parents prefer a corner solution in which children only learn incidentally because income is so low that the marginal utility from consumption and fertility outweighs the marginal benefit from educational investments over and above the basic level. However, once wages surpass the threshold $\widehat{w}_t = \gamma\bar{e}/(\delta\xi_f\psi)$, it becomes optimal for parents to invest in their children's education such that e_t turns positive (cf. Strulik et al., 2013). Notably, the threshold depends on female health alone. By implying a greater opportunity cost of child-care, greater female health tends to bias the quality-quantity trade-off toward educational investments rather than the number of children.

For increasing income and human capital, the model replicates a transition from high to low fertility, that is, fertility converges from above to

$$\lim_{\widehat{w}_t \to \infty} n_t = \frac{(\gamma - \delta)(\xi_m + \xi_f)}{(1+\gamma)\xi_f\psi} < \frac{\gamma(\xi_m + \xi_f)}{\xi_f\psi(1+\gamma)}, \tag{6}$$

where the right-hand side represents fertility in the low-growth regime. Furthermore, as can be seen by inspecting Equation (5), once the income threshold for positive educational investments is surpassed, these investments rise with income, paving the way for mass education (cf. Galor, 2005, 2011; Strulik et al., 2013). With regard to the impact of gender-specific health on the household allocation we can now state the following.

Proposition 1. *Given the level of earnings, $h_t w_t$:*

(i) consumption increases (symmetrically) in male (ξ_m) and female (ξ_f) health;

(ii) fertility increases (decreases) in male (female) health both in the low-growth and in the modern growth regime as well as in the long-run limit;

(iii) educational investments in the modern growth regime increase in female health and are unaffected by male health.

Proof. Immediate from differentiation of (4), (5), and (6) with respect to ξ_f and ξ_m, respectively. □

Improvements in male health yield an income effect that unambiguously leads to an expansion of both consumption and the number of children. In contrast, female health improvements yield both an income and a substitution effect. The former leads again to an unambiguous expansion of consumption, but this is no longer true with regard to the number of children. Here, the substitution effect, driven by the greater opportunity cost of children, leads to a reduction in the number of children. While this is true even in the low-growth regime, in the modern growth regime the reduction in fertility comes with greater educational investments.

2.2 Population development and labor force participation

Since each couple gives birth to n_t children at time t, the replacement rate of fertility is given by $n_t = 2$ and the adult population of our model economy evolves according to

$$N_{t+1} = \frac{n_t}{2} N_t. \tag{7}$$

Furthermore, as far as labor market participation is concerned, we abstract from leisure and assume that individuals inelastically supply their available time net of child-rearing. While the interpretation of $\xi_j,\ j = f, m$ as health-dependent participation or as health-dependent productivity has not made any difference to the household analysis, and while it will not make a difference to the key macro-economic relationships as summarized in the system of Equations (22)-(29), the subsequent intermediate analysis of employment in terms of workers (L_t) is based on the interpretation of $\xi_j,\ j = f, m$ as health-dependent participation. Note that for this case human capital h_t is homogeneous across gender so that the wage rate, $\widehat{w}_t$, is gender-neutral, while labor supply

$$L_t = \frac{N_t}{2} \left[\xi_m + \xi_f \left(1 - \psi n_t\right)\right] \tag{8}$$

depends on health in addition to the time that women allocate to child-care.

Remark 1. *The productivity interpretation of $\xi_j,\ j = f, m$, implies that the level of human capital $\xi_j h_t$ is gender-specific, implying that (i) the wage rate $\xi_j \widehat{w}_t$ is now gender-specific, and (ii) labor demand and employment in terms of workers (L_t) will now depend on the gender-composition, whereas (iii) labor supply in terms of workers is no longer health-dependent. In this case, one would have to write out Equations (8), (10), (11), (14)-(16), and (18) in terms of aggregate human capital (H_t). Doing so, one can easily derive wages and earnings as (19) and (20) and the dynamic system (22)-(29) all of which apply regardless of the particular interpretation of $\xi_j,\ j = f, m$.*

2.3 Education sector

Once the income threshold for positive educational investments is surpassed, aggregate spending on formal education is given by education expenditures per couple ($e_t n_t$) multiplied by the number of couples ($N_t/2$), thus amounting to

$$e_t n_t \frac{N_t}{2} = \frac{\delta \xi_f \psi \widehat{w}_t - \gamma \bar{e}}{\xi_f \psi \widehat{w}_t - \bar{e}} \cdot \frac{(\xi_m + \xi_f)\widehat{w}_t}{1+\gamma} \cdot \frac{N_t}{2}. \tag{9}$$

Aggregate education spending is then used to employ a number of $L_{t,E}$ teachers whose aggregate wage bill is given by $\widehat{w}_t L_{t,E}$. Thus, we can derive the equilibrium number of teachers as

$$L_{t,E} = \frac{e_t n_t}{\widehat{w}_t} \frac{N_t}{2} = \frac{\delta \xi_f \psi \widehat{w}_t - \gamma \bar{e}}{\xi_f \psi \widehat{w}_t - \bar{e}} \cdot \frac{\xi_m + \xi_f}{1+\gamma} \cdot \frac{N_t}{2}. \tag{10}$$

These teachers produce the human capital level of the next generation. Recognizing that the productivity of teachers is h_t and that educational resources devoted to each child are given by $h_t L_{t,E}/N_{t+1}$ with $N_{t+1} = n_t N_t/2$, leads to the following equation of motion for individual human capital

$$h_{t+1} = \begin{cases} \bar{e} & \text{for } \widehat{w}_t \leq \frac{\gamma \bar{e}}{\delta \xi_f \psi} \\ \frac{h_t L_{t,E}}{n_t N_t/2} + \bar{e} = \frac{e_t}{w_t} + \bar{e} = \frac{\delta \xi_f \psi \widehat{w}_t - \gamma \bar{e}}{(\gamma - \delta) w_t} + \bar{e} & \text{otherwise.} \end{cases} \tag{11}$$

In the infinite limit, the growth factor of human capital converges to

$$\lim_{\widehat{w}_t \to \infty} \frac{h_{t+1}}{h_t} = \frac{\delta \xi_f \psi}{\gamma - \delta} \tag{12}$$

for rising income levels. The following result is immediate.

Proposition 2. *The long-run growth factor of human capital increases in female health but is unrelated to male health.*

2.4 Production sector

We follow Galor and Weil (2000) and assume that the production technology is given by

$$Y_t = H_{t,Y}^{\alpha} \left(A_t X\right)^{1-\alpha}, \tag{13}$$

where $H_{t,Y} = h_t L_{t,Y}$ refers to aggregate human capital employed in production, with $L_{t,Y}$ being the number of workers, where $A_t \geq 1$ denotes the stock of technologies that a country has at its disposal, where X denotes natural resources of fixed supply, and where α denotes the output elasticity of human capital. This production function implies that, ceteris paribus, an increase in human capital employed in goods production and an increase in the technological sophistication of a country both raise output. Following Galor and Weil (2000) and assuming that there are no property rights defined on the fixed resource X (such that its return is zero), gives the wage per unit of human capital as the average product of human capital, that is,

$$w_t = \frac{Y_t}{H_{t,Y}} = \left(\frac{A_t X}{h_t L_{t,Y}}\right)^{1-\alpha}. \tag{14}$$

The wage rate (per unit of time) is then given by

$$\widehat{w}_t := h_t w_t = h_t^{\alpha} \left(\frac{A_t X}{L_{t,Y}}\right)^{1-\alpha}. \tag{15}$$

As expected, it declines with labor supply and increases with human capital.

2.5 Market clearing

Labor market clearing requires that labor is either employed in goods production or in the education sector such that $L_t = L_{t,E} + L_{t,Y}$, from which we obtain

$$L_{t,Y} = \frac{N_t}{2}\left[\xi_m + \xi_f\left(1 - \psi n_t\right) - \frac{e_t n_t}{\widehat{w}_t}\right], \tag{16}$$

where the second term in square brackets adjusts female labor supply for productivity and child-rearing and the third term in square brackets refers to employment in the education sector. Following Walras' law, we can also determine the amount of human capital employed in production by recognizing that production of final goods has to equal aggregate consumption, that is, goods markets are cleared. Hence, production per capita $y_t := Y_t/N_t$ has to equal consumption per capita such that

$$y_t = \frac{c_t}{2} = \frac{(\xi_m + \xi_f)\widehat{w}_t}{2(1+\gamma)}. \tag{17}$$

Since $w_t = Y_t/H_{t,Y} = y_t/(H_{t,Y}/N_t)$, we obtain the following expressions for human capital and labor employment in final goods production, respectively,[11]

$$H_{t,Y} = \frac{(\xi_m + \xi_f)h_t}{2(1+\gamma)}N_t \qquad \Rightarrow \qquad L_{t,Y} = \frac{\xi_m + \xi_f}{2(1+\gamma)}N_t. \tag{18}$$

Using Equations (14) and (15), we can recalculate wages as

$$w_t = \left[\frac{2(1+\gamma)A_t X}{h_t\left(\xi_m + \xi_f\right)N_t}\right]^{1-\alpha} \tag{19}$$

and

$$\widehat{w}_t = h_t^{\alpha}\left[\frac{2(1+\gamma)A_t X}{\left(\xi_m + \xi_f\right)N_t}\right]^{1-\alpha}, \tag{20}$$

respectively.

2.6 International technology diffusion

In specifying the diffusion of technologies from the technology leaders, i.e., countries that are advancing the world technological frontier according to Keller (2002), we follow Benhabib and Spiegel (2005), p. 941 and assume that

$$A_{t+1} = \max\left\{\frac{h_t}{\bar{h}_t}\left(\frac{\bar{A}_t}{A_t} - 1\right)A_t + A_t, \bar{A}_t\right\} \tag{21}$$

where $\bar{A}_t$ and $\bar{h}_t$ refer to the technological frontier and the human capital level in the most advanced countries, respectively. In this formulation the gap between the average human

[11] The expression for $L_{t,Y}$ can be verified when substituting the optimal values of e_t and n_t into Equation (16) and simplifying the expression.

capital of the less developed country and that of the technology leaders, $h_t/\bar{h}_t$, would act as a technology adoption barrier (cf. Parente and Prescott, 1994). The faster technological progress is in advanced countries, the faster it diffuses to less developed economies (ceteris paribus). This can be justified by the notion that adopting new technologies is more likely to pay off the larger the additional amount of output that can be produced by using them. A proxy for this additional output is given by the technological gap (cf. Howitt, 2000; Acemoglu et al., 2006). The role of the gap between human capital levels of developed and less developed countries as a technology adoption barrier can be justified by the idea of Nelson and Phelps (1966) that the handling of new technologies requires a certain amount of skills.

3 Dynamic behavior of the economy in general equilibrium

Combining our building blocks, we obtain the following dynamic system that describes our model economy in the low-growth regime

$$A_{t+1} = \frac{h_t}{\bar{h}_t}\left(\frac{\bar{A}_t}{A_t} - 1\right) A_t + A_t, \tag{22}$$

$$h_{t+1} = \bar{e}, \tag{23}$$

$$N_{t+1} = \frac{\gamma(\xi_m + \xi_f)}{2\xi_f \psi(1+\gamma)} N_t, \tag{24}$$

$$w_{t+1} = \left[\frac{2(1+\gamma)A_{t+1}X}{(\xi_m + \xi_f)h_{t+1}N_{t+1}}\right]^{1-\alpha}, \tag{25}$$

while the modern growth regime is characterized by

$$A_{t+1} = \frac{h_t}{\bar{h}_t}\left(\frac{\bar{A}_t}{A_t} - 1\right) A_t + A_t, \tag{26}$$

$$h_{t+1} = \frac{\delta\xi_f\psi\widehat{w}_t - \gamma\bar{e}}{(\gamma-\delta)\,w_t} + \bar{e}, \tag{27}$$

$$N_{t+1} = \frac{(\gamma-\delta)(\xi_m + \xi_f)\widehat{w}_t}{2(1+\gamma)(\xi_f\psi\widehat{w}_t - \bar{e})} N_t, \tag{28}$$

$$w_{t+1} = \left[\frac{2(1+\gamma)A_{t+1}X}{(\xi_m + \xi_f)h_{t+1}N_{t+1}}\right]^{1-\alpha}. \tag{29}$$

Consider now the development of the economy from some time t_0 onward and assume that at t_0 the economy is in the low-growth regime. Specifically, this implies

$$h_{t_0} = \bar{e}; \quad n_{t_0} = \frac{\gamma(\xi_m + \xi_f)}{\xi_f\psi(1+\gamma)}; \quad e_{t_0} = 0; \quad w_{t_0} = \left[\frac{2(1+\gamma)A_{t_0}X}{(\xi_m + \xi_f)\bar{e}N_{t_0}}\right]^{1-\alpha} < \frac{\gamma}{\delta\xi_f\psi},$$

where the inequality implies $\widehat{w}_{t_0} < \gamma\bar{e}/(\delta\xi_f\psi)$ and, thus, high fertility and no education investments. One sufficient condition for sustained economic development is the ongoing growth of wages due to international knowledge diffusion. Using Equation (20) we can calculate the growth rate of wages as

$$g_t := \frac{\widehat{w}_{t+1}}{\widehat{w}_t} - 1 = \left(\frac{h_{t+1}}{h_t}\right)^{\alpha} \left(\frac{A_{t+1}/A_t}{n_t/2}\right)^{1-\alpha} - 1, \tag{30}$$

where $A_{t+1}/A_t = \max\left\{h_t/\overline{h}_t\left(\overline{A}_t/A_t - 1\right) + 1, 1\right\}$. It is sufficient for sustained wage growth ($g_t > 0$) that $h_{t+1}/h_t \geq 1$, i.e., human capital is non-decreasing, and $A_{t+1}/A_t \geq n_t/2$, i.e., technological progress does not fall short of population growth, implying that the wage rate is non-decreasing. We can then derive the following more specific sufficient conditions for a transition from low-growth to modern growth and for sustained economic growth in the very long-run.

Proposition 3. *The following holds for the occurrence of a transition, and for its sustainability, respectively:*

(i) A transition from low growth to modern growth arises if

$$\frac{A_{t+1}}{A_t} > \frac{\gamma(\xi_m + \xi_f)}{2\xi_f\psi(1+\gamma)}, \tag{31}$$

with $A_{t+1}/A_t = \max\left\{\overline{e}_t/\overline{h}_t\left(\overline{A}_t/A_t - 1\right) + 1, 1\right\}$ *up until the point of transition.*

(ii) Sustained economic development in the very long run arises if

$$\frac{\delta\xi_f\psi}{\gamma - \delta} \geq 1 \geq \frac{(\gamma-\delta)(\xi_m + \xi_f)}{2(1+\gamma)\xi_f\psi}. \tag{32}$$

Proof. See Appendix 7. □

Within the low-growth regime the wage rate can only increase through a rising "baseline" wage per unit of human capital. This requires that technological growth A_{t+1}/A_t overcompensates population growth $n_t/2$ under high fertility. Given that, realistically, $n_t/2 > 1$ in these economies, this requires that technological growth is positive and sufficiently strong as by condition (31). Assuming that technological growth abates in the very long-run, wages continue to increase (without ambiguity) if human capital continues to grow and if the population stays constant or declines, implying a constant or growing baseline wage. Thus, considering the long-run limits of human capital growth given in Equation (12) and fertility given in Equation (6), we find the sufficient condition (32) for sustained long-run growth.[12]

We can now identify the role of female health for sustained growth and for a transition to a modern growth regime. To this end, assume that transition takes place at $\widehat{t} \geq t_0 + 1$ and that technology growth $A_{t+1}/A_t \simeq \widehat{A}$ is roughly constant on the interval $\left[t_0, \widehat{t}\right]$.

[12] For an exogenous fast drop of technological progress immediately after the transition to the sustained growth regime, a fall back to the low-growth regime cannot be entirely ruled out. A closer investigation of this rather unrealistic case can be found in the appendix.

Defining $\widehat{w}_{\hat{t}} := \gamma\bar{e}/(\delta\xi_f\psi)$ as the wage level at which transition occurs and combining this with the initial wage level

$$\widehat{w}_{t_0} = \bar{e}^{\alpha}\left[\frac{2(1+\gamma)A_{t_0}X}{(\xi_m+\xi_f)N_{t_0}}\right]^{1-\alpha} \tag{33}$$

as well as with the growth rate in the low growth regime

$$g := \left[\frac{2\widehat{A}(1+\gamma)\xi_f\psi}{\gamma(\xi_m+\xi_f)}\right]^{1-\alpha} - 1, \tag{34}$$

we can use the relationship $\widehat{w}_{\hat{t}} = [1+g_t]^{\hat{t}-t_0}\,\widehat{w}_{t_0}$ to solve for the time to transition as a function of ξ_f and ξ_m

$$\Delta := \hat{t} - t_0 = \frac{\ln \widehat{w}_{\hat{t}} - \ln \widehat{w}_{t_0}}{\ln(1+g)}.$$

We then obtain

$$\frac{\partial \Delta}{\partial \xi_f} = \frac{1}{\xi_f \ln(1+g)}\left[-1 + (1-\alpha)\frac{\xi_f}{\xi_m+\xi_f} - (1-\alpha)\,\Delta\frac{\xi_m}{\xi_m+\xi_f}\right] < 0, \tag{35}$$

$$\frac{\partial \Delta}{\partial \xi_m} = \frac{(1-\alpha)(1+\Delta)}{(\xi_m+\xi_f)\ln(1+g)} > 0, \tag{36}$$

which allows us to state our main result.[13]

Proposition 4. *Better female (male) health, that is, a higher ξ_f (ξ_m)*

(i) leads to faster (slower) wage growth in the low-growth regime and in the long-run limit;

(ii) speeds up (slows down) the transition to modern growth.

Economies with better female health tend to experience faster wage growth during the low-growth regime and in the long-run limit. This is because they tend to exhibit a lower downward pressure on the wage rate for an expanding population throughout, and a greater accumulation of human capital in the modern growth regime. While greater wage growth in the low-growth regime is suggesting that economic transition is taking place earlier, this is not quite a foregone conclusion. The reason is that while wages grow faster within economies with healthy females [the last term in (35)] and while these economies enter transition at a lower wage level [the first term in brackets in (35)], they are also starting at a lower wage level [the second term in (35)]. This is because greater female labor participation (or productivity) tends to depress wages to begin with. As it turns out, the economy with a healthier (and more productive) female labor force experiences

[13] Part (i) follows immediately when inserting the low-growth and limiting values of n_t [cf. Equations (4) and (6)] and the limiting value of h_{t+1}/h_t [cf. Equation (12)] into (30) and taking the appropriate derivatives with respect to ξ_f and ξ_m, respectively. Part (ii) follows immediately from Equations (35) and (36), respectively.

economic take-off at an earlier time. We note from (35) that the impact of female health on the speed to transition decreases with the growth rate on the path to transition and increases with the time to transition. Finally, we note that the reduction in the transition threshold is a crucial factor: This is because when the time to transition is short, the impact of lower fertility on the growth rate is insufficient to offset the initial reduction in the wage rate.

All of this is in contrast to the impact of male health which, by raising fertility, tends to slow down economic development. Indeed, male health militates against an economic transition through lowering both the initial level of wages and their growth.

4 Policy applications

From a development policy perspective, our main result in Proposition 4 implies that efforts toward health improvements should be targeted at women. Indeed, the model appears to suggest that it may even be beneficial to redistribute health care from men to women.[14] The following result shows, however, that such a policy would create a conflict with the interests of the unitary household in the short run.

Proposition 5. *Consider a redistribution of health-care from men to women such that* $d\xi_f = -d\xi_m > 0$.

(i) Such a policy unambiguously raises economic growth rates throughout and speeds up the economic transition; but

(ii) for any given wage, $\widehat{w}_t$*, it unambiguously lowers household utility, both in the low-growth and in the modern growth regime.*

Proof. See Appendix 7. □

Thus, while enhancing economic growth and hastening economic transition, a redistribution of health is also lowering household utility. This is true even where such a policy fosters educational investments in the modern growth regime or induces a transition. Indeed, this follows from a revealed preference argument: Noting from the budget constraint (2) that the redistribution is unambiguously lowering family income, it must be true that the household with better male health could always mimic the allocation chosen by a household with better female health and, thereby, do at least as good. Any deviation in the allocation (i.e., the choice of a larger number of children) must then be associated with even greater utility. We realize that this result depends on the assumption of unitary household decision-making and may well change in the presence of collective decision-making. This notwithstanding, it suggests the scope for a conflict between the

[14] The following argument is notwithstanding any justification of the redistribution of health care "opportunities" to women based on an unequal distribution biased against women to begin with (cf. the literature referenced in the introduction).

short-term interests of households, which may favor male health improvements, and the long-term interests of development policies, favoring female health improvements.

In many instances, health policies are not targeted at particular individuals within the household. One may wonder then what the implications for economic development are if women and men benefit from the policy alike.

Proposition 6. *Consider an increase in the health of both sexes by a common factor $\lambda > 1$. Such a policy*

(i) leaves the growth rate unaffected in the low-growth regime and raises the growth rate in the long-run limit;

(ii) speeds up economic transition but lowers the wage for all $t < \widehat{t} + \epsilon$, with $\epsilon \in (0, \infty)$.

Proof. See Appendix 7. □

Given the opposing effects of male and female health on growth and development it is unclear a priori whether health improvements that affect both sexes alike are promoting development. Indeed, it turns out that to some extent this depends on the economic regime itself. While a proportional increase in the health of both males and females promotes growth by lowering fertility and raises education in the modern growth regime, this is not true in the low-growth regime. In the absence of educational investments, proportional health improvements do not reduce fertility and, thereby, leave the growth rate unaffected. At the same time, the increase in labor supply lowers the wage rate, implying that the increase in participation/productivity, does not translate into greater earnings at household level. This result echoes the finding by Cervellati and Sunde (2011) that the impact of health on economic growth depends on whether the demographic transition has yet occurred or not. According to their analysis, health improvements as measured by increases in life-expectancy tend to depress fertility after the demographic transition, thereby unambiguously fostering per capita income growth. This is less clear before the transition, where health improvements may well lead to an increase in fertility and, thereby, compromise per capita growth. While in our model, the health effects work through morbidity/productivity rather than mortality/life expectancy, the impact is very similar: In the presence of a quality-quantity trade-off, female health improvements raise educational investments and the ensuing increase in the cost of child-care is enough to offset the positive income effect of male health on fertility, which is unambiguously reduced. In contrast, before the transition, the income effect, calling for an increase in fertility, exactly cancels the effect from greater female opportunity cost.[15] What our analysis also shows is that common health improvements do, however, facilitate economic take-off.

Table 1: Parameter values for simulation

Parameter	Value	Parameter	Value
δ	0.4660	α	2/3
γ	0.5200	g_h (foreign)	0.45% p.a.
ψ	0.1591	g_A (foreign)	3.85% p.a.
ξ_f	0.8760	ξ_m	0.8900
$\bar{e}$	4.2500	period length t	25 yrs.

5 Numerical analysis

We now illustrate the analytical results by means of a numerical example based on the parameter values given in Table 1. Specifically, we consider two exercises: First, we examine the impact of gender-specific health on the time to transition, seeking to assess the size of the effect; second, we simulate the dynamic system as given by Equations (22) to (29), seeking to assess the impact of gender-specific health on the overall development process. With respect to health we rely on data of Vos et al. (2012), p. 2184, reporting that at global level and for the year 1990 males and females aged 30 live about $YLD_m = 0.11$ and $YLD_f = 0.124$ life years in disability. In terms of labor participation, this implies $\xi_f = 0.876$ and $\xi_m = 0.89$ (i.e., 45.6 and 46.3 weeks per year). We use these values for the baseline scenario and then assess the impact of a percentage point increase in female health in Scenario 1, a percentage point increase in male health in Scenario 2, and a percentage point increase in the health of both sexes in Scenario 3. Note that a percentage point increase in female and male health amounts to an increase of healthy time by a little more than 3 days per year.

Table 2 presents for the baseline case and the three scenarios the pre-transition outcomes in terms of fertility, female labor participation, economic growth, and the time to transition. Fertility lies in the order of 4.3 children per household, a value that is reasonably well in line with empirical evidence for developing economies. Female labor force participation amounts to 0.272, broadly corresponding with the female participation rates reported for India or Turkey (cf. ILO, 2012). The growth rate of 5.6% over a time span of 25 years amounts to annual growth in the order of 0.2% and, thus, to an almost stagnating economy.[16] In consequence, for our baseline economy, the (latent) time to transition amounts to 52.6 years. The percentage point improvement in female health (Scenario 1) lowers this time by some 5 years and 4 months, which is enough to trigger a transition after 50 years (i.e., with the third generation) rather than after 75 years (i.e., with the fourth generation) as in the baseline. In contrast, a percentage point increase in male

[15] Whether fertility increases or decreases ultimately depends on the distribution of health gains in the household. Thus, it is easy to conceive that if males benefit to larger extent, fertility does, indeed, increase.

[16] We assume for this experiment constant technology growth of about 3.8 per cent per year. In our simulation later on below, technology growth is specified according to the flexible form given in Equation (21), giving rise to an average in the same order.

health (Scenario 2) raises the time to transition by about 2 and a half years. Given our assumption of a period length of 25 years, this does not have a bearing on the transition process. Finally, an improvement by one percentage point in the health of both sexes reduces the time to transition by about 3 years and 1 month, which again is enough to induce an earlier transition.[17]

A period length of 25 years leads to rather extreme impacts of changes in health on the transition process as it is modeled. Changes in the latent time to transition of similar (and sizable) magnitude (as e.g. those for scenarios 2 and 3) may either trigger no effect (as for Scenario 2) or a change in the timing of transition by 25 years (as for Scenario 3). In that regard, the latent time to transition is a more realistic measure of the likely impact of health care on the transition process. One second issue with a long period length is that whether health changes advance or delay economic transition (by a generation) is very sensitive to the level of the initial wage $\widehat{w}_{t_0}$.

In light of these concerns one can arrive at a more robust statement about the role of health for economic take-off by considering the following stochastic setting. Suppose the initial conditions of the economy $\{A_{t_0}, N_{t_0}, X\}$ are randomly drawn from a set of values G so that they generate an initial wage $\widehat{w}^b_{t_0} \in \left[\underline{w}^b, \overline{w}^b\right]$ for which transition arises after 3 periods (and 3 periods only) in the baseline scenario (b).[18] It is easy to see that the range of initial wages $\left[\underline{w}^1, \overline{w}^1\right]$ for which transition arises after 3 periods in scenario 1 satisfies $\underline{w}^1 < \underline{w}^b$ and $\overline{w}^1 < \overline{w}^b$ (i.e., the range is shifted "downward"). Intuitively this is due to the fact that better female health reduces the threshold wage for economic take-off.

It can further be shown that, for any given $\{A_{t_0}, N_{t_0}, X\} \in G$ the initial wage in Scenario 1 will satisfy $\widehat{w}^1_{t_0} \in \left[\left(\widehat{w}^1_{t_0}/\widehat{w}^b_{t_0}\right)\underline{w}^b, \left(\widehat{w}^1_{t_0}/\widehat{w}^b_{t_0}\right)\overline{w}^b\right]$ with $\widehat{w}^1_{t_0}/\widehat{w}^b_{t_0} < 1$. This is because of the greater effective labor supply associated with the better female health in scenario 1. Nevertheless, it can be shown that there exists an interval $\left[\overline{w}^1, \left(\widehat{w}^1_{t_0}/\widehat{w}^b_{t_0}\right)\overline{w}^b\right]$ such that a draw $\widehat{w}^1_{t_0} \in \left[\overline{w}^1, \left(\widehat{w}^1_{t_0}/\widehat{w}^b_{t_0}\right)\overline{w}^b\right]$ will induce a transition after 3 periods in the baseline case but a transition after 2 periods in Scenario 1. The probability of such a draw, $\pi_{b1} = \left[\left(\widehat{w}^1_{t_0}/\widehat{w}^b_{t_0}\right)\overline{w}^b - \overline{w}^1\right]\left[\left(\widehat{w}^1_{t_0}/\widehat{w}^b_{t_0}\right)\left(\overline{w}^b - \underline{w}^b\right)\right]^{-1}$, can now be read as the probability that the improvement in female health under Scenario 1 advances the economic transition by 1 period (i.e., by 25 years). For our numerical example we obtain $\pi_{b1} = 0.22$, which is of sizable magnitude.[19]

In our second exercise, we graph the development paths for human capital, population,

[17]A similar exercise can be performed for Scenario 3, where $\pi_{b3} = 0.1259$ gives the probability that the transition is advanced by one generation for an equiproportionate increase in health; as well as for Scenario 2, where $\pi_{b2} = 0.1208$ now gives the probability that a percentage point increase in male health leads to a delay in the transition by one period.

[18]More specifically, $\underline{w}^b := \frac{\gamma\overline{e}/\delta\psi\xi^b_f}{\left(1+g^b\right)^3}$ and $\overline{w}^b := \frac{\gamma\overline{e}/\delta\psi\xi^b_f}{\left(1+g^b\right)^2}$ with g^b as defined by Equation (34). Thus, the lower (upper) bound correspond to the baseline threshold wage discounted by the growth over three (two) periods. If $\widehat{w}^b_{t_0} < \underline{w}^b$, the transition would arise after 4 periods; if $\widehat{w}^b_{t_0} > \overline{w}^b$, the transition would arise after 2 periods.

[19]Similarly, we obtain $\pi_{b3} = 0.126$ as the probability that an equiproportionate increase of health for both genders advances economic take-off by one period (generation); and (in an analogous way) we obtain $\pi_{b2} = 0.121$ as the probability that an improvement in male health delays take-off by one period (generation).

Table 2: Impact of health on pre-transition outcomes and time to take-off.

	Baseline	Scenario 1	Scenario 2	Scenario 3
Health				
ξ_f	0.8760	0.8848	0.8760	0.8848
ξ_m	0.8900	0.8900	0.8989	0.8989
Pre-transition outcome				
Fertility n	4.3349	4.3131	4.3567	4.3348
Participation $\xi_f(1-\psi n)$	0.2718	0.2776	0.2688	0.2745
25-yr. growth rate g	0.0557	0.0574	0.0539	0.0557
Time to transition (yrs.)	52.623	47.313	55.1	49.538
Yrs. gained on baseline	–	5.31	−2.477	3.085

and income, embracing both pre- and post transition periods. The impact of female health improvements is shown in Figure 1. The solid blue line refers to the baseline case, whereas the dashed red line refers to Scenario 1, i.e., an economy which has experienced at the initial time (1950) a percentage point increase in female healthy time. Both economies start with the same population size, the same state of technology, and the same endowment with land. They follow the same path until around the year 2000 when they are still in a low-growth regime without the accumulation of human capital [see Panels a) and b)] and very sluggish growth of income [see Panel f)]. The sole reason for wages to grow at all is that the technological frontier in the rest of the world grows with a constant rate such that the distance to the frontier increases, leading to more intense technology adoption (cf. Howitt, 2000; Acemoglu et al., 2006). On the other hand, the human capital level in the rest of the world also grows persistently such that the gap between the human capital level of the country under consideration and the rest of the world widens. This acts as a barrier to technology adoption and prevents an economic take-off from occurring (cf. Nelson and Phelps, 1966; Parente and Prescott, 1994; Benhabib and Spiegel, 2005). At the point of take-off (for the baseline scenario, this is the year 2025 and for Scenario 1 this is the year 2000), per capita income surpasses the value at which it becomes optimal for individuals to invest in the education of their offspring. From then on parents choose to have fewer children but to educate them better. Consequently, a fertility transition sets in and population growth declines [see Panel d)]. The increase in human capital helps to close the gap between the human capital level of the country under consideration and the rest of the world. This in turn leads to faster technology adoption and a take-off of per capita income [see Panels e) and f)].

By comparison we see that the benefits from female health improvements materialize only over time, but then in an accelerating way. This is due to diverging growth rates of human capital and income in the modern growth regime, implying that an initial advantage is magnified. Interestingly, there is little perceivable difference between the two economies in the “immediate” aftermath of the early transition (i.e., over the years 2000-2025). Thus,

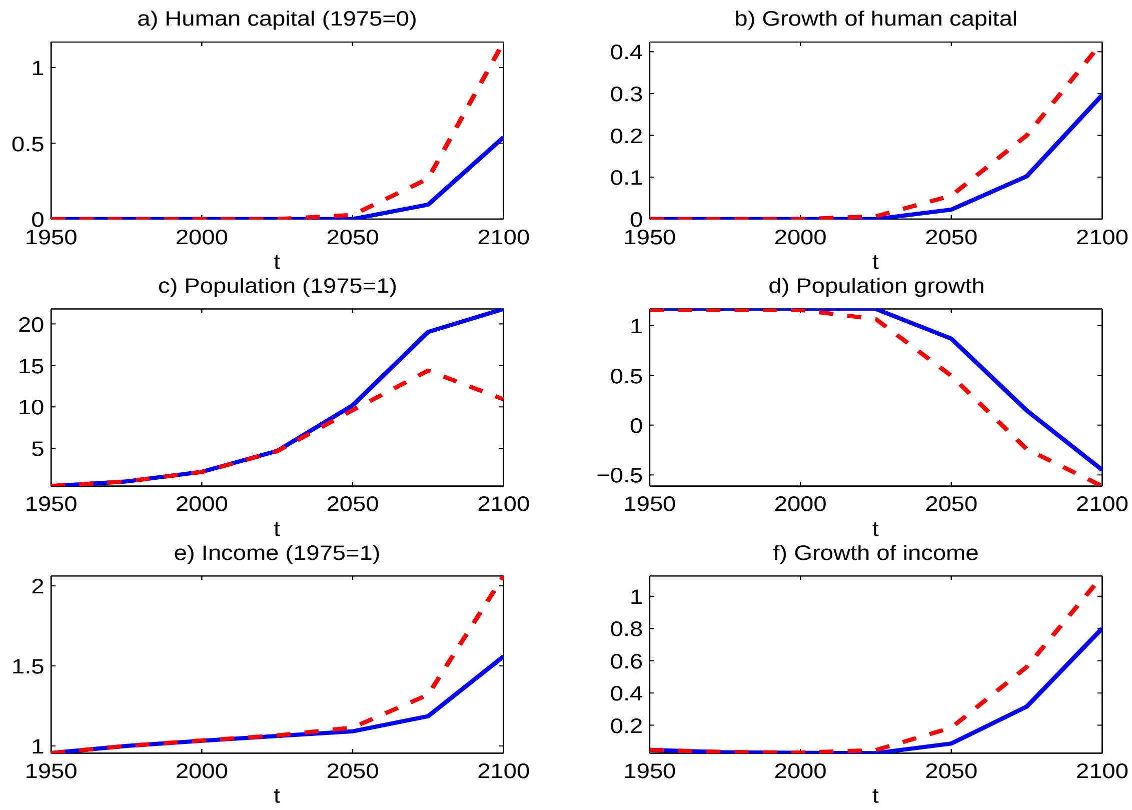

Figure 1: Illustration of the differential take-off in Scenario 1. The baseline simulation is reflected by the solid blue line. The dashed red line refers to a simulation with similar parameter values except that female health increases by 1 percentage point as compared to the baseline simulation.

as it appears, female health improvements create only a small initial advantage in terms of both (slightly) higher growth rates at a (slightly) earlier point in time, but this effect is vastly magnified over the subsequent 50 years.

In Figure 2 we hold female health constant and simulate an increase in male health by 1 percentage point (Scenario 2). In this case, both economies take-off in the year 2025. Nevertheless, the higher fertility level in Scenario 2 even under the modern growth regime places a drag on income growth and the growth of human capital, causing these economies to diverge as well. Finally, in Figure 3, we simulate an equiproportional increase in health of both sexes (Scenario 3). Despite the earlier take-off of the economy with better health, the difference in post-transition growth rates is rather limited, implying that these economies do not pursue grossly diverging development paths.

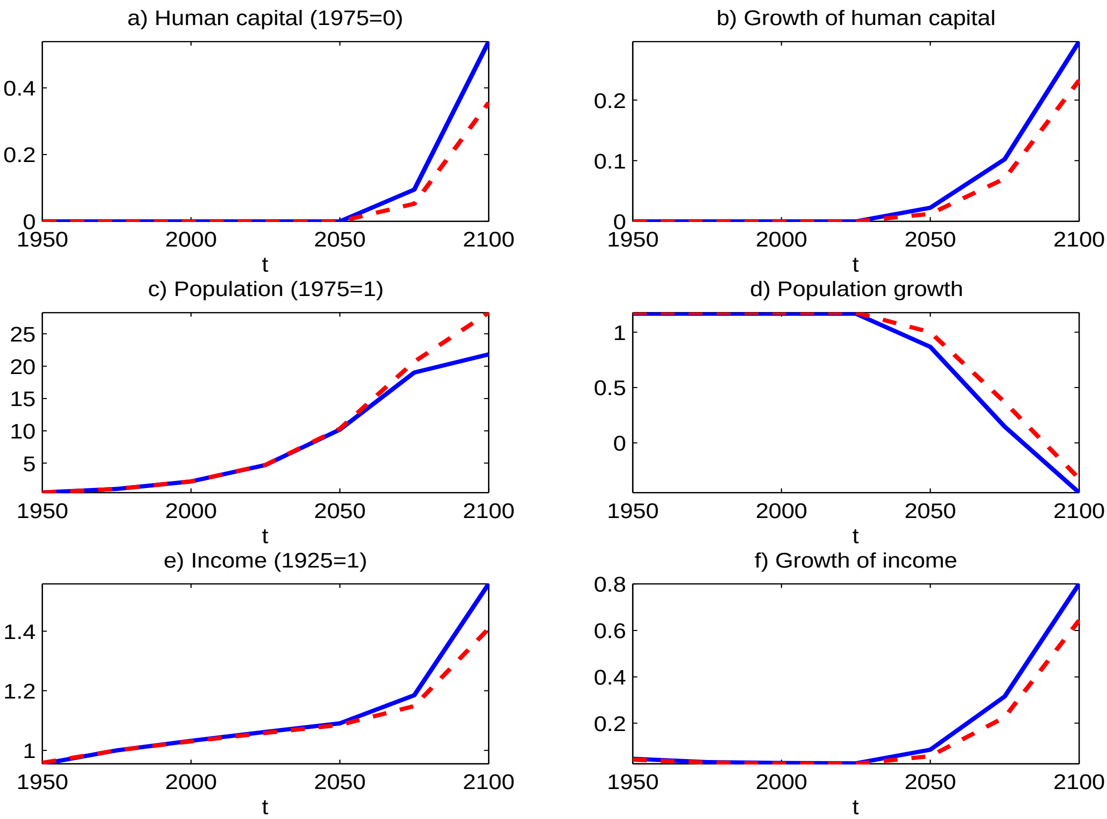

Figure 2: Illustration of the differential take-off in Scenario 2. The baseline simulation is reflected by the solid blue line. The dashed red line refers to a simulation with similar parameter values except that male health increases by 1 percentage points as compared to the baseline simulation.

6 Model with collective household preferences

It is frequently argued that household allocations are (empirically) better represented by models of collective rather than unitary preferences.[20] In order to illustrate the robustness of our main results, this section derives the allocation under collective household preferences and sketches out the implications of (female) health improvements. Thus, consider collective preferences of the form

$$
\begin{aligned}
u \quad = \quad & \widehat{\theta}\left[\log\left(c_t^m\right)+\gamma_m \log\left(n_t\right)+\delta_m \log\left(\bar{e}+e_t\right)\right] \\
& +\left(1-\widehat{\theta}\right)\left[\log\left(c_t^f\right)+\gamma_f \log\left(n_t\right)+\delta_f \log\left(\bar{e}+e_t\right)\right], \qquad (37)
\end{aligned}
$$

according to which each partner $j=m,f$ derives a utility from private consumption c_t^j as well as from the number of children and their education, the latter two being public goods within the household. The distribution function $\widehat{\theta}=\theta\left(\xi_m,\xi_f\right)$ is assumed to depend on

[20] See Browning and Chiappori (1998) for a general characterization and de la Croix and Vander Donckt (2010) and Rees and Riezman (2012) for applications to the economic-demographic transition.

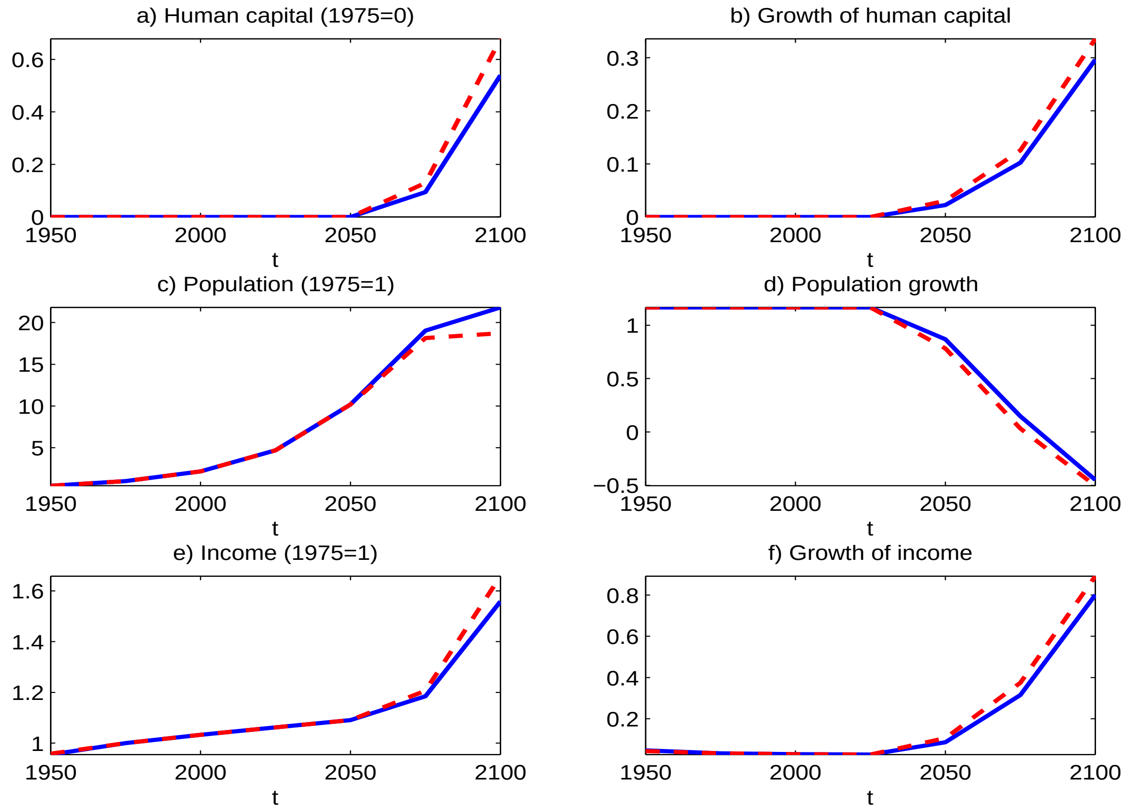

Figure 3: Illustration of the differential take-off in Scenario 3. The baseline simulation is reflected by the solid blue line. The dashed red line refers to a simulation with similar parameter values except that there is an equiproportional increase in health increases by 1 percentage point for males and females as compared to the baseline simulation.

the distribution of health. This can be viewed as a reduced form of the more common representation, where $\widehat{\theta}$ depends on the income distribution within the household. Naturally, we have $\partial\theta/\partial\xi_m := \theta_m \geq 0 \geq \theta_f := \partial\theta/\partial\xi_f$, implying that better female (male) health tends to increase (decrease) the women's bargaining power. We allow that partners differ in their preferences over children and their education. Similar to Rees and Riezman (2012) we follow empirical evidence that men tend to have a stronger preference for private consumption and the number of children as opposed to education (e.g. Schultz, 1990; Thomas, 1990) such that we assume $\delta_m < \delta_f \leq \gamma_f \leq \gamma_m$. Solving the utility maximization problem subject to the original budget constraint (2) we obtain

$$c_t^m = \frac{\widehat{\theta}(\xi_m + \xi_f)\widehat{w}_t}{1+\widehat{\gamma}}; \qquad c_t^f = \frac{\left(1-\widehat{\theta}\right)(\xi_m + \xi_f)\widehat{w}_t}{1+\widehat{\gamma}} \tag{38}$$

for male and female consumption and

$$n_t = \begin{cases} \frac{\widehat{\gamma}(\xi_m+\xi_f)}{\xi_f \psi (1+\widehat{\gamma})} & \text{for } \widehat{w}_t \leq \frac{\widehat{\gamma}\bar{e}}{\widehat{\delta}\xi_f\psi} \\ \frac{(\widehat{\gamma}-\widehat{\delta})(\xi_m+\xi_f)\widehat{w}_t}{(1+\widehat{\gamma})(\xi_f\psi\widehat{w}_t-\bar{e})} & \text{otherwise,} \end{cases} \tag{39}$$

$$e_t = \begin{cases} 0 & \text{for } \widehat{w}_t \leq \frac{\widehat{\gamma}\bar{e}}{\widehat{\delta}\xi_f\psi}, \\ \frac{\delta\xi_f\psi\widehat{w}_t-\widehat{\gamma}\bar{e}}{\widehat{\gamma}-\widehat{\delta}} & \text{otherwise,} \end{cases} \tag{40}$$

for fertility and education with $\widehat{\gamma} := \widehat{\theta}\gamma_m + \left(1-\widehat{\theta}\right)\gamma_f$ and $\widehat{\delta} := \widehat{\theta}\delta_m + \left(1-\widehat{\theta}\right)\delta_f$, respectively. Thus, the allocation follows the same principles as for the unitary household, the only differences being (i) that aggregate household consumption $c_t = \widehat{\theta}c_t^m + \left(1-\widehat{\theta}\right)c_t^f = (\xi_m+\xi_f)\widehat{w}_t/\left(1+\widehat{\gamma}\right)$ is now split according to the distribution rule, and (ii) that fertility and education as household public goods now depend on the weighted sums $\widehat{\gamma}$ and $\widehat{\delta}$ of individual preferences. Noting that $sgn(\partial\widehat{\gamma}/\partial\xi_j) = sgn\left[(\gamma_m-\gamma_f)\,\theta_j\right] = sgn(\theta_j)$ and $sgn(\partial\widehat{\delta}/\partial\xi_j) = \left[(\delta_m-\delta_f)\,\theta_j\right] = -sgn(\theta_j)$, it is straightforward to derive the following result.

Proposition 7. *Given the wage rate $\widehat{w}_t$,*

(i) aggregate consumption at household level increases in female health (ξ_f) but responds ambiguously to male health (ξ_m);

(ii) fertility increases (decreases) in male (female) health both in the low-growth and in the modern growth regime as well as in the long-run limit;

(iii) educational investments in the modern growth regime increase (decrease) in female (male) health.

Generally, the direct impact of health on the household's choices is now modified by the impact of health on the household distribution. For female (male) health improvements this implies that the preference-weight on the number of children is reduced (increased), whereas the weight on education is increased (reduced). In most cases this simply leads to a reinforcement of the effects found for the unitary household model. In particular, female health improvements tend to lower fertility and raise education (in the modern regime) both directly and through the greater emphasis on education as opposed to children in household decision-making. There are two notable changes: First, male health improvements now have an ambiguous impact on household consumption. This is because the positive income effect is now offset by a greater emphasis on fertility. Second, in the modern growth regime, male health now has a negative impact on education, feeding through the lower weight on education in household decision-making.

The implications for the process of economic development then follow in a straightforward way. Note first, that the threshold for economic development $[\widehat{\gamma}\bar{e}/(\widehat{\delta}\xi_f\psi)]$ is unambiguously decreasing with female health. This is both directly and indirectly through the shift in household preferences toward the quality rather than quantity of children. Furthermore, the economic growth rates both in the low-growth and modern growth regime increase with female health due to the reduction in fertility. Finally, it can be established in analogy to Proposition 4 that improvements in female health unambiguously hasten the time to economic take-off.[21]

7 Conclusions

We have studied the impact of health-related differences in female as opposed to male productivity within a dynamic general equilibrium model of economic development with overlapping generations and endogenous consumption, education, and fertility. We solved the model and studied the conditions under which the economy switches from a low-growth regime with high fertility and no educational investments into a modern growth regime with declining fertility and increasing educational investments. By raising female labor participation and, thus, the opportunity cost of children, greater female health has a direct negative impact on fertility. While this moderately enhances earnings growth during the low-growth phase, which is otherwise driven by technology adoption, it also has important level effects: on the one hand, it lowers the earnings threshold beyond which the educational and demographic transition occurs; on the other hand, it lowers the wage level. As it turns out, however, starting from the same initial condition, an economy with greater female health will always take off at an earlier date. In contrast, by raising income at household level, male health improvements tend to increase fertility and, thereby, slow down growth and the progress toward educational and demographic transition and the resulting economic take-off. These analytical results are reflected in our numerical analysis as well.

From a development policy perspective, there appears to be a case for health improvements to be targeted at women. While this may also be justified on intra-household equity grounds, male health improvements may be more effective in promoting household utility in the short run. This is because in societies in which males supply a greater share of their time on the labor market, household income increases by more if it is men rather than women who benefit from a health-related increase in their hourly earnings. Thus, there may well be a conflict between the short-term interests of the household with a stronger emphasis on male health, and long-term development goals with a stronger emphasis on female health. When health improvements benefit both sexes alike, growth is only promoted when an economic-demographic transition has already taken place. Only then will the increase in educational investments associated with better female health lead to an increase in the cost of children that overcompensates the positive income effect on fertility. Nevertheless, economic take-off is still sped up as long as health improvements are not too much biased toward men.

One shortcoming of our model is that it only examines the impact of health on economic

[21] A proof is available from the authors on request.

development that comes through morbidity and, ultimately, productivity and/or labor participation. While such a channel has been identified as empirically relevant (e.g. Field et al., 2009), it is by no means the sole channel. As Jayachandran and Lleras-Muney (2009) and Albanesi and Olivetti (2013) show, reductions in maternal mortality also serve as a trigger by fostering investments in female education, which will ultimately translate into greater participation and lower fertility. An examination of this channel would clearly call for an extension of our model in order to incorporate gender-specific educational investments. While such modeling may prove insightful, it is our view that this would not alter dramatically the mechanics and the results. To some extent, reductions in maternal mortality solely alter the sequence of events: In this case, investments in female education increase before female labor participation increases. By contrast, in our case, reductions in morbidity trigger greater female participation before greater educational investments are triggered. In both cases, however, the joint increase in education and participation comes with a reduction in fertility, which altogether sets out the virtuous cycle of development. That said, reductions in male mortality may also turn out to be conducive to economic development. As Soares and Falcão (2008) show, a fertility decline is triggered by the greater educational investments into children with higher life-expectancy, regardless of their gender.

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Appendix

Proofs

Proof of Proposition 3. Part (i) Since $h_{t+1} = h_t = \bar{e}$ in the low-growth regime, Equation (30) simplifies to

$$g_t = \left(\frac{A_{t+1}/A_t}{n_t/2}\right)^{1-\alpha} - 1.$$

A transition from low growth to modern growth occurs if $g_t > 0$ for all $t \geq t_0$. As is readily checked, this holds if and only if $A_{t+1}/A_t > n_t/2$. Substituting from Equation (4) the low-growth level of fertility gives the condition in Equation (31). Part (ii) Assume that $A_{t+1}/A_t = 1$ in the very long-run, where the economy has reached the technological boundary. In this case the condition $g_t \geq 0$ is satisfied if $h_{t+1}/h_t \geq 1 \geq n_t/2$. Substituting the limit values from Equations (12) and (6) gives the condition in Equation (32). □

Remark 2 (Remark regarding Proposition 3). *Even if Equations (31) and (32) hold, it is difficult to ascertain that $g_t \geq 0$ holds for intermediate values. Consider, for instance,* *a setting where*

$$\frac{A_{t+1}}{A_t} > \frac{\gamma(\xi_m + \xi_f)}{2\xi_f \psi(1+\gamma)} > 1$$

holds before the transition at period $\widehat{t}$, *say, where* $\widehat{w}_{t_0} < \widehat{w}_{\widehat{t}} = \gamma\bar{e}/(\delta\xi_f\psi)$. *Assume that* A_{t+1}/A_t *is declining over time such that* $A_{t+1}/A_t < A_{\widehat{t}+1}/A_{\widehat{t}} = \gamma(\xi_m + \xi_f)/[2\xi_f\psi(1+\gamma)]$ *for* $t > \widehat{t}$. *Also assume that* $\alpha \to 0$ *so that earnings growth is mostly driven by wage growth. But with regard to the latter it is no longer clear whether* $A_{t+1}/A_t > n_t/2$ *holds for* $t > \widehat{t}$. *Indeed, this is true if and only if*

$$\frac{A_{t+1}}{A_t} > \frac{(\gamma-\delta)(\xi_m+\xi_f)\widehat{w}_t}{2(1+\gamma)(\xi_f\psi\widehat{w}_t - \bar{e})},$$

where the right-hand side reflects fertility in the modern growth regime. The condition can be rewritten to

$$\widehat{w}_t > \frac{2\left(A_{t+1}/A_t\right)(1+\gamma)\bar{e}}{2\left(A_{t+1}/A_t\right)(1+\gamma)\xi_f\psi - (\gamma-\delta)(\xi_m+\xi_f)}.$$

As is readily checked, the right-hand side decreases in A_{t+1}/A_t. *Now consider a worst case, where* A_{t+1}/A_t *declines toward* 1 *within a short time span. In such a case the condition runs*

$$\widehat{w}_t > \frac{2(1+\gamma)\bar{e}}{2(1+\gamma)\xi_f\psi - (\gamma-\delta)(\xi_m+\xi_f)}, \tag{41}$$

assuming that the numerator is positive, which is equivalent to assuming that $n_t/2 \leq 1$ *in the long-run limit. Otherwise*

$$\frac{A_{t+1}}{A_t} \to 1 < \frac{(\gamma-\delta)(\xi_m+\xi_f)}{2(1+\gamma)\xi_f\psi} < \frac{n_t}{2}$$

implying that wages decline. Assuming from now on that $1 > (\gamma-\delta)(\xi_m+\xi_f)/2(1+\gamma)\xi_f\psi$, *we note that* $2(1+\gamma)\bar{e}/[2(1+\gamma)\xi_f\psi - (\gamma-\delta)(\xi_m+\xi_f)] > \gamma\bar{e}/\delta\xi_f\psi$, *whenever* $\gamma(\xi_m+\xi_f)/2\xi_f\psi(1+\gamma) > 1$, *that is, whenever there is positive population growth in the low-growth regime. In this case, we have sustained wage growth if Equation (41) holds, but ambiguous outcomes are possible for*

$$\widehat{w}_t \in \left[\frac{\gamma\bar{e}}{\delta\xi_f\psi}, \frac{2(1+\gamma)\bar{e}}{2(1+\gamma)\xi_f\psi - (\gamma-\delta)(\xi_m+\xi_f)}\right].$$

Note that the interval increases in male health. If technological progress declines too quickly for $\widehat{w}_t$ *to grow beyond the upper limit of the above interval, then growth in* $\widehat{w}_t$ *may be reversed and the economy may fall back to the low-growth regime. This may be an unrealistic case but it cannot entirely be excluded.*

Proof of Proposition 5. Part (i) follows immediately from Proposition 4.

Part (ii): As is readily verified from Equations (3)-(5) the redistribution $d\xi_f = -d\xi_m = z > 0$ leaves optimal consumption c_t unaffected. Referring by $\{u_t, n_t, e_t\}$ and $\{u_t', n_t', e_t'\}$ to pre- and post-redistribution levels of utility, fertility, and education, respectively, we then obtain from Equation (1) that

$$u_t > u_t' \Leftrightarrow \gamma\left[\log\left(n_t\right) - \log\left(n_t'\right)\right] + \delta\left[\log\left(\bar{e} + e_t\right) - \log\left(\bar{e} + e_t'\right)\right] > 0. \tag{42}$$

Consider now in turn the three cases, where (a) the low-growth regime arises both pre- and post-reform, i.e. the case where $\widehat{w}_t = h_t w_t < \gamma\bar{e}/\delta\xi_f\psi$; (b) the modern growth regime arises both pre- and post-reform, i.e. the case where $\widehat{w}_t > \gamma\bar{e}/\delta\xi_f\psi$; and (c) the case where for $\widehat{w}_t \in \left[\gamma\bar{e}/\left[\delta\left(\xi_f + z\right)\psi\right], \gamma\bar{e}/\delta\xi_f\psi\right]$ the regime switches from low-growth to modern growth.

Case (a): As is readily checked from (4) and (5), we have $n_t > n_t' = \gamma(\xi_m + \xi_f)/\left\{(1+\gamma)\left(\xi_f + z\right)\psi\right\}$ and $e_t = e_t' = 0$, implying immediately that the second equality in Equation (42) holds.

Case (b): Substituting from Equations (4) and (5) the modern growth values n_t and e_t together with

$$n_t' = \frac{(\gamma-\delta)(\xi_m + \xi_f)\widehat{w}_t}{(1+\gamma)\left[\left(\xi_f + z\right)\psi\widehat{w}_t - \bar{e}\right]} \tag{43}$$

$$e_t' = \frac{\delta\left(\xi_f + z\right)\psi\widehat{w}_t - \gamma\bar{e}}{\gamma - \delta}, \tag{44}$$

we can rewrite the second inequality in Equation (42) as

$$(\gamma - \delta)\left\{\log\left[\left(\xi_f + z\right)\psi\widehat{w}_t - \bar{e}\right] - \log\left(\xi_f\psi\widehat{w}_t - \bar{e}\right)\right\} > 0,$$

which holds since the term in bracelets is positive and $\gamma > \delta$ by assumption.

Case (c): Substituting from Equations (4) and (5) the value n_t from the low-growth regime and $e_t = 0$ together with n_t' and e_t' as from Equations (43) and (44), we can rewrite the second inequality in (42) as

$$G\left(\widehat{w}_t\right) := \left\langle \begin{array}{c} \gamma\left\{\log\left(\gamma/\xi_f\psi\right) - \log\left(\gamma - \delta\right) + \log\left[\left(\xi_f + z\right)\psi - \bar{e}/\widehat{w}_t\right]\right\} \\ +\delta\left\{\log\left(\bar{e}/\delta\right) - \log\left[\left(\xi_f + z\right)\psi\widehat{w}_t - \bar{e}\right] + \log\left(\gamma - \delta\right)\right\} \end{array} \right\rangle > 0.$$

It can be verified that $G_{\widehat{w}_t} < 0$ for $\widehat{w}_t \in \left[\gamma\bar{e}/\left[\delta\left(\xi_f + z\right)\psi\right], \gamma\bar{e}/\delta\xi_f\psi\right]$, implying that

$$\begin{aligned} G\left(\widehat{w}_t\right) &\geq G\left(\gamma\bar{e}/\delta\xi_f\psi\right) \\ &= \left\langle \begin{array}{c} \gamma\left\{\log\left(\gamma/\xi_f\psi\right) - \log\left(\gamma - \delta\right) + \log\left\{\left(\psi/\gamma\right)\left[\gamma z + \left(\gamma - \delta\right)\xi_f\right]\right\}\right\} \\ +\delta\left\{\log\left(\bar{e}/\delta\right) - \log\left\{\left(\bar{e}/\delta\xi_f\right)\left[\gamma z + \left(\gamma - \delta\right)\xi_f\right]\right\} + \log\left(\gamma - \delta\right)\right\} \end{array} \right\rangle \\ &= (\gamma - \delta)\left\{\log\left[\gamma z + \left(\gamma - \delta\right)\xi_f\right] - \log\left(\gamma - \delta\right) - \log\left(\xi_f\right)\right\} \\ &> (\gamma - \delta)\left\{\log\left[\left(\gamma - \delta\right)\xi_f\right] - \log\left(\gamma - \delta\right) - \log\left(\xi_f\right)\right\} = 0, \end{aligned}$$

where the second inequality follows for $z > 0$. Hence, $u_t > u_t'$ for $\widehat{w}_t \in \left[\gamma\bar{e}/\left[\delta\left(\xi_f + z\right)\psi\right], \gamma\bar{e}/\delta\xi_f\psi\right]$, which completes the proof.

□

Proof of Proposition 6. Part (i) follows immediately when recalling from Equation (30) that the growth rate declines with n_t in all regimes and increases with e_t in the long-run limit, and then noting from Equations (4), (6) and (12) that n_t is independent of λ, whereas $\lim_{w_t h_t \to \infty} h_{t+1}/h_t$ is increasing with λ. Part (ii) follows in analogy to part (ii) of the proof of Proposition 4 with the time to transition given by

$$\Delta = \frac{\ln\left(\widehat{w}_{\widehat{t}}/\lambda\right) - \ln\left(\widehat{w}_{t_0}/\lambda^{1-\alpha}\right)}{\ln(1+g)}$$

with $\widehat{w}_{\widehat{t}} = \gamma\bar{e}/\delta\xi_f\psi$, and $\widehat{w}_{t_0}$ and g as defined in Equations (33) and (34), respectively. We then have $\partial\Delta/\partial\lambda = -\alpha\lambda^{-1}\left[\ln(1+g)\right]^{-1} < 0$. Finally, from Equation (33) we have $\partial\widehat{w}_{t_0}/\partial\lambda < 0$, which together with the finding of an unchanged growth rate for $t \in \left[t_0, \widehat{t}\right]$ implies that the wage is unambiguously lower for $t \in \left[t_0, \widehat{t}\right]$ and for some $\widehat{t} + \epsilon$ with $\epsilon \in (0, \infty)$. □

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