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THE GENDER GAP IN EDUCATION INVESTMENT AND THE DEMOGRAPHIC TRANSITION IN DEVELOPING COUNTRIES: THEORY AND EVIDENCE

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The Gender Gap in Education Investment and the Demographic Transition in Developing Countries: Theory and Evidence*

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Abstract

We propose a unified growth model linking technology, education investment across genders, and fertility to explain, for 20th century developing countries: (i) the demographic transition, (ii) the improvement in gender equality in education, and (iii) the transition to sustained growth. The mechanism comprises three components. First, technological progress reduces housework time —through the creation and diffusion of labor-saving home appliances— freeing women's time for childrearing and labor-force participation. Second, as housework time decreases, households invest relatively more in their daughters' education given its higher return —due to the initial imbalance— thus improving gender equality in education and increasing the opportunity cost of childrearing. Third, the narrowing of the education gender gap increases average human capital, accelerating technological progress. This reinforcing loop results in the transition to a new fertility regime and accelerated economic growth. We provide the empirical confirmation of the model's predictions using data from developing countries in the late 20th and early 21st centuries.

Keywords: Unified growth model; gender inequality; demographic transition; developing countries.

JEL Classification: J11, J13, J16, O11, O40.

1 Introduction

In order to explain some stylised facts characterising developing countries in the late 20th and early 21st centuries, we provide a *new mechanism* that combines and goes beyond Galor and Weil (1996, 2000), Greenwood et al. (2005a, b) and Soares and Falcao (2008). Specifically, we show how: (i) the transition to a lower fertility and sustained growth, (ii) the reduction of earnings and human capital gender gaps, and (iii) the increase of female labor market participation are all linked to the reduction of housework time due to technological progress, through its interaction with households' education and fertility choices.

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Indeed, the generalisation of home appliances in the 20th century reduced women's housework burden —see Greenwood and Seshadri (2005) and Greenwood *et al.* (2005a) for the US, and Mayers and Sathaye (1989) for their rapid spread in developing countries.[1] This technology diffusion has reduced housework time, freeing women's time for childrearing and labor market participation. In turn, foreseeing a higher labor market participation, parents have invested relatively more in their daughters' education —to increase their income— and hence relatively less in their sons' education, improving gender equality in education. Fertility has decreased thus because of the increasing opportunity cost of childrearing. In addition, the improvement in gender equality in education has accelerated technological progress —as it has raised the average human capital in the economy— leading to the creation and diffusion of additional time-saving home appliances. The resulting reinforcing loop has thus generated a fertility transition along with accelerated economic growth.

This mechanism explains why, in the late 20th and early 21st centuries, developing countries have experienced a transition exhibiting the following stylised facts, illustrated in figures 1 and 2:

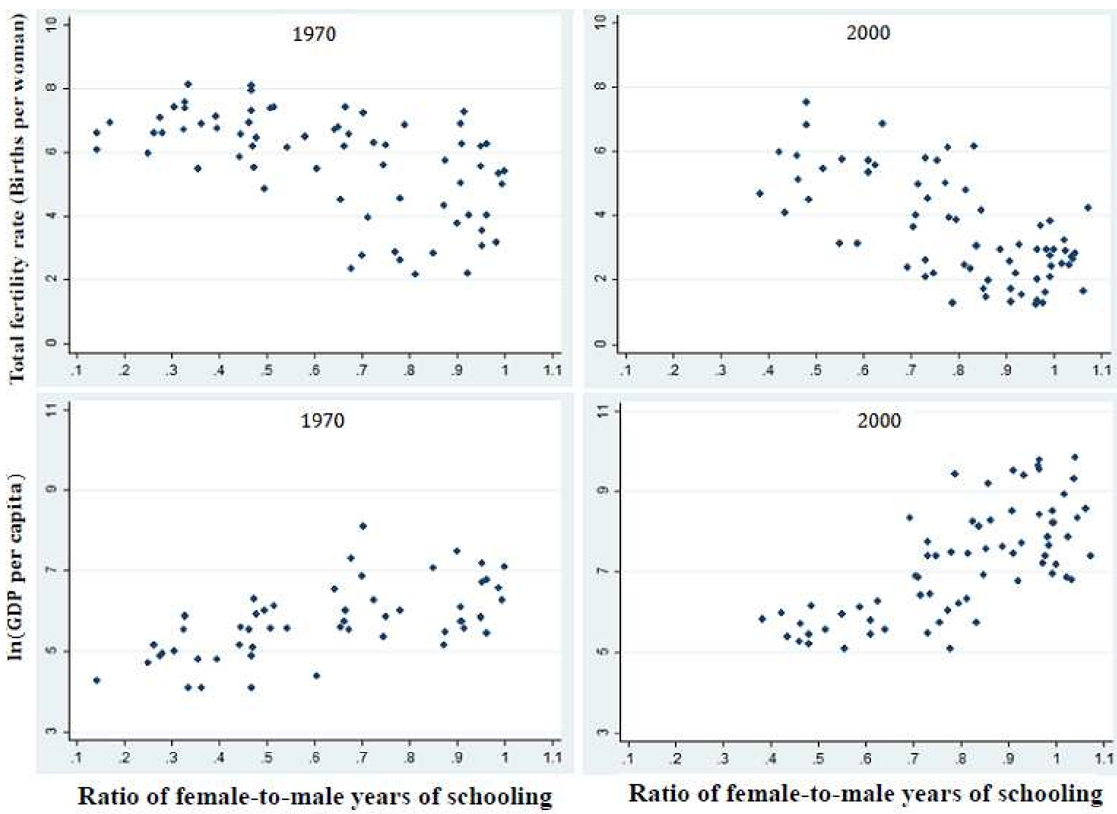

Figure 1: Cross-country plots of fertility and per capita income (in US dollars) against gender equality in education (1970 and 2000). Each dot represents one country. Source: World Bank (2018a, b)

1. a negative correlation between fertility and female-to-male education ratio
2. a positive correlation between *per capita* income and female-to-male education ratio
3. a decline over time in the education and labor income gender gaps

[1] The share of households in Bangkok with refrigerators increased from 26% to 62%, and from 63% to 95% in Taiwan in the period 1975-1984. The generalisation of home appliances also shows up in the increase in residential electricity consumption per capita, from 17 kWh to 110 kWh per capita in the period 1970-1986 in Thailand; from 25 kWh to 248 kWh in South Korea; from 75 kWh to 190 kWh in Mexico; and from 90 kWh to 261 kWh in Brazil (Mayers and Sathaye 1989).

4. an increase over time in the female labor market participation
5. a fertility transition as sustained economic growth takes off
6. an eventual reversal in education across genders

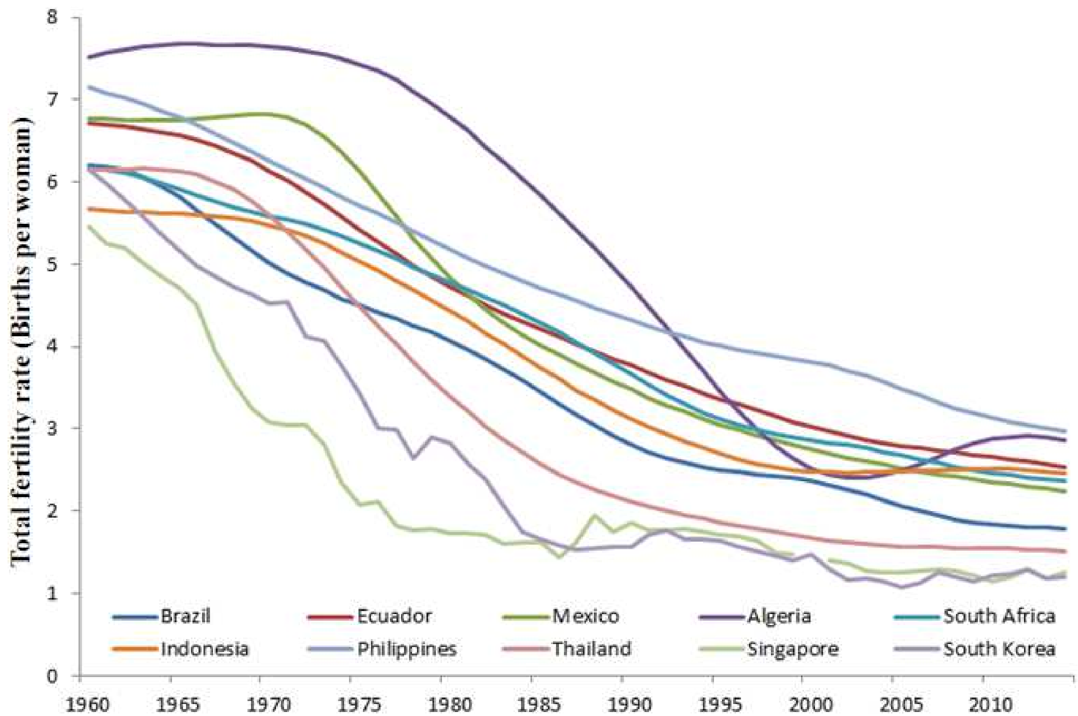

Figure 2: Fertility across countries 1960 - 2014. Source: World Bank (2018b).

This paper thus completes the literature on 19th century demographic transitions[2] in the West (see Galor and Weil (2000), Galor and Moav (2002), Hansen and Prescott (2002), Doepke and Tertilt (2009), Cervellati and Sunde (2015), and recently Dao (2016), among others). It then seeks to explain the 20th century fertility transition of developing countries. Indeed, compared to that of the West, the demographic transitions in Asia, North Africa, and Latin America started around a century later at much lower *per capita* GDP, with fertility falling faster and from higher rates, prompting the search for alternative explanation. Consistent with Galor (2011), our model does not seek to explain the demographic transition simply through mere improvements in income, but rather through technological progress that has strong effects on households' fertility and human capital investment decisions. Still, unified growth theory (Galor and Weil 2000, Galor 2011) would suggest that the child quantity-quality tradeoff is induced by an *increasing rate of technological progress* beyond some threshold. This implies that a faster demographic transition should follow from faster technological progress. However, in the second half of the 20th century, developing countries experienced faster demographic transitions while *rates of technological progress* that did *not* increase over time —e.g. South Korea and Singapore in

[2] A demographic transition refers to the passing from a high fertility and high mortality regime —including child mortality— to a low fertility and low mortality one, generating an inverted U pattern for *net* fertility along the way. For exposition purposes, we do not address mortality throughout the paper, but fertility here can be interpreted as *net fertility*. Child mortality can be included in the model without changing its results significantly. This is consistent with the related literature, where the term demographic transition is used instead of fertility transition to refer implicitly to the potential extension/power of the models. In addition, as pointed out in Herzer *et al.* (2012), the decline in fertility triggered by falling mortality is not essential to explain the secular decline in population growth experienced in the 20th century. For a more comprehensive discussion on this, see Doepke (2005) and Galor (2012).

the period 1965-1990 (Fig. 3) during which their fertility rates declined sharply (Fig. 2). To explain this, our model proposes instead that the developing countries' transitions hinge specifically on the spread of home appliances, and its effects on households' fertility and education choices.[3] The fall in fertility in developed countries took place instead, almost a century earlier, in the absence of a comparable creation and diffusion of home appliances, which was therefore understandably overlooked by the literature. Our model focuses precisely on the role of innovation in home appliances and its diffusion to explain the demographic transition of developing countries in the late 20th and early 21st centuries. Compared to that of developed countries, the literature on the demographic transition in developing countries is limited. The two cases differ mainly in the timings of the fall in fertility that are linked to the literatures on comparative development, based on geographical factors (Dao 2016) and trade between industrial and less developed countries (Galor and Mountford 2006, 2008).

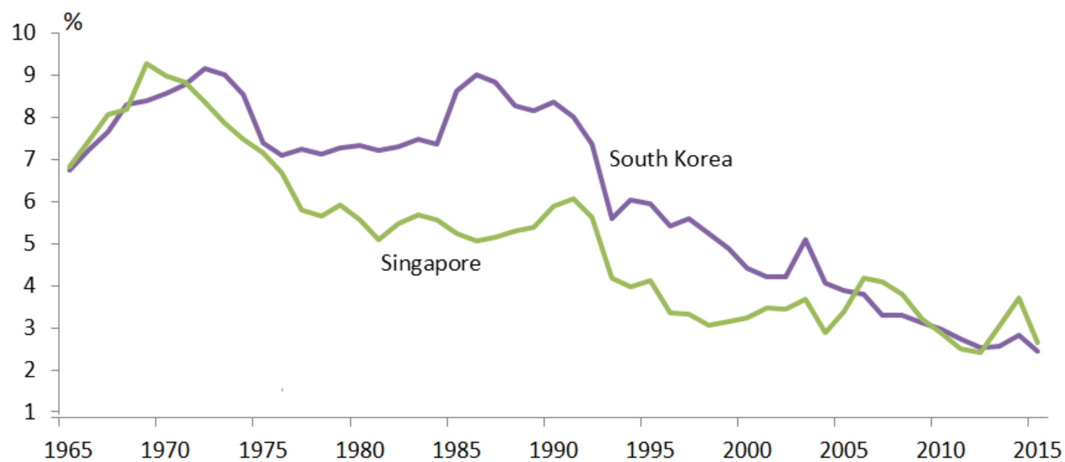

Figure 3: 10-year moving average growth rates of GDP per capita as a proxy for rates of technological progress in Singapore and South Korea (1965 - 2015). Source: World Bank (2018c).

The rest of paper is organised as follows. Section 2 reviews the literature. Section 3 introduces the model and its equilibrium dynamics. Section 4 analyses the evolution of the economy. Section 5 analyses its development to explain the stylised facts and discusses some extensions of the model. The empirical investigation is presented in Section 6, and Section 7 concludes the paper.

2 Related literature

In addition to inserting itself in the child quantity-quality tradeoff tradition (Becker 1960, Becker and Lewis 1973, Galor and Weil 2000, Tamura 2006, Hazan and Zoabi 2015a), our paper relates to the literature on technology and the changing role of women in the household and society (Galor and Weil 1996, Greenwood and Seshadri 2005, Greenwood et al. 2005b, Soares and Falcao 2008, Bloom et al.

[3]The impact of technological progress on the economic role of women was even anticipated very early in the 20th century, as shown by Thomas A. Edison's words: "*The housewife of the future will be neither a slave to servants nor herself a drudge. She will give less attention to the home, because the home will need less; she will be rather a domestic engineer than a domestic labourer, with the greatest of all handmaidens, electricity, at her service. This and other mechanical forces will so revolutionise the woman's world that a large portion of the aggregate of woman's energy will be conserved for use in broader, more constructive fields*", Good Housekeeping Magazine, LV, no. 4 (October 1912, p. 436). Quoted in Greenwood *et al.* (2005a).

2009, Doepke and Tertilt 2009, De la Croix and Vander Donckt 2010, Duflo 2012), as well as the demographic transition (Galor and Weil 2000, Hansen and Prescott 2002, Doepke 2004, Cervellati and Sunde 2015, among others).

Greenwood *et al.* (2005b) study the link between home appliances and the baby boom in *developed* countries after World War II. Home appliances have reduced the marginal cost of childrearing —higher in developed countries— and have thus increased fertility as the depressing effect of rising incomes is more than offset.[4] We focus instead on the reduction of the education gender gap due to the rebalancing across genders of educational investment resulting from the diffusion of time-saving appliances, which shapes the demographic transition in *developing* countries.

Doepke (2004) shows (in a unified growth theory framework) that the introduction of child labor regulations accounts for the different timings and speeds of the demographic transition across countries. Hazan and Berdugo (2002) consider child labor too, and argue that during the development process, technological progress enlarges the wage differential between parental and child labor, thereby inducing a substitution of child education for child labor, which in turn reduces fertility. In an open economy model, the authors suggest that a compulsory schooling policy and an intergenerational transfer to the elders would be Pareto-improving and would accelerate development. While not contradicting these papers, our approach is different in not focusing child labor. We pay instead particular attention to the effect of creating and diffusing home appliances on educational investment in children and on fertility during the development process.

The decline in the gender wage gap in Galor and Weil (1996) is due to the accumulation of physical capital, which is more complementary to women's labor than to men's labor. However, we show instead that technological progress plays also a crucial role in reducing the human capital gender gap, thus improving income equality across genders. Soares and Falcao (2008), in turn, suggest that the narrowing of the gender wage gap and the increase in the female labor supply follow from a demographic transition initially triggered by improvements in life expectancy and the decline in fertility. This does not contradict, but rather complements our paper.

Regarding women's rights and evolution of human capital, Doepke and Tertilt (2009) argue that an expansion of wives' legal rights increases human capital investment for children. This, in turn, helps children to find quality spouses, just like fathers wish for their children. Thus, when voting on women's rights, men hold conflicting goals, between the diminished rights they want for their own wives and the expanded rights they wish for other women. Men's weight on these goals shifts over time with the increasing value of human capital as technological progress takes place, shaping the evolution of human capital and demographic transition.

The model by De la Croix and Vander Donckt (2010) is based on intra-household bargaining to analyse the impact of gender inequality on economic outcomes for least developed countries. It points to the increasing survival probabilities of females and infants, making women more likely to be active in the market and leading to an increase in female education as a key means to escape poverty. Furthermore, higher female education increases women's bargaining power within the household, decreasing fertility

[4]Using US data at county level, Bailey and Collins (2011) have identified a negative coefficient of the home technology adoption rate on fertility, while a baby boom implies a positive one. This result is usually interpreted as evidence contradicting Greenwood *et al.* (2005b). But in a paper reply to these finding, Greenwood *et al.* (2015) point to a misinterpretation by Bailey and Collins (2011), who ignore that poorer households adopted electricity and home appliances later than richer ones, while the latter intrinsically have lower fertility rates.

and improving the quality of children, and so fostering economic growth.[5]

Our paper could have followed the literature of women's empowerment and development more closely (Duflo 2012, Doepke and Tertilt 2019, Hazan et al. 2019). But we do not engage in this interesting debate here. In our view, this literature does not contradict, but rather complements, our paper. The interdependence between women's empowerment and development is a naturally complex issue that no single model captures, the exact nature of the link between women's empowerment and development remaining elusive.

Finally, as for the empirical literature on gender equality and development, most papers study the effects of gender inequality in education or human capital on economic growth: *e.g.* Barro and Lee (1994), Dollar and Gatti (1999), Klasen (2002), and Klasen and Lamanna (2009), among others. More recently, Klasing and Milionis (2017) show the empirical link between improvements in life expectancy and the closing of the education gap across genders —as the global spread of Western medicine against infectious diseases led to relatively larger gains in female life expectancy. These results complement ours to explain the improvement of gender equality in education in the 20th century, since the model can be extended to capture the effect of an increase in life expectancy on fertility and education investment, in order to explain the empirical evidence in Klasing and Milionis (2017). Regarding fertility, human capital and development, Vogl (2016) shows empirically that before 1960 children from larger families obtained more education because they had richer and more educated parents, while this pattern had reversed by the end of the 20th century. These results again also do not contradict ours, even if our model does not take into account heterogeneity across households.

3 The Model

This section sets up a model to explain the demographic transition in *developing* countries. Accordingly, it does not take into account the markets for childcare services and housework aid that contributed to shape fertility patterns in developed countries throughout the second half of the 20th century. Instead, it focuses on the introduction and diffusion of home appliances and their impact on households' decisions on education investment, female labor force participation, and fertility. The economy consists, at any period t, of a number L_t of identical 2-people and 2-gender (male and female) households. Each member of a household lives for two periods —childhood and adulthood— and is endowed with one unit of time when adult. Adults (i) allocate their time between supplying labor, doing housework, and childrearing, (ii) decide how much to invest in their children's human capital, and (iii) consume the remainder of their income. As in Becker (1985), in order to capture gender gaps in earnings and human capital, childrearing and housework are assumed to be carried out by the woman, in accordance with cross-cultural evidence.[6] Regarding childrearing, each household's "child" —also a 2-people, 2-gender household— requires ρ units of parents time, while the human capital of each member of a "child" household is a power $\theta \in (0, 1)$ of the parent household's educational investment, e_t for a son and $\tilde{e}_t$ for a daughter. As for housework time, it is assumed to be decreasing with technological progress, so

[5] On women's rights and marital bargaining power see also Basu (2006), Fernandez (2009), Doepke *et al.* (2012), Doepke and Tertilt (2019).

[6] Specially in developing economies, conventions still make women responsible for childrearing and housework, while the labor market for mostly physically demanding tasks leads households to specialise in a division of labor that sees almost only men participating in wage labor. In Galor and Weil (1996), the opportunity cost of raising children is higher for men than women. Thus, the woman takes care of children until her time constraint is binding, when the man gets involved. However, Galor and Weil (1996) restrict the weight of children in preferences so that men do not participate in childrearing, devoting instead all their time to wage labor. Anyway, letting men do housework and childcare does not change the qualitative analysis as long as it is assumed they do less than women, which seems uncontroversial.

that the fraction of time $\phi_t \in [0,1)$ devoted by period t's adult household to housework is a function $\phi_t = \phi(a_t)$ of the technological level a_t satisfying the assumption[7]

Assumption 1. $\phi'(a) < 0$ and $\lim_{a\to+\infty} \phi(a) = 0$.

For the sake of simplicity, we do not assume that childcare time ρ decreases with technology.[8] In the model, ρ should be interpreted as the time for pregnancy, initial care, and breastfeeding being closely linked to the birth. As for the housework time $\phi(a)$, it could alternatively be made to depend on the size of the household. However, in *developing countries* children usually participate in housework alongside their parents (see Webbink *et al.* 2012) so that fertility has opposite effects on women's housework burden. For the sake of simplicity, we assume that these effects offset each other. Finally, we model housework as unavoidable and hence as not being a choice variable. That fits well into the case of developing countries in which the outsourcing of household chores is almost nil.

3.1 Households

Households choose consumption c_t, the number of their household-children n_t,[9] and the *potential income* of the latter through its educational investment in human capital e_t for sons and $\tilde{e}_t$ for daughters solving

$$\max_{c_t, n_t > 0;\, e_t, \tilde{e}_t \geq 0} (1-\gamma)\ln c_t + \gamma \ln\left(n_t w_{t+1}[e_t^\theta + (1-\phi_{t+1})\tilde{e}_t^\theta]\right) \tag{1}$$

$$c_t + n_t(e_t + \tilde{e}_t) \leq w_t\left[e_{t-1}^\theta + (1-\phi_t-\rho n_t)\tilde{e}_{t-1}^\theta\right] \tag{2}$$

$$\phi_t + \rho n_t \leq 1 \tag{3}$$

given the wage rates w_t, w_{t+1} and the time ϕ_t, ϕ_{t+1} needed for housework, at t and $t+1$, as well as the educational investments e_{t-1} and $\tilde{e}_{t-1}$ made by the household's parents.[10] The parameter $\gamma \in (0,1)$ captures the household's degree of altruism.

A household adult at t is thus assumed to perfectly foresee the fraction of time ϕ_{t+1} that its household-children will devote to housework, since this is determined by its own average human capital through technological progress.[11] But the adult will not foresee what results follow from its *children's choices,* hence the absence of ρn_{t+1} in the objective. Thus, since households derive utility from their

[7] Greenwood *et al.* (2005a) argue that technological progress plays a key role in households' allocation of time. Indeed, the appearance of a mass market for ready made clothes (in the 19th century) and the generalisation of appliances —washing machines, vacuum cleaners, refrigerators (in the mid-20th century), etc.— as well as frozen foods and ready meals (in the mid-late 20th century) freed a considerable amount of time from housework.

[8] This effect —that would indeed foster fertility— can be introduced without changing the qualitative results, in particular, the explanation of the hump-shaped fertility pattern. On the increasing part of the hump, this effect reinforces our mechanism, while on the decreasing part it is dominated by the reduction in fertility through an increased gender equality in education —for reasonable parameters and functional forms.

[9] We assume that the gender birth ratio (male over female) is 1 which is close to the natural gender ratio. Accordingly, a "household-child" is assumed to consist of a son and a daughter.

[10] The main results of our model *do not* change if we assume that the input for educational investment is parents' time instead of income, while this alternative modelling choice requires additional assumptions about who —the father or the mother— is responsible for it, or what is the parents' division of labor in educating children. At any rate, regardless of this, the educational investments in our model would correspond, in the alternative approach, to the opportunity cost of educating children. All in all, the gender gap in education and its properties are determined by equations (11) and (12) whose qualitative behaviour does not depend on this modelling choice. Ours is, at any rate, in accordance with the fact that the importance of formal education for the labor market increasingly exceeds that of education involving parents' time.

[11] Indeed, ϕ_{t+1} has been assumed to be determined by the level of technology a_{t+1}, which itself is determined by the educational investments e_t and $\tilde{e}_t$ chosen for this household by its parent household (see equation (13) below), all of which is known to it.

children's *potential* income $w_{t+1}[e_t^\theta + (1-\phi_{t+1})\tilde{e}_t^\theta]$, parents always invest in their daughters' education regardless of the latter's choice on childrearing and housework time.[12]

It follows from the necessary first order conditions of the problem (derived in the Appendix) that, since by Assumption 1 housework time $\phi_t = \phi(a_t)$ decreases with the technological level a_t, the time constraint is not binding, so that women supply labor to the market, whenever a_t is beyond

$$a^* = \phi^{-1}\left(1 - \left[\frac{\gamma(1-\theta)}{1-\gamma(1-\theta)}\right]^{1-\theta}\right) \tag{4}$$

The following assumption guarantees that $a^* > 0$.

Assumption 2. $\phi(0) = \bar{\phi} > 1 - \left[\frac{\gamma(1-\theta)}{1-\gamma(1-\theta)}\right]^{1-\theta} > \phi(a)$, *for some* $a > 0$.[13]

Assumption 2 requires (for very low technologies) housework time to be so high as to keep women away from the labor market. Without this assumption, the time constraint would never be binding, women would always participate in the labor market regardless of the level of technology, and fertility would always be decreasing in the latter. Nevertheless, in the early stages of development, fertility is typically observed to increase with the level of technology, and women participate in the labor market only when the return to labor is high enough. Assumption 2 also allows chosen fertility to be expressed as

$$n_t = \begin{cases} \frac{1-\phi(a_t)}{\rho} & \text{if} \quad a_t \leq a^* \\ \frac{\gamma(1-\theta)}{\rho}\left[[1-\phi(a_t)]^{\frac{\theta}{\theta-1}} + 1 - \phi(a_t)\right] & \text{if} \quad a_t \geq a^* \end{cases} \tag{5}$$

Comparative statics for education investments and fertility in (16), (17), and (18) with respect to the wage rate w_t and parameters ρ, γ deliver

$$\frac{\partial e_t}{\partial w_t}, \frac{\partial \tilde{e}_t}{\partial w_t}; \frac{\partial e_t}{\partial \rho}, \frac{\partial \tilde{e}_t}{\partial \rho} > 0 \qquad \text{and} \qquad \frac{\partial n_t}{\partial w_t} = 0, \frac{\partial n_t}{\partial \rho} < 0$$

$$\frac{\partial e_t}{\partial \gamma}, \frac{\partial \tilde{e}_t}{\partial \gamma} \begin{cases} > 0 & \text{if} \quad \phi_t + \rho n_t = 1 \\ = 0 & \text{if} \quad \phi_t + \rho n_t < 1 \end{cases} \qquad \text{and} \qquad \frac{\partial n_t}{\partial \gamma} \begin{cases} = 0 & \text{if} \quad \phi_t + \rho n_t = 1 \\ > 0 & \text{if} \quad \phi_t + \rho n_t < 1 \end{cases}$$

Thus, when the woman's time constraint is not binding, a rise in the wage rate w_t generates income and substitution effects on fertility such that the former raises fertility while the latter, which reflects an increase in the opportunity cost of childrearing, reduces it. From the homotheticity of preferences, the two effects offset each other. A rise in w_t translates therefore into a rise in education investments for children. As for the impact of the time cost of childrearing, an increase in ρ reduces the fertility of the household, that trades child quantity for child quality, increasing the education investments.

When women's time constraint is binding, a higher weight γ for children in preferences makes parents invest more in their children's education. When the time constraint of the woman is *not* binding,

[12]That is to say, a daughter's education has a value for her parents, independently of the use that she makes of it. This is consistent with Becker and Tomes (1979) and Galor and Weil (2000), and captures other aspects excluded from the model, like the use of education as hedging device against the risk of a daughter's divorce: see Chiappori and Weiss (2007).

[13]This necessarily requires the condition $1 - \left[\frac{\gamma(1-\theta)}{1-\gamma(1-\theta)}\right]^{1-\theta} > 0$ —since ϕ is decreasing and non-negative for all a— *i.e.* $\gamma(1-\theta) < 1/2$ must holds. This last condition obviously holds for an altruism factor $\gamma < 1/2$, conventionally assumed in the literature: *e.g.* Galor and Weil (1996), Doepke (2004), and Lagerlöf (2003, 2006). We will restrict the value of θ in such a way that this condition holds.

a higher γ increases fertility without changing educational investments, as it generates two opposite effects on child quality. On the one hand, it makes parents allocate more resources to children, both for child quantity and quality. On the other hand, it increases the marginal costs of education investments through the increase in fertility n_t. The two effects cancel out, leaving educational investments unchanged.

Finally, equations (16) and (17) show that when the woman's time constraint is not binding, children's education depends on the income of the mother only, since an increase in the father's income has two opposing effects on children's education that cancel each other out: the income effect increases the number of children, but the increase in the number of children increases the marginal cost of education investment for all children.

3.2 Production

Output y_t is linear in the effective units of labor supplied,[14] so that

$$y_t = A_t\big[e^{\theta}_{t-1} + (1-\phi_t-\rho n_t)\tilde{e}^{\theta}_{t-1}\big] \tag{6}$$

where $A_t > 0$ is the productivity per effective unit of labor, and hence the return to human capital and the wage rate too (i.e. $w_t = A_t$). Productivity is assumed to be a function where$A_t = A(a_t)$ of the level of technology a_t, with $A(a) > 0$ and $A'(a) > 0$ for all $a > 0$, as well as $\lim\limits_{a\to+\infty} A(a) = \bar{A}$. In turn, technology is assumed to evolve according to

$$a_{t+1} = \left[1 + g\Big(\frac{e^{\theta}_{t-1} + \tilde{e}^{\theta}_{t-1}}{2}\Big)\right]a_t \tag{7}$$

where the rate of technological progress between t and $t+1$ is determined by the average human capital —as a function of educational investments— of the generation educated at $t-1$ and working at t, with $g(\cdot) > 0$, $g'(\cdot) > 0$.[15] We consider the impact of *average* (rather than *aggregate*) human capital on technological progress, not taking into account the population size. For the impact of population size on technological progress see for example Galor and Weil (2000), Galor (2005), and Dao and Dávila (2013), according to whom population growth fostered technological progress in the very early stages of development, before education takes place. Beyond some technological level, education plays the essential role and the marginal effect of population size on technological progress is negligible. In the 20th century, population in the developing world was already big and the level of technological high, while education investment was growing. For the sake of simplicity, we therefore ignore the impact of population size on technological progress, without loss of generality for the qualitative results of the

[14] For the sake of simplicity, we do not take into account physical capital. However, the main results are robust when introducing physical capital and assuming diminishing returns for all production factors. Indeed, with physical capital and 3-period living households working and saving in the second period and consuming in the third —the first period being childhood— savings are lent to firms and their return is consumed in the third period, while education investments and fertility choices remain the same. Also, we ignore consumption when young. Nonetheless, with a log-linear utility the saving rate is constant and fertility is independent of the interest rate, and consumption when young could be incorporated into the logarithm utility function, altering the dynamics of the model by just a multiplicative constant.

[15] The impact of human capital on technological progress might depend on the effective participation of workers in production, so that g would depend on $\frac{1}{2}(e^{\theta}_{t-1} + [1-\phi(a_t)-\rho n_t]\tilde{e}^{\theta}_{t-1})$ instead. This would only slow down the transition to sustained growth, but not change it qualitatively (the proof is available upon request). It can nonetheless be argued that women's human capital impacts technological progress through childrearing *via* the children's cognitive abilities, capacity of adaptation to new knowledge, and health, which in turn impact their human capital. The function $g(.)$ describing the dynamics for technology follows the literature of unified growth theory, e.g. Galor and Weil (2000), Galor and Moav (2002), Diebolt and Perrin (2013 a, b).

model.

3.3 Equilibria

At equilibrium, households maximize their utility according to their budget constraints, while output matches consumption and educational investment, in every period t, given the dynamics for technology. A competitive equilibrium is thus characterized —given initial conditions e_{-1}, $\tilde{e}_{-1}$, a_0— by a reduced dynamics in the educational investments for sons and daughters e_t and $\tilde{e}_t$, along with the level of technology a_{t+1},

$$e_t = \begin{cases} \frac{\gamma\theta}{1-\gamma+\gamma\theta} \frac{\rho}{(1-\phi(a_t))\left(1+[1-\phi(a_{t+1})]^{\frac{1}{1-\theta}}\right)} A(a_t) e_{t-1}^{\theta} & \text{if} \quad a_t \leq a^* \\ \frac{\theta}{1-\theta} \frac{\rho}{1+[1-\phi(a_{t+1})]^{\frac{1}{1-\theta}}} A(a_t) \tilde{e}_{t-1}^{\theta} & \text{if} \quad a_t \geq a^* \end{cases} \tag{8}$$

$$\tilde{e}_t = \begin{cases} \frac{\gamma\theta}{1-\gamma+\gamma\theta} \frac{\rho}{(1-\phi(a_t))\left(1+[1-\phi(a_{t+1})]^{\frac{1}{\theta-1}}\right)} A(a_t) e_{t-1}^{\theta} & \text{if} \quad a_t \leq a^* \\ \frac{\theta}{1-\theta} \frac{\rho}{1+[1-\phi(a_{t+1})]^{\frac{1}{\theta-1}}} A(a_t) \tilde{e}_{t-1}^{\theta} & \text{if} \quad a_t \geq a^* \end{cases} \tag{9}$$

$$a_{t+1} = \left[1 + g\left(\frac{e_{t-1}^{\theta} + \tilde{e}_{t-1}^{\theta}}{2}\right)\right] a_t \tag{10}$$

given e_{-1}, $\tilde{e}_{-1}$, $a_0 > 0$.

4 The Evolution of the Economy towards its Long Run Regime

Subsections 4.1 and 4.2 study the dynamics for gender inequality in education, fertility, female labor supply as they interact with technology. Subsection 4.3 addresses the convergence to sustained growth.

4.1 Gender inequality in education

Gender inequality in education is gauged by the female-to-male education investment ratio

$$\mu_t = \frac{\tilde{e}_{t-1}}{e_{t-1}} \tag{11}$$

That is to say, from (8) and (9), lagged one period, it follows that

$$\mu_t = \frac{1 + [1-\phi(a_t)]^{\frac{1}{1-\theta}}}{1 + [1-\phi(a_t)]^{\frac{1}{\theta-1}}} = [1-\phi(a_t)]^{\frac{1}{1-\theta}} \equiv \mu(a_t) < 1 \quad \text{with} \quad \mu'(a_t) = \frac{[1-\phi(a_t)]^{\frac{\theta}{1-\theta}} \phi'(a_t)}{\theta - 1} > 0 \tag{12}$$

so that: (i) there is an education bias against women when $\mu_t < 1$; (ii) a higher μ_t means more equality across genders in education, with complete equality at $\mu_t = 1$; and (iii) gender equality in education improves with technological progress. And, under Assumption 1 and given the technology dynamics in (10), the education gender gap eventually vanishes, i.e. $\lim_{a_t \to +\infty} \mu(a_t) = 1$.

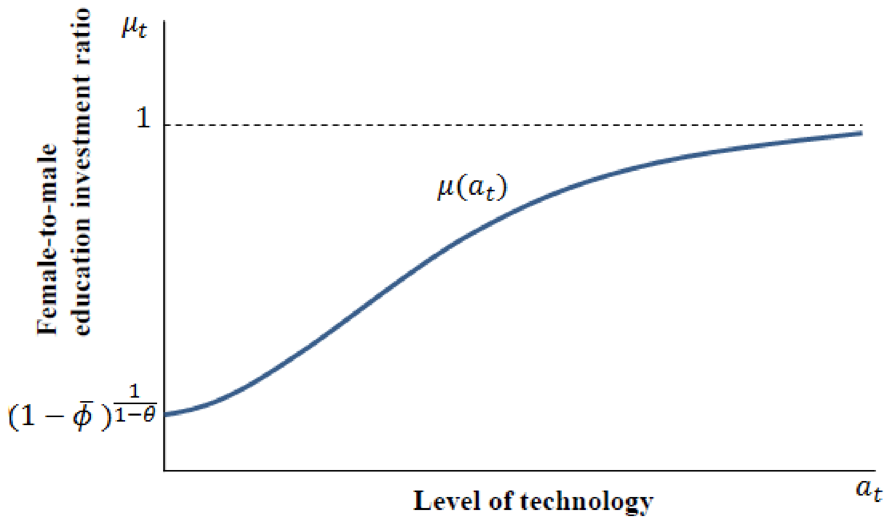

Figure 4: Gender inequality in education against level of technology.

Thus, parents' educational choice is biased against daughters (i.e. sons receive more educational investment than daughters) because women allocate a time to childrearing and housework for which they do not earn any income.[16] Moreover, gender equality in education increases with the level of technology since a higher level of technology reduces housework time, so that women can increase their labor market participation, leading parents to invest more in their daughters' education in order to increase their labor productivity. As a result, inequality in education decreases with technological progress. In turn, the narrowing of the educational gender gap speeds up technological progress, in a reinforcing feedback loop, as established in Lemma 1 next.

Lemma 1. *Whenever the rate of technological progress increases with the average human capital, a higher equality in education across genders (i.e. a higher $\mu_t < 1$) implies a faster technological progress (i.e. a higher growth rate g_t for a_t), for any given level of aggregate human capital*

$$e_t + \tilde{e}_t = \begin{cases} \frac{\gamma\theta}{1-\gamma+\gamma\theta} \frac{\rho}{1-\phi(a_t)} A(a_t) e_{t-1}^{\theta} & \text{if} \quad \rho n_t + \phi(a_t) = 1 \\ \frac{\theta}{1-\theta} \rho A(a_t) \tilde{e}_{t-1}^{\theta} & \text{if} \quad \rho n_t + \phi(a_t) < 1 \end{cases} \tag{13}$$

—*according to (8) and (9).*

Proof. See Appendix **A1**.

□

Intuitively, Lemma 1 follows from the diminishing returns to educational investment captured by $\theta \in (0,1)$, since a reallocation of educational investments towards gender equality in education increases average human capital, and hence the rate of technological progress that boosts income growth.[17]

[16] In section 5 and in the Appendix we introduce heterogeneity across genders in non-cognitive skills to generate a reversal of this bias in educational investment.

[17] Lemma 1 is also consistent with the empirical results in Klasen (2002) showing a positive effect of gender equality in education on economic growth. Klasen (2002) shows that gender inequality in education affects economic growth directly by lowering the average level of human capital, and indirectly through its impact on population and investment.

4.2 Fertility and female labor supply

To see how technology impacts fertility and female labor supply, we rewrite the fertility function

$$n_t = n(a_t) \equiv \begin{cases} \frac{1}{\rho}[1-\phi(a_t)] \equiv n_1(a_t) & \text{if} \quad a_t \leq a^* \\ \frac{\gamma(1-\theta)}{\rho}\left[[1-\phi(a_t)]^{\frac{\theta}{\theta-1}} + 1 - \phi(a_t)\right] \equiv n_2(a_t) & \text{if} \quad a_t \geq a^* \end{cases} \tag{14}$$

and define the women's fraction of time allocated to labor market participation as follows

$$\mathcal{L}(a_t) = 1 - \rho n(a_t) - \phi(a_t) \tag{15}$$

The following proposition states the responses of fertility and female labor force participation to a change in the level of technology.

Proposition 1. *In the economy as set out above:*

(i) When the level of technology is sufficiently low, in particular $a < a^*$, then

(i.a) fertility increases in technological level

(i.b) women spend their full time rearing children and doing housework.

(ii) When the level of technology surpasses the threshold a^* and the return on education does not decrease too quickly, in particular $\theta \in [\frac{1}{2}, 1)$,[18] *then*

(ii.a) fertility decreases with the level of technology, and converges to a constant level

(ii.b) female labor force participation increases with the level of technology, and converges to an upper bound.

Proof. Indeed,

$$n_1'(a_t) = -\frac{1}{\rho}\phi'(a_t) > 0 \qquad \text{and} \qquad n_2'(a_t) = \frac{\gamma(1-\theta)}{\rho}\left[\frac{\theta}{1-\theta}[1-\phi(a_t)]^{\frac{1}{\theta-1}} - 1\right]\phi'(a_t) < 0$$

Note that $n_1(a_t)$ starts below $n_2(a_t)$ at the origin, since

$$n_1(0) = \frac{1-\bar{\phi}}{\rho} < \frac{\gamma(1-\theta)}{\rho}\left[(1-\bar{\phi})^{\frac{\theta}{\theta-1}} + 1 - \bar{\phi}\right] = n_2(0)$$

while $n_1(a_t)$ converges to a higher limit than $n_2(a_t)$, overtaking $n_2(a_t)$ at a^*, as a_t increases

$$\lim_{a_t \to +\infty} n_2(a_t) = \frac{2\gamma(1-\theta)}{\rho} < \frac{1}{\rho} = \lim_{a_t \to +\infty} n_1(a_t)$$

And

$$\mathcal{L}(a_t) = \begin{cases} 0 & \text{if} \quad a_t \leq a^* \\ 1 - \rho n_2(a_t) - \phi(a_t) & \text{if} \quad a_t \geq a^* \end{cases}$$

[18] This is just a sufficient condition to guarantee fertility decreasing with technological progress when the level of technology is high enough.

$$\mathcal{L}'(a_t) = \begin{cases} 0 & \text{if} \quad a_t < a^* \\ -\rho n_2'(a_t) - \phi'(a_t) > 0 & \text{if} \quad a_t > a^* \end{cases} \quad \text{and} \quad \lim_{a_t \to +\infty} \mathcal{L}(a_t) = 1 - 2\gamma(1-\theta).$$

□

The effects of technological progress on fertility and female labor force participation are illustrated in Figure 5.

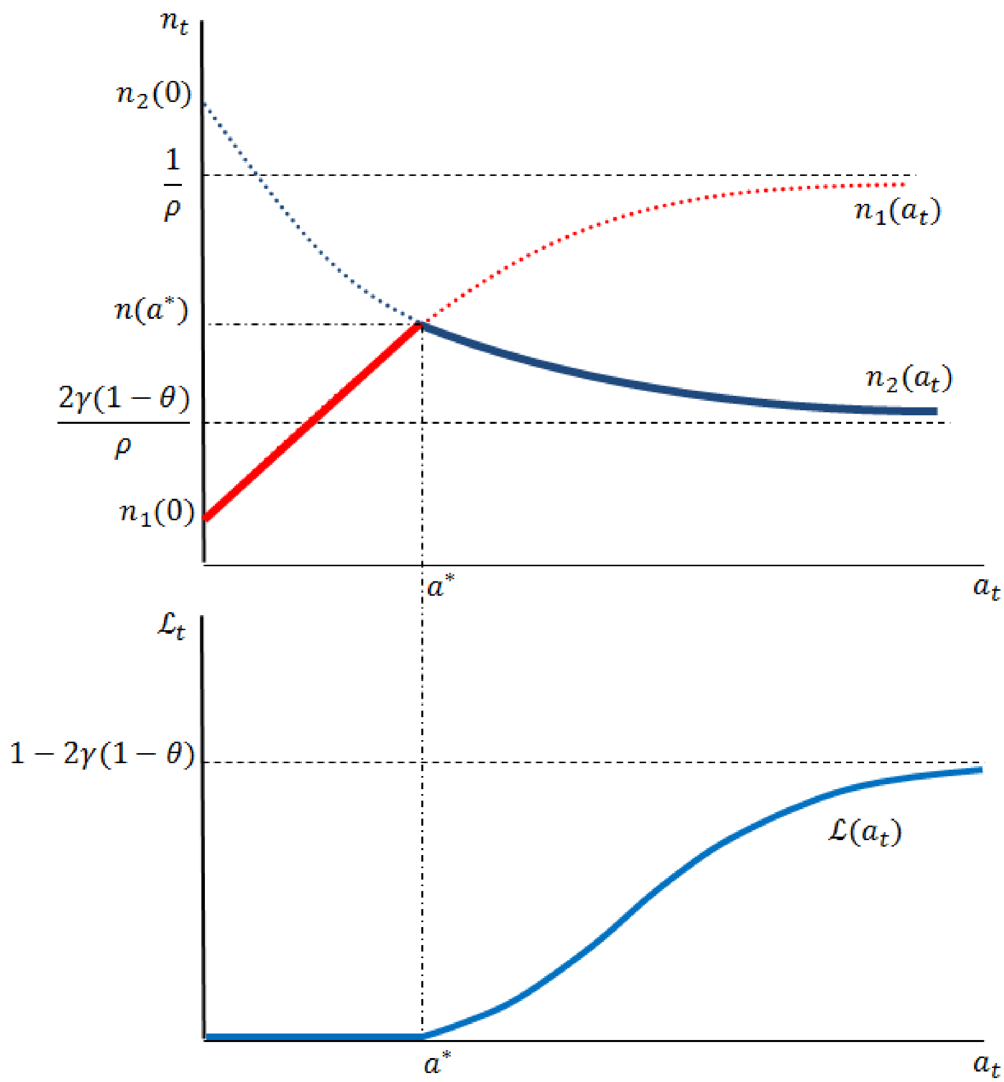

Figure 5: Fertility (upper graph) and female labor-force participation (lower graph) against technology

Thus, while at low enough levels of technology women's time is entirely devoted to childrearing and housework, as a_t increases (but stays below a^*) the time freed from housework shifts to childrearing so that, during the early stages of development, technological progress increases fertility.[19] As a_t surpasses a^*, women enter the labor market and carry out housework and childrearing only part-time. Technological progress shrinks the human capital gender gap in (12) because of the higher returns to female education and their new labor market participation, reducing thus the earnings gender gap.

[19]Some studies in the literature provide empirical evidence on the positive correlation between income/productivity and fertility in early stages of development supporting this Malthusian feature (see Crafts and Mills (2009) for England in the 16th-18th centuries, Lagerlöf (2015) for Sweden in the 18th-19th centuries, and Ashraf and Galor (2011) for the period 1-1500 CE). Several theories also predict such a positive correlation in early stages of development (see e.g. Malthus 1798, Galor and Weil 2000, Galor and Moav 2002).

The increase in women's earnings raises, in turn, the opportunity cost of childrearing. Thus, as the cost of raising children increases, households substitute the quality of children to quantity.[20]

Finally, note that while the model predicts a female labor supply which is constant at zero when fertility is increasing, this is consistent with the reports in Goldin (1995) of a sharp increase in female clerical employment in the US during period 1890-1950, as the reported labor supply increase is associated with a decline in fertility during that period, i.e. when the technological level exceeded threshold a^*.

4.3 Long run convergence

The long run behavior of the economy in Section 3 is characterized in the following proposition.

Proposition 2. *The overlapping generations economy converges —from any initial conditions a_0, e_{-1}, $\tilde{e}_{-1} > 0$— to a stationary regime of sustained growth characterized by: (i) a growth rate of technology $\bar{g}$, (ii) high educational investments $\bar{e}$ and complete equality across genders, and (iii) a low fertility rate $\bar{n}$.*

Proof. Firstly, Proposition 2 hinges next on the following Lemma 2 whose proof is in Appendix A2.

Lemma 2. *For $x_{t+1} = m_t x_t^\alpha$ with $0 < \alpha < 1$, $x_0 > 0$, and $\lim\limits_{t \to +\infty} m_t = m > 0$, it holds $\lim\limits_{t \to +\infty} x_t = m^{\frac{1}{1-\alpha}}$.*

Thus, according to (10), since $e_t > 0$ or $\tilde{e}_t > 0$ for all t, the level of technology a_t increases unboundedly over time. Therefore, since $\lim\limits_{a \to +\infty} \phi(a) = 0$ is decreasing and $\lim\limits_{a \to +\infty} A(a) = \bar{A}$ is increasing, it follows from (8), (9) and Lemma 2 that technology will progress asymptotically at a constant rate

$$\bar{g} = g(\bar{e}^\theta) \quad \text{where} \quad \bar{e} = \lim_{t \to +\infty} \tilde{e}_t = \lim_{t \to +\infty} e_t = \left[\frac{\theta}{1-\theta} \frac{\rho}{2} \bar{A} \right]^{\frac{1}{1-\theta}}$$

Finally, from (14), the fertility will converge at a decreasing rate towards the constant rate

$$\bar{n} = \lim_{t \to +\infty} n_2(a_t) = 2 \frac{\gamma(1-\theta)}{\rho}.$$

□

Proposition 2 is consistent with the modern regime of sustained growth characterized by unbounded economic growth, a low and decreasing fertility rate, and high human capital. It allows the process experienced by developing countries in the 20th century to be accounted for, and which was characterized by: (i) an initial increase in per capita income and fertility; (ii) a demographic transition after which fertility fell while per capita income kept growing; and (iii) a final regime of sustained growth with fertility converging to a low level and accelerated per capita income growth. During the transition

[20] The model abstracts from child mortality to explain the demographic transition. Indeed, there has been a lack of consensus in the literature about the role of child mortality in explaining demographic transition. Kalemli-Ozcan (2002, 2003), Tamura (2006), Tamura et al. (2016), Tamura and Simon (2017), and recently Cuberes and Tamura (2019) are in favor of the view that falls in child mortality may induce declines in fertility. Using the altruistic parents model of Barro and Becker (1989), Doepke (2005) provides results suggesting that the fall in net fertility during the 19th century in the industrialized countries was driven by factors other than the fall in child mortality, pointing out that the decline in child mortality has been dismissed as a cause of the decline in fertility, because of the inconsistency of this link. Galor (2012) shares this view, showing that the fall in fertility in Western Europe started nearly a century after the decline in child mortality. Herzer *et al.* (2012) show a positive correlation between child mortality and fertility in the 20th century, but not a strong enough relationship to explain the secular decline of population growth. Recently, Murphy (2015) has shown empirically that child mortality had no impact on fertility during the demographic transition in France, while female education seems to have played a role.

through these three stages, gender equality in education and income, as well as female labor force participation, increased steadily.

Indeed, consider an economy at an early stage of development, with a low level of technology $a_0 < a^*$ and low human capital across genders. The low technological level prevents women from participating in the labor market in two ways. First, directly, as a large fraction of women's time is required for housework. Second, indirectly, as the low level of technology biases the educational investments against daughters,[21] making the opportunity cost of childrearing too low, so that households choose a high fertility rather than female labor market participation. In turn, as at this early stage, household income is very low —due to the low human capital and low technological level— households' educational investments are very small too. Average human capital, which drives technological progress, is very low for both male and female children, and the growth rate of technology therefore also remains low. In addition, at this early stage of development, since housework requires a very large fraction of women's time, the remaining time for childrearing is very small, so that the population growth rate is initially low. Nevertheless, since technology improves even when the average human capital is small, albeit very slowly, the technological level eventually increases, so that housework time decreases, as long as it stays low enough (i.e. for $a_t < a^*$). This frees time for childrearing, while the cost of childrearing is still low, so that the fertility rate increases. As the technological level a_t increases, fertility increases and reaches a maximum when a_t reaches a^*. When it increases even further (i.e. for $a_t > a^*$), women start and increase their labor market participation due to two effects. First, technological progress reduces housework time. Second, it improves the return to human capital, increasing women's earnings, and thus raising the opportunity cost of childrearing. Fertility therefore decreases as the level of technology increases. It follows also from (8) and (9) that the total educational investment increases with the level of technology when $a_t > a^*$, so that households substitute quality to quantity in their fertility choice. The increase in the level of technology makes households invest relatively more in daughters' education as the return to female education is higher and, as a consequence, gender equality in education improves, accelerating technological progress. This reinforcing feedback loop makes the economy enter a regime of sustained economic growth.

5 Discussion

Our model captures key aspects of the development process experienced by many developing countries during the late 20th end early 21st centuries, but it does not address them all. Related to this process there is, for instance, the U-shaped relation between female labor force participation and income, the U-shaped relation between women's education and fertility, and the reversal in education across genders that we discuss next. Other aspects not captured by the model like the link between women's empowerment and development (Duflo 2012, Doepke and Tertilt 2019, and Hazan et al. 2019, among others) are worth integrating into future research.

As for the U-shaped relationship between female labor force participation and income, the model

[21] Households anticipate the large fraction of time that daughters will have to devote to housework, due to the low level of technology. Since men's supply of labor to the market is inelastic, while women have to spend a fraction of their time for housework, households allocate most of their educational investment to their sons, making the education of their offspring very unequal across genders.

predicts that female labor force participation never decreases with the level of technology, and increases when the latter is high enough, specifically for $a_t > a^*$, which is consistent with Galor and Weil (1996). Nevertheless, Goldin (1995) and Mammen and Paxson (2000) find an empirical U-shaped relation between female labor force participation and per capita income, across countries and stages of economic development. Goldin (1995) argues that, during early stages of development, most households live in rural areas where childrearing and agricultural work are easily compatible, and women are often unpaid workers on their family farms. As incomes increase, driven by technological progress going hand in hand with urbanization, female labor force participation rates fall because of an income effect and a fall in the demand for female labor in agriculture.

Our model is actually silent about women's non-market activities during the early stages of development, considering only formal labor market participation. Galor and Weil (1996) discuss variations of their model that generate a U-shaped relationship. One of them consists of considering that women can produce marketable goods at home, as well as taking care of childrearing, which can be incorporated in the current model to replicate the U-shaped relationship in Goldin (1995). Indeed, if we assume that home production is compatible with childrearing and housework, and the time for home production $\tilde{\phi}(a_t)$ is a decreasing function of the level of technology so that women spend a large fraction of time doing housework and home production during the early stages of development when the level of technology is low, then the low fertility rate in this period is combined with a high rate of female participation in the labor force. As the level of technology increases —reducing housework time *and home production time*— fertility increases. When technology reaches a high enough level, increasing the return to female education, women enter the paid labor force, generating a persistent increase in female labor market participation rates.

Looking at the current U-shaped relationship between women's education and fertility in the US, Hazan and Zoabi (2015a) recently used the emergence of markets for childcare and housework aid to explain the current U-shaped relationship between women's education and fertility in the US. Nonetheless, while these factors matter for developed countries, where increases in female education and labor force participation go hand in hand with outsourcing housework and childrearing to cheap immigrant labor and kindergartens, these factors play much less of a role in developing countries. Thus, Hazan and Zoabi (2015a) do not contradict the stylized fact of a negative correlation between fertility and the female-to-male education ratio addressed in this paper.

As for the reversal in education across genders, Goldin *et al.* (2006) show that by 2002 women's college enrollment rates exceeded men's in 15 out of 17 OECD countries, compared to 4 out of 17 in the mid-1980s (before the 1980s, women's enrollment had never exceeded men's). Interestingly, the reversal in education across genders has not only taken place in developed countries but also in many developing ones (Becker *et al.* 2010). This phenomenon has generated a lot of research recently, and several factors, causes, and mechanisms have been proposed to explain it.[22] In the Appendix, we present a modification of our model incorporating a difference in non-cognitive skills across genders

[22] An incomplete list includes, to name but a few: the cost of college education (Goldin *et al.* 2006 and Becker *et al.* 2010), the rise of divorce rates (Goldin *et al.* 2006 and Chiappori *et al.* 2009), discrimination in labor market (Gosling 2003, Chiappori *et al.* 2009, Hazan and Zoabi 2015b), technological progress in the household sector (Chiappori *et al.* 2009), a short supply of men in the marriage market (Iyigun and Walsh 2007), differences in the anticipated dispersion of future wages across genders (Charles and Louh 2003), and the independence of fertility on the gender composition of the children when the return to human capital is sufficiently high (Hazan and Zoabi 2015b).

to generate a reversal in the education gap within our mechanism. The difference in non-cognitive skills may refer to, for example, the degree of self-motivation and seriousness in study, the dislike of homework exercises, and the like. A poorly non-cognitively skilled person finds school more difficult and hence more costly (Becker *et al.* 2010). The effects of heterogeneity in non-cognitive skills on college costs across genders in Goldin *et al*. (2006) and Becker *et al.* (2010) can be reinterpreted as the fact that investing in education for an average daughter is more efficient than that for an average son.

6 Empirical Analysis

In this section, we illustrate the correlation which has existed within developing countries during the second half of the 20th century and the early 21st century between technical progress on the one hand and fertility, woman's education and woman's employment on the other hand. Our theoretical model suggests that the impact of technological progress on fertility, the gender gap in education and female formal labor force participation is transmitted through the creation and diffusion of labor-saving home appliances. More specifically, our model-based hypotheses can be stated, in the context of developing countries throughout the 20th century, as follows:

- **H1**: *Fertility has an inverted U-shaped response to the increasing creation and diffusion of labor-saving home appliances.*
- **H2**: *The increasing creation and diffusion of labor-saving home appliances reduces the gender gap in education investment.*
- **H3**: *The increasing creation and diffusion of labor-saving home appliances increases the female formal labor-force participation.*

A challenge for the empirical investigation is the unavailability of data about the diffusion and uses of labor-saving home appliances in the household sector for emerging and developing countries. Hitherto existing empirical studies on the impact of home appliances on gender-related issues such as fertility and economic participation are mostly based on developed countries. Cavalcanti and Tavares (2008), for example, show by using data for OECD countries between 1980 and 1999, that declining prices and the greater availability of home appliances have a positive impact on female labor force participation. To control for endogeneity, they use the manufactured price index and the terms of trade adjustment as instrumental variables for the price index of home appliances. However, as data on the price and diffusion of home appliances is not available for a large number of less developed countries and time periods, we have to find plausible proxies.

In order to proxy the diffusion of labor-saving home appliances in less developed countries, we use three different measures:

1. The density of telephone subscriptions (measure available for 157 emerging and developing countries; yearly observations for the time period 1960 to 2015; $N = 6186$; data source: World Bank World Development Indicators)

2. The percentage of the population with access to electricity (measure available for 159 emerging and developing countries; yearly observations for the time period 1990 to 2015; $N = 3855$; data source: World Bank World Development Indicators)

3. The percentage of households with a refrigerator (measure available for 82 emerging and developing countries; highly unbalanced panel covering the time period 1990-2018; $N = 281$; data source: Demographic Health Surveys)

We investigate the within-country variations between fertility and the diffusion of technology by modeling Total Fertility Rates as a function of every single one of these three variables which proxy the diffusion of time-saving home appliances. Our empirical setup is as follows:

$$TFR_{i,t} = \alpha + \alpha_i + \beta_1 \log(technology\,proxy) + \beta_2 \log^2(technology\,proxy) + \sum_j \gamma_j c^j_{i,t} + \varepsilon_{i,t}$$

where $TFR_{i,t}$ is the fertility rate of country i in period t; α_i is a dummy variable for country i; and $c^j_{i,t}$s are country- and year-specific control variables.

We use the log of our technology variables in order to capture proportional rather than linear changes. Country-fixed effects are included in the regression analysis in order to implicitly control for country-specific variables that are constant over time. Our fixed-effects models therefore focus on within-country variations.[23]

Control variables filter out technical advancement from other forms of progress, in economic, social, and institutional terms. This helps us interpret our technology variables as proxies of technical progress in the field of home appliances. The control variables, which are added progressively, are the log of GDP per capita and its square, population density, exports in % of GDP and the under-five mortality rate. They are taken from World Bank World Development Indicators.

When using telephone lines and electricity as proxies for time-saving home appliances, we focus on developing and emerging countries by dropping advanced countries, tax heaven, very small countries with a population size smaller than 30,000, and oil exporting Arab countries from the World Bank's data base.[24] The DHS data on the diffusion of refrigerators is available for emerging and developing countries only.

Access to electricity and the diffusion of refrigerators are certainly more plausible proxies for the diffusion of time-saving home appliances than the density of telephone subscriptions. But these measures contain important technical limitations for our empirical investigation: the observations are only available for a very short time period (from 1990 on), they cover a lower number of countries and

[23]Note that all our results hold when adding year-fixed effects, which capture general trends in fertility that are common to all countries. Results are available on request.

[24]List of dropped countries: **Advanced countries**: Australia, Austria, Belgium, Canada, Finland, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK, USA; **Fiscal paradises**: oil exporting Arab countries; **Very small countries**: American Samoa, Andorra, Aruba, Bahamas, Bahrain, Bermuda, British Virgin Islands, Brunei Darussalam, Channel Islands, Cayman Islands, Cyprus, Faroe Islands, Gibraltar, Guam, Greenland, Hong Kong, Isle of Man, Kuwait, Liechtenstein, Macao, Malta, Marshall Islands, Monaco, Nauru, Northern Mariana Islands, Palau, Qatar, San Marino, Saudi Arabia, St. Martin (French part), Turks and Caicos Islands, Tuvalu, United Arab Emirates, Virgin Islands (U.S.)

We also run alternative specifications which: (1) focus only on countries and time periods for which GDP per capita is smaller than 20,000 (constant 2010 USD); (2) exclude only the first 23 advanced countries listed in footnote 24; and (3) include all developed countries listed in footnote 24. The results are consistent with those presented in this section. Results are available on request.

are, in the case of refrigerator diffusion, very unevenly distributed over time. When using the density of telephone subscriptions, we dispose of over 6,000 observations, while the number of observations is reduced by half when using access to electricity, and reduced to 4% only when using refrigerator diffusion.

In the following, we illustrate the within-country correlation patterns between fertility and technology for all three technology proxies. However, due to the technical superiority of the first proxy, our further empirical investigations presented in this article focus on telephone density as proxy for time-saving home appliances. This concerns the empirical investigation of the within-country correlation between technology diffusion on the one side and the gender gap in education and female formal employment on the other side. Results based on the other two proxies are, however, in line with our theoretical predictions and are available on request.

Data on female formal labor-force participation comes from the World Bank World Development Indicators, covering the time period 1990 – 2015 (yearly observations). Data on education comes from the Barro and Lee Database, and observations are available from 1950 on, on a five-year (quinquennial) basis. A summary of the panel data used for our empirical investigations can be found in Appendix A4. This appendix also provides a correlation matrix of all regressors used in our empirical analysis.

Telephone subscriptions certainly do not directly reflect the diffusion of labor-saving home appliances. However, as several studies have shown that the appearance of fixed telephone lines in households was observed soon after the arrival of other home appliances in the 20th century, even in the developing world, we assume that the penetration of telephone lines can be used as a plausible proxy for the diffusion of labor-saving home appliances. Studies by Paroush (1965), McFall (1969), Hebden and Pickering (1974), Kasulis et al. (1979), Dicken et al. (1983) or more recently Dholakia and Banerjee (2012), for example, order consumer acquisition priorities for home appliances during the second half of the 20th century. They show an absence of telephone lines in the priority list of home appliances while other time-saving appliances such as refrigerators, clothes washers, kitchens, ovens, etc. were listed. Dholakia and Banerjee (2012) point out the late penetration of telephone lines for the case of India. Such a pattern of acquisition priorities for home appliances is also observed in other developed countries at earlier time periods. Bowen and Offer (1994) point out the ranking of diffusion rate of selected home appliances in the US and Britain since 1920s, in which the penetration of telephone lines is ranked after those of refrigerators, electric irons, clothes washers, and vacuum cleaners. This time delay suggests that the observed penetration of telephone lines in households in the 20th century reflects the diffusion of many other time-saving home appliances a couple of years before. Furthermore, telephone densities are found to be highly correlated with income, while other proxies of technical advancements such as electricity consumption or air transport vary markedly even at similar income levels, especially in developing and emerging countries (World Bank, 2008).

For our empirical illustrations using telephone density as proxy for time-saving home appliances, we group together fixed and mobile telephone lines. We furthermore use the variable "number of fixed and mobile telephone lines per 100 inhabitants" with a 10-year forward lag as exogenous variable. This means, telephone density is observed 10 years later than fertility, which is due to the above mentioned priority order of owning home appliances. In concrete terms, in order to proxy the correlation of total fertility rates (TFRs) and labor-saving home appliances at time t, we use TFRs at time t as endogenous variable and the density of telephone lines at time $t+10$ as exogenous variable. The density of telephone lines at time $t+10$ is supposed to reflect the access to labor-saving home appliances 10 years earlier, at the time when fertility outcomes are observed.[25]

6.1 The effect of home appliances on fertility

Figure 6 shows the estimated within-country correlation between TFRs and the ten-year forward lag of log(telephone lines) and plots the correlation against real observations (pooled data of cross-country and time series). The underlying estimation results can be found in column 1 of the regression results in Table 1 in Appendix A4: The basic regression (model 1) shows a significantly negative coefficient of the square of the 'log(telephone lines)' variable, implying an inverted U-shaped pattern between TFR and technology diffusion. Figure 6 illustrates this concave pattern between telephone lines and TFRs by confirming a maximum in the estimated correlation: this implies that at low technology levels, TFRs increase with an increasing diffusion of technology, while at higher technology levels, fertility decreases with further increases in the diffusion of technology. This estimation result is consistent with our theoretical prediction of an inverted U-shaped pattern of fertility in response to the increase in the level of technology as depicted in the upper graph of figure 5.

The estimated maximum point of the correlation pattern is situated at a fertility level of 5.7 and a level of log(telephone lines) at -1.785, which corresponds to 0.16 telephone lines per 100 inhabitants. Around 6% of the observations are in the interval of a positive correlation between TFRs and telephone penetration following model 1.[26]

Model 2 of Table 1 in Appendix A4 confirms the robustness of this finding when controlling for increases in GDP per capita, population density and exports. According to model 2, the maximum TFRs is situated at a log(tel. lines) level of -1.055, which corresponds to 0.35 telephone lines per 100 inhabitants. Around 20% of the observations are in the interval of a positive correlation between TFRs and telephone penetration following model 2. Furthermore, model 2 shows that the estimated correlation pattern between fertility and GDP per capita is U-shaped (in line with Myrskil et al. 2009, Luci-Greulich and Thévenon 2014), while the estimated correlation between population density and fertility is significantly negative and the estimated correlation between exports and fertility is significantly positive.

Model 3, in which child mortality is added among the control variables, again confirms an inverted U-shaped pattern between telephone density and fertility. According to model 3, the maximum TFR is situated at a log(tel. lines) level of 0.236, which corresponds to 1.3 telephone lines per 100 households. Around 30% of the observations are now in the interval of a positive correlation between TFR and telephone penetration following model 3. Moreover, model 3 suggests that social progress in terms of

[25]Our theory works with an overlapping generations model in which each period lasts for 20 - 25 years, corresponding to the reproductive period of women or childhood period of children. Consistent with our theory, the proxy for technological progress should cover a certain period of time, and not only a point in time when we observe fertility. That is to say, fertility observed in year 1970 should not only depend on the contemporary diffusion of home appliances but also on the expected diffusion of home appliances in the following years. Given the time delay between the penetration of time-saving home appliances and the penetration of telephone lines, we choose a 10-year forward lag for the variable 'telephone lines' when estimating its correlation with fertility. Results are robust when using a 5-year and a 15-year forward lag instead of the 10-year forward lag. Results are available on request.

[26]The inverse U-shape is confirmed when using a reduced panel with observations until the year 1990 only. This robustness check was applied due to the fact that since the 1990s, telephone lines and other home appliances appear almost simultaneously in households.

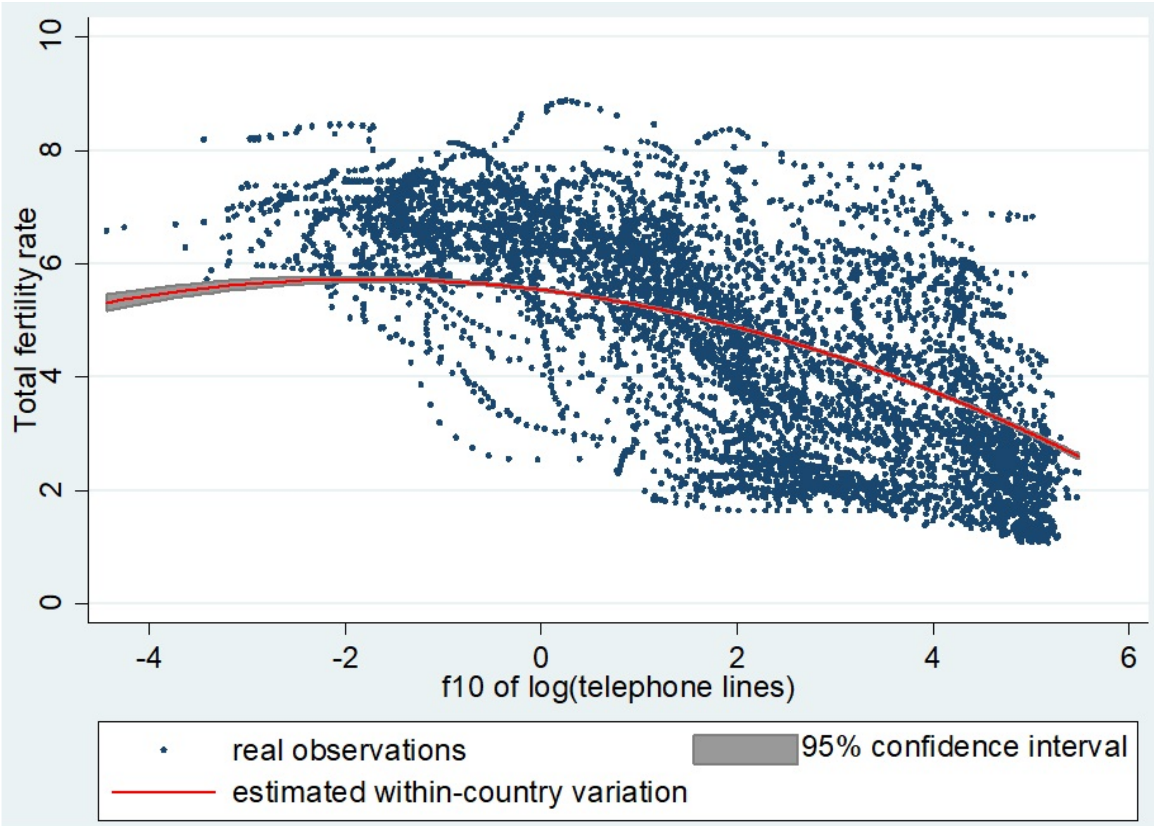

Figure 6: Fertility and density of telephone lines. Data: WB WDI, 157 countries, 1960-2015 ($N = 5927$).

access to health care, sanitation, etc. is more important for fertility decreases than economic progress, as GDP per capita and exports become insignificant when controlling for child mortality.[27]

Figure 7 shows the estimated within-country correlation between TFRs and our second proxy for time-saving home appliances, i.e. the percentage of the population with access to electricity. The correlation pattern is again inverted U-shaped, suggesting that fertility first increases with access to technology at lower technology levels and then decreases with the further diffusion of technology. Figure 7 also plots the real observations, illustrating the much lower number of observations in comparison to figure 6. This lower number is due to the late appearance of the time series data on access to electricity, which explains the accumulation of observations at relatively high electricity levels (a log of 'electricity' of 4.6 corresponds to 100% of electricity coverage). Indeed, in the 1990s, most countries —even the least developed ones— had already experienced their peak of fertility and many more developed countries have already completed their demographic transitions with stable and low fertility rates. The estimation line illustrated in Figure 7 corresponds to a basic regression with country-fixed effects. Regression results hold when adding control variables and are available on request.

Figure 8 shows the estimated within-country correlation between TFRs and our third proxy for time-saving home appliances, i.e. the diffusion of refrigerators. The number of observations used here

[27] We also tested for the indirect link that exists between telephone density and fertility due to the relative increase in female education. We therefore first estimated the ratio of female to male education as a function of telephone density (while controlling for population density and child mortality), and then estimated fertility in a second step, as a function of the estimated gender ratio in education, while we include population density and child mortality as control variables. Our results suggest that an access of parents to time-saving home appliances leads to relative increases in their daughters' education, which later on leads to decreases in total fertility rates within developing and emerging countries. Subsequent impacts are taken into account by allowing for a certain time delay between the observed technology level, the education and the fertility outcomes. Results are available upon request.

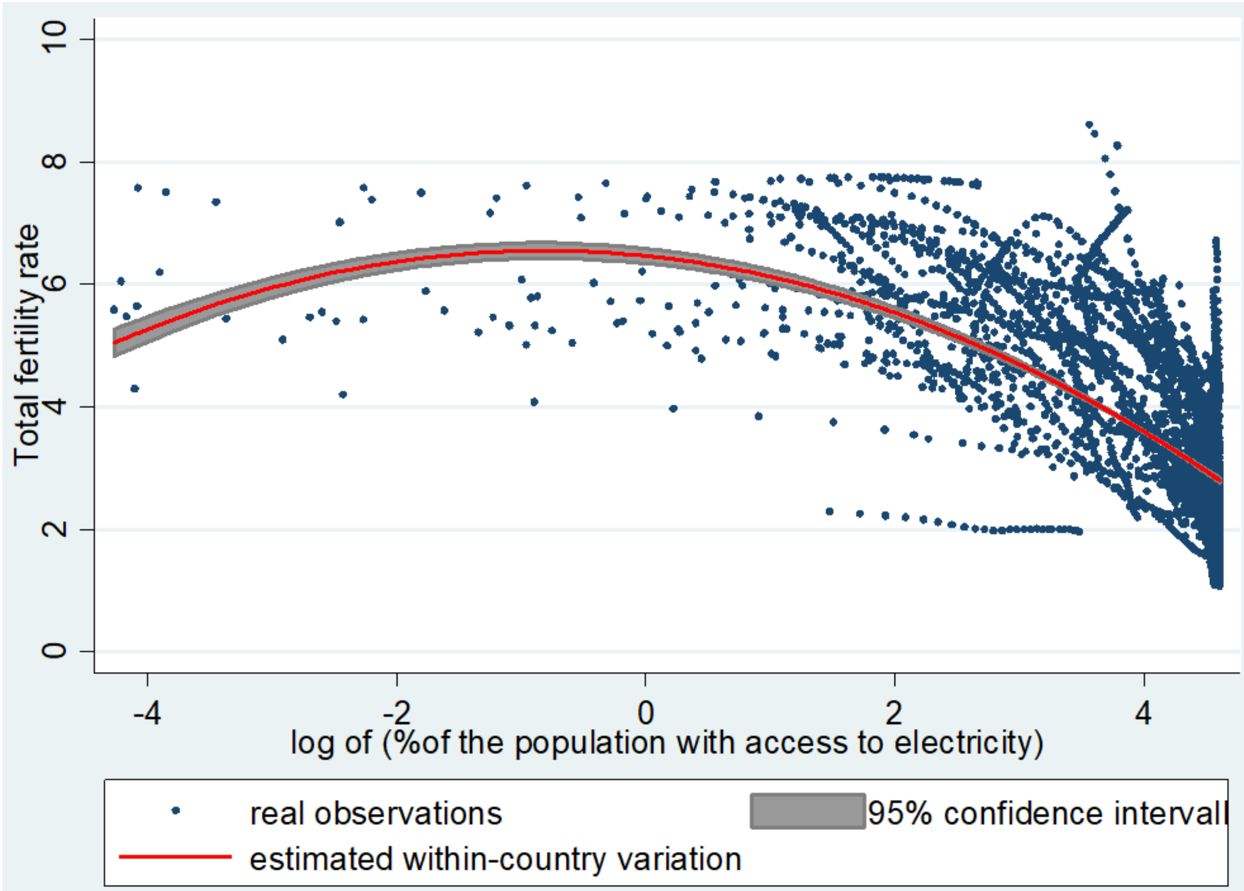

Figure 7: Fertility and access to electricity. Data: WB WDI, 159 countries, 1990-2015 ($N = 3764$).

extremely reduced is due to the limited time and country coverage of the DHS. However, Figure 8 confirms nevertheless a significantly concave within-country correlation pattern between fertility and technology, albeit with a more dominant negative pattern in comparison to Figures 6 and 7. Here again, these properties holds when adding control variables, and regression results are available on request.

6.2 The effect of home appliances on the gender gap in education

Figure 9 presents the estimated within-country correlation between telephone lines and the gender gap in education, and contrasts this to real observations. The gender gap in education is measured by the female-to-male ratio of average years of total schooling for ages 20-24.

Access to telephone lines, which figures here as a proxy for access to time-saving home appliances one decade before, allows parents to send their children, and especially girls, to school, when they are around ten to fifteen years old. The telephone density that we observe at the time when the children are aged 20-24 gives us thus information about the parental access to time-saving home appliances 10 years earlier, i.e. when their children were 10 to 15 years old. Thus, in this setting, we do not need a forward lag for telephone lines when empirically investigating the correlation between telephone lines and the gender gap in education.

Figure 9 illustrates a concave pattern between telephone lines and the gender ratio in education with a dominating rising branch: the female to male ratio in education increases with an initial increase in

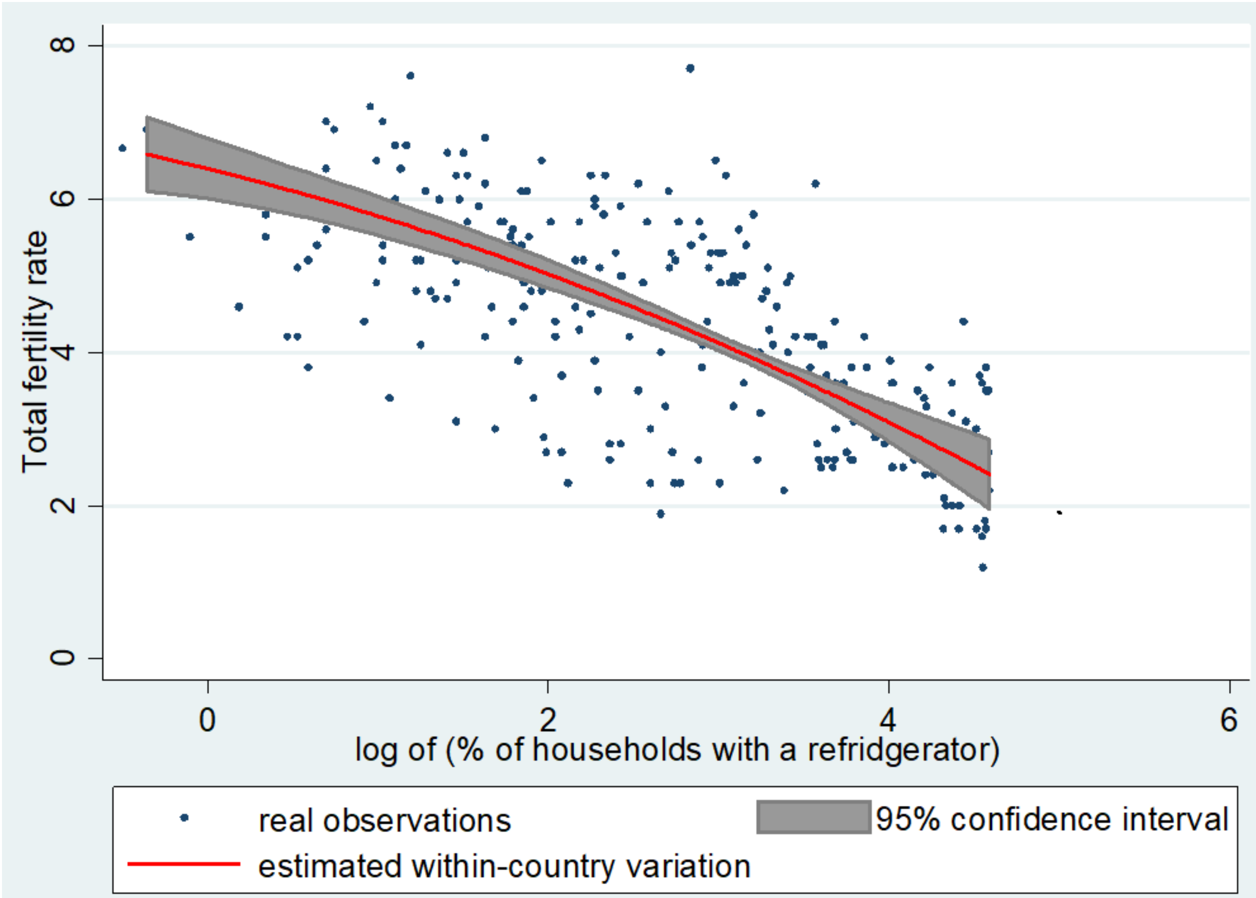

Figure 8: Fertility and refrigerator diffusion. Data: DHS, 76 countries, 1990-2018 ($N = 276$).

telephone density, and then stagnates at higher levels of access to telephone lines. The ratio actually converges around 1 (i.e. gender equality in education) once a certain level of technological advancement is achieved. This is in line with our theoretical prediction about the improvement of gender equality in education in response to an increase in the level of technology, as depicted in figure 4. Estimation results hold when adding control variables (GDP per capita, population density, exports, TFRs, child mortality) and are available on request. Further controls, which confirm the robustness of our findings are available on request. They include alternative measures of education (for example the female to male ratio of years of total schooling for ages 20-24, with the female to male ratio of years of total schooling for ages 15+) and different time lags for "telephone lines".

6.3 The effect of home appliances on female formal labor-force participation

Figure 10 finally presents the estimated within-country correlation between telephone lines and formal female wage employment. For our empirical investigation, we prefer formal employment over general employment measures including informal employment and subsistence activities, as female formal employment has the technical advantage that it evolves uniformly more or less during the process of economic development (and therewith over time), whereas women's general labor market participation is known to follow a U-shaped pattern (i.e. decrease first with initial stages of economic development: see "feminization U" hypothesis by Goldin (1995)).

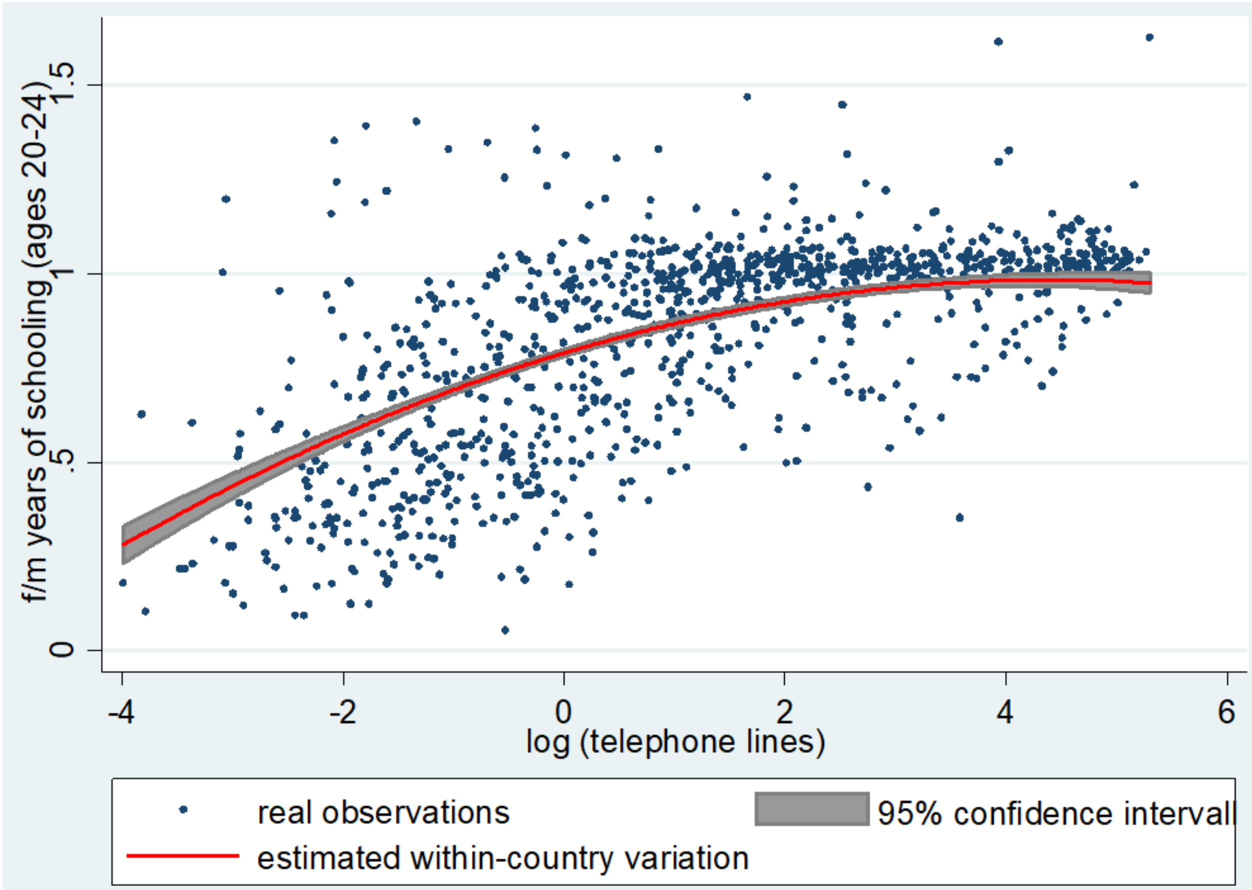

Figure 9: Female/male years of schooling (ages 20 to 24) and density of telephone lines. Data: WB WDI and Barro & Lee, 108 countries, 1960-2010; 5-year intervals ($N = 1026$).

Formal female employment is measured by the share of women in wage-employment in the non-agricultural sector, for which data is available for the 1990s onwards only. In order to keep the data set as large as possible, we abstain here from using forward lags of the exogenous variable 'telephone lines'. Note that results hold, however, when applying a 10-year forward lag for 'telephone lines'.

Figure 10 shows that the estimated within-country correlation pattern between access to telephone lines and formal female wage employment is again concave, with a dominating rising branch: within countries, increases in access to telephone lines are positively correlated with increases in female formal wage employment for initial stages of technological advancement, while levels of formal female wage employment stagnate at relatively high levels of technological advancement. Estimation results confirm that the concavity is significant once we control for GDP per capita, the female to male ratio in education and fertility. These estimation results are consistent with our theoretical prediction of an increase in female labor force participation, in response to an increase in the level of technology, as depicted in the lower graph of figure 5.

7 Concluding remarks

This paper combines the theoretical ideas of Galor and Weil (1996, 2000), Greenwood *et al.* (2005a,b), and Soares Falcao (2008) in a unified growth model whose predictions are tested against evidence from

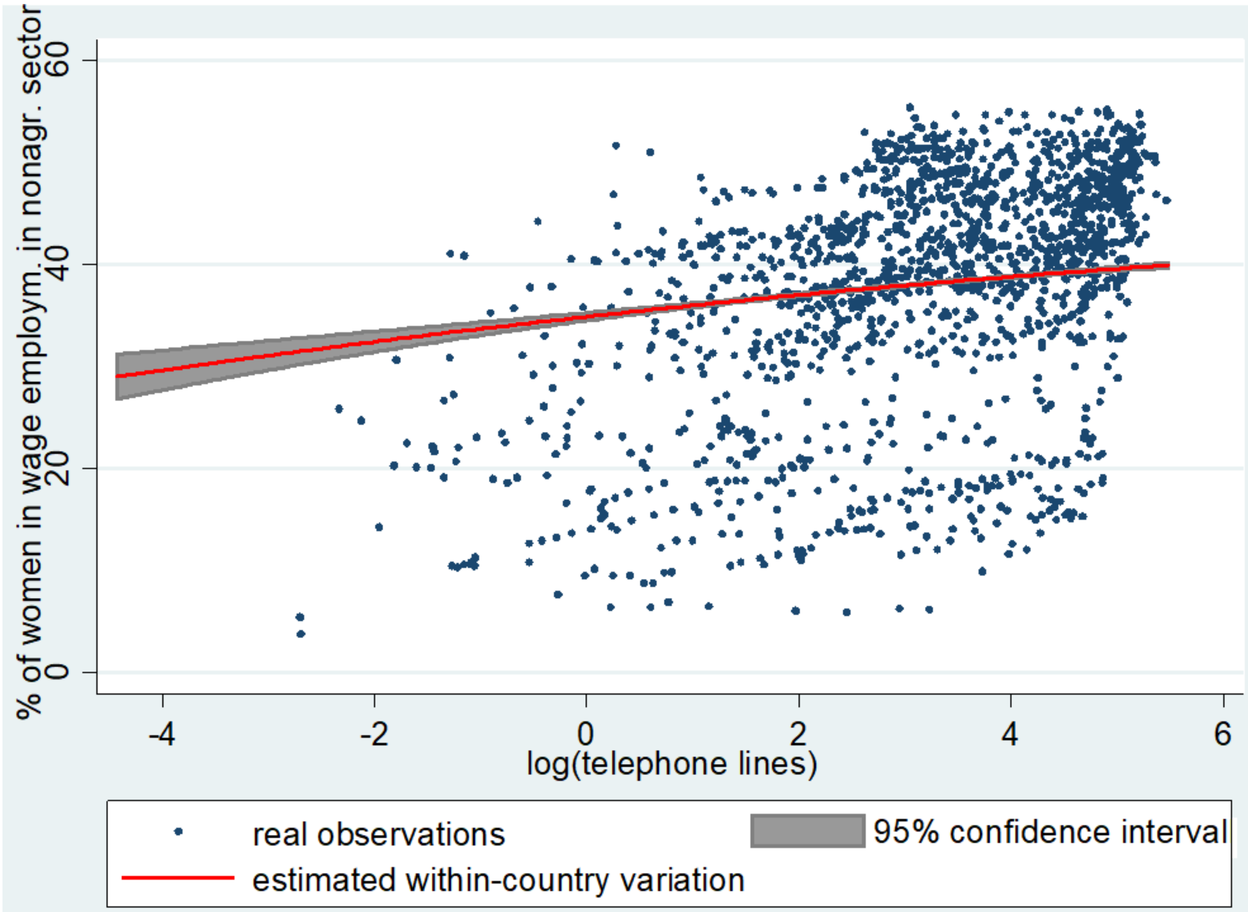

Figure 10: The percentage of women in wage employment in the nonagricultural sector and density of telephone lines. Data: WB WDI, 151 countries, 1990-2013 ($N = 1624$).

developing countries having undergone a demographic transition. Specifically, it uncovers a new mechanism capturing the interaction between technological progress, households' educational investment across genders, and fertility, in order to explain some stylized facts characterizing the development process. The paper thus sheds light on the transition from stagnation, through a demographic transition, to sustained growth by developing countries in the late 20th and early 21st centuries. An improvement in gender equality in education, income, and the female labor-force participation result from a development process in which the driving force for technological progress is the increase in the average level of human capital. The paper also shows that technological progress may increase female labor market participation, not only by freeing women's time from housework due to the appearance of time-saving household-sector products, but also by leading households to reduce fertility due to an increase in the return of women's human capital, which increases the opportunity cost of raising children. In addition, technological progress makes households substitute quality to quantity in their fertility choice. Finally, the paper provides empirical evidence to validate the main predictions of the model about the effects of technological progress, through the creation and spread of labor-saving home appliances, on fertility and educational investment across genders, as well as on formal female labor force participation.

Identifying the main mechanisms that capture as many stylized facts as possible during the development process of developing countries is key for policy design. This is especially so for the less developed regions, where access to basic infrastructures such as electricity, freshwater and sewage networks is very limited. Although most developing countries have experienced fast demographic transitions, some less developed ones —particularly in sub-Saharian Africa— are still experiencing persistently high fertility rates, at the same time as households in these countries have only poor access to the basic infrastructures for daily life. Since population growth has been shown to induce local environmental degradation as well as to contribute to global climate change (IPCC 2014), then policies aimed at improving basic infrastructures —in particular those that help women to free up time in order to participate in the labor market too— may speed up the demographic transition in these countries and help reduce pressure on the environment. Given the mechanisms uncovered in this paper, the question of "*whether improvement in human capital to achieve gender equality is key to implementing sustainable growth*" is clearly worth being investigated in future research.

8 Appendix

A0. Household's first-order conditions

The first-order conditions of the household's problem are

$$\begin{pmatrix} U_c^t \\ U_n^t \\ U_e^t \\ U_{\tilde{e}}^t \end{pmatrix} = \lambda_1 \begin{pmatrix} 1 \\ \rho w_t \tilde{e}_{t-1}^{\theta} + e_t + \tilde{e}_t \\ n_t \\ n_t \end{pmatrix} + \lambda_2 \begin{pmatrix} 0 \\ 0 \\ -1 \\ 0 \end{pmatrix} + \lambda_3 \begin{pmatrix} 0 \\ 0 \\ 0 \\ -1 \end{pmatrix} + \lambda_4 \begin{pmatrix} 0 \\ \rho \\ 0 \\ 0 \end{pmatrix}$$

along with the constraints and the slackness conditions, for multipliers $\lambda_i \geq 0$, where U_j^t are the marginal utilities. Accordingly, households choose education investments to equalize the marginal utilities of their sons' and daughters' human capitals, as well as fertility and consumption, in order to equalize the marginal rate of substitution of consumption and fertility with the marginal cost of the latter. Thus, depending on whether the time constraint is binding, the household's choice on education and fertility is

$$e_t = \begin{cases} \frac{\gamma\theta}{1-\gamma+\gamma\theta} \frac{\rho}{(1-\phi_t)[1+(1-\phi_{t+1})^{\frac{1}{1-\theta}}]} w_t e_{t-1}^{\theta} & \text{if} \quad \phi_t + \rho n_t = 1 \\ \frac{\theta}{1-\theta} \frac{\rho}{1+(1-\phi_{t+1})^{\frac{1}{1-\theta}}} w_t \tilde{e}_{t-1}^{\theta} & \text{if} \quad \phi_t + \rho n_t < 1 \end{cases} \tag{16}$$

$$\tilde{e}_t = \begin{cases} \frac{\gamma\theta}{1-\gamma+\gamma\theta} \frac{\rho}{(1-\phi_t)[1+(1-\phi_{t+1})^{\frac{1}{\theta-1}}]} w_t e_{t-1}^{\theta} & \text{if} \quad \phi_t + \rho n_t = 1 \\ \frac{\theta}{1-\theta} \frac{\rho}{1+(1-\phi_{t+1})^{\frac{1}{\theta-1}}} w_t \tilde{e}_{t-1}^{\theta} & \text{if} \quad \phi_t + \rho n_t < 1 \end{cases} \tag{17}$$

$$n_t = \min\left\{ \frac{1-\phi_t}{\rho}, \frac{\gamma(1-\theta)}{\rho} \left[\frac{e_{t-1}^{\theta}}{\tilde{e}_{t-1}^{\theta}} + 1 - \phi_t \right] \right\} \tag{18}$$

so that the fertility in the binding and non-binding cases coincide for some ϕ_t, *i.e.*

$$\frac{\gamma(1-\theta)}{\rho} \left[\frac{e_{t-1}^{\theta}}{\tilde{e}_{t-1}^{\theta}} + 1 - \phi_t \right] = \frac{1-\phi_t}{\rho} \tag{19}$$

but, since from (16) and (17) it holds in any period $t-1$

$$\frac{e_{t-1}^{\theta}}{\tilde{e}_{t-1}^{\theta}} = \left[\frac{1+(1-\phi_t)^{\frac{1}{\theta-1}}}{1+(1-\phi_t)^{\frac{1}{1-\theta}}}\right]^{\theta} = (1-\phi_t)^{\frac{\theta}{\theta-1}}, \tag{20}$$

then (19) implies that the time constraint will be binding whenever

$$\phi_t = 1 - \left[\frac{\gamma(1-\theta)}{1-\gamma(1-\theta)}\right]^{1-\theta} \tag{21}$$

for which the binding and non-binding consumption and educational choices coincide.

A1. Proof of Lemma 1

Let us denote $E_{t-1} = e_{t-1} + \tilde{e}_{t-1}$, which is determined in period $t-1$ as in (13). The growth rate of technological progress between periods t and $t+1$ is

$$g_t = g\left(\frac{e_{t-1}^{\theta} + \tilde{e}_{t-1}^{\theta}}{2}\right) = g\left(\frac{(E_{t-1}-\tilde{e}_{t-1})^{\theta} + \tilde{e}_{t-1}^{\theta}}{2}\right)$$

so that

$$\frac{\partial g_t}{\partial \tilde{e}_{t-1}} = g'\left(\frac{(E_{t-1}-\tilde{e}_{t-1})^{\theta} + \tilde{e}_{t-1}^{\theta}}{2}\right)\frac{\theta}{2}\left[\tilde{e}_{t-1}^{\theta-1} - (E_{t-1}-\tilde{e}_{t-1})^{\theta-1}\right]$$

Since $g'(.) > 0$ and $\theta \in (0,1)$ then $\partial g_t/\partial \tilde{e}_{t-1} > (=)(<)\, 0 \;\Leftrightarrow\; \tilde{e}_{t-1} < (=)(>)\, E_{t-1}/2$, which implies the result stated in Lemma 1.

A2. Proof of Lemma 2

Since $\lim_{t\to+\infty} m_t = m > 0$ then $\forall \varepsilon \in (0,m)$, $\exists T$ such that $\forall t \geq T$, we have

$$m - \varepsilon \leq m_t \leq m + \varepsilon$$

Define

$$X_0 = Q_0 = Z_0 = x_T$$

and

$$X_{t+1} = m_{T+t}X_t^{\alpha}, \quad Q_{t+1} = (m+\varepsilon)Q_t^{\alpha}, \quad Z_{t+1} = (m-\varepsilon)Z_t^{\alpha}$$

We know that

$$\lim_{t\to+\infty} Q_t = (a+\varepsilon)^{\frac{1}{1-\alpha}} \quad \text{and} \quad \lim_{t\to+\infty} Z_t = (a-\varepsilon)^{\frac{1}{1-\alpha}}$$

We also have

$$Z_1 = (m-\varepsilon)X_0^\alpha \leq X_1 = m_T X_0^\alpha \leq (m+\varepsilon)X_0^\alpha = Q_1$$

$$Z_2 = (m-\varepsilon)Z_1^\alpha \leq (m-\varepsilon)X_1^\alpha \leq X_2 = m_{T+1}X_1^\alpha \leq (m+\varepsilon)X_1^\alpha \leq (m+\varepsilon)Q_1^\alpha = Q_2$$

$$\vdots$$

and so on, by induction we have

$$Z_t \leq X_t \leq Q_t, \forall t.$$

Hence,

$$(m-\varepsilon)^{\frac{1}{1-\alpha}} = \lim_{t\to+\infty} Z_t \leq \lim_{T\to+\infty}\left(\inf_{t\geq T} X_t\right) \leq \lim_{T\to+\infty}\left(\sup_{t\geq T} X_t\right) \leq \lim_{t\to+\infty} Q_t = (m+\varepsilon)^{\frac{1}{1-\alpha}}$$

That is to say

$$(m-\varepsilon)^{\frac{1}{1-\alpha}} \leq \lim_{T\to+\infty}\left(\inf_{t\geq T} X_t\right) \leq \lim_{T\to+\infty}\left(\sup_{t\geq T} X_t\right) \leq (m+\varepsilon)^{\frac{1}{1-\alpha}}, \forall\varepsilon \in (0,m)$$

Hence,

$$\lim_{\varepsilon\to 0^+}(m-\varepsilon)^{\frac{1}{1-\alpha}} \leq \lim_{T\to+\infty}\left(\inf_{t\geq T} X_t\right) \leq \lim_{T\to+\infty}\left(\sup_{t\geq T} X_t\right) \leq \lim_{\varepsilon\to 0^+}(m+\varepsilon)^{\frac{1}{1-\alpha}}$$

i.e.

$$m^{\frac{1}{1-\alpha}} \leq \lim_{T\to+\infty}\left(\inf_{t\geq T} X_t\right) \leq \lim_{T\to+\infty}\left(\sup_{t\geq T} X_t\right) \leq m^{\frac{1}{1-\alpha}}$$

which implies

$$\lim_{t\to+\infty} X_t = m^{\frac{1}{1-\alpha}}, \qquad i.e. \qquad \lim_{t\to+\infty} x_t = m^{\frac{1}{1-\alpha}}.$$

A3. Reversal in the education gap across genders

Following Goldin *et al*. (2006) and Becker *et al.* (2010) on heterogeneity in non-cognitive skills across genders, we can modify the human capital formation function for women to be $\tilde{\psi}\tilde{e}_t{}^\theta$ with $\tilde{\psi} > 1$, while the human capital formation function for men remains unchanged. The parameter $\tilde{\psi}$ gauges the non-cognitive skills advantage of an average daughter. Also, let a man's income with education e_{t-1} be $w_t(\psi + e_{t-1}^\theta)$ in period t, where $\psi > 0$ captures the gender discrimination because of men's physical strength and no career interruptions linked to paternity. This allows capturing the fact that, with the same levels of education, men usually receive higher wages than women.

The household's optimization problem then becomes

$$\max_{c_t, n_t>0,\, e_t, \tilde{e}_t \geq 0} (1-\gamma)\ln c_t + \gamma \ln\left(n_t w_{t+1}[\psi + e_t^\theta + (1-\phi_{t+1})\tilde{\psi}\tilde{e}_t^\theta]\right)$$
$$c_t + n_t(e_t + \tilde{e}_t) \leq w_t\left[\psi + e_{t-1}^\theta + (1-\phi_t - \rho n_t)\tilde{\psi}\tilde{e}_{t-1}^\theta\right]$$

$$\phi_t + \rho n_t \leq 1$$

—note that the potential incomes of sons $w_{t+1}(\psi + e_t^\theta)$ consists of two parts, the potential basic, unskilled labor income $w_{t+1}\psi$ and the potential skilled labor income $w_{t+1}e_t^\theta$. At the solution to the optimization problem above, the gender inequality in education μ_t is determined by

$$\mu_t = \frac{\tilde{e}_{t-1}}{e_{t-1}} = \left[(1-\phi(a_t))\tilde{\psi}\right]^{\frac{1}{1-\theta}} \equiv \tilde{\mu}(a_t)$$

with, from Assumption 1,

$$\tilde{\mu}'(a) > 0 \qquad \text{and} \qquad \lim_{a\to+\infty} \tilde{\mu}(a) = \tilde{\psi}^{\frac{1}{1-\theta}} > 1 \tag{22}$$

The following assumption further guarantees that for low levels of technology, the educational investment in daughters is lower than in sons.

Assumption 3. $(1-\bar{\phi})\tilde{\psi} < 1$.

Thus, the following lemma states that the reversal in educational investment across genders, for a high level of technology follows straightforwardly from Assumption 3 and the properties of $\tilde{\mu}(a_t)$ in (22).

Lemma 3. *Under assumptions 1 and 3, there exists a unique level of technology $\tilde{a} > 0$ at which $\tilde{\mu}(\tilde{a}) = 1$ so that complete equality in education investment across genders holds. Moreover, for all $a \in (0, \tilde{a})$ it holds $\tilde{\mu}(a) < 1$, and for all $a > \tilde{a}$, $\tilde{\mu}(a) > 1$.*

In other words, during the development process, and along with the technological progress, the educational investment in daughters increases relative to that in sons, and a reversal in the educational investment gap across genders occurs with a sufficiently high level of technology. The reasoning here is quite intuitive. Technological progress makes parents invest relatively more in their daughters' education when the marginal return to education investment in daughters is greater than in sons. So whenever the technology surpasses a tipping point $\tilde{a}$ above which the potential income of the daughter is greater than the potential skilled labor income of the son, the parents will optimally invest more in the education for their daughter than for their son, in order to equalize the marginal utility from an increase in the education of either child. Thus, the daughter's education eventually exceeds the son's.[28]

A4. Regression results, correlation matrix, and summary of data

[28] Note that, what we observe from the data is the reversal in educational *achievement* —e_t^θ and $\tilde{\psi}\tilde{e}^\theta$ for sons and daughters respectively— rather than educational investment. Assumption 1 and $\tilde{\psi} > 1$ are sufficient for a reversal in educational investment across genders, *i.e.* $\lim_{a\to+\infty} \tilde{\mu}(a) = \lim_{a\to+\infty} \left[(1-\phi(a))\tilde{\psi}\right]^{\frac{1}{1-\theta}} = \tilde{\psi}^{\frac{1}{1-\theta}} > 1$. Such a reversal, however, can occur for the education achievement even if there is not any in educational investment, i.e. when $\lim_{a\to+\infty} \left[(1-\phi(a))\tilde{\psi}\right]^{\frac{1}{1-\theta}} = 1$. Indeed, as proved in Proposition 2, $e = \lim_{t\to+\infty} e_t = \lim_{t\to+\infty} \tilde{e}_t = \tilde{e}$. As a consequence, eventually $e^\theta < \tilde{\psi}\tilde{e}^\theta$, so that the educational achievement of the daughter exceeds that of the son even if the daughter's educational investment does not. That is to say, when the level of technology is sufficiently high the educational achievement will reverse across genders because of both (i) the improvement in gender equality in educational investment and (ii) the better efficiency of female educational investment.

	Total fertility rates		
	M1	M2	M3
F10 of log(telephone lines)	-0.211***	-0.125***	0.0321**
	(-25.35)	(-12.58)	(2.78)
F10 of $\log^2$(telephone lines)	-0.0591***	-0.0592***	-0.0681***
	(-30.51)	(-26.18)	(-31.38)
log(GDP per capita)		-1.269***	-0.288
		(-5.54)	(-1.26)
$\log^2$(GDP per capita)		0.0598***	0.00464
		(3.94)	(0.31)
Population density		-0.00499***	-0.00427***
		(-14.96)	(-13.59)
Exports in % of GDP		0.00192*	-0.000513
		(2.08)	(-0.59)
Under 5-mortality rate			0.00834***
			(23.82)
Female/male years of schooling (ages 20-24) estimated as a fct. of f15 of log(telephone lines) and its square[5]			
Country fixed-effects	Yes	Yes	Yes
Constant	5.536***	11.93***	6.649***
	(480.37)	(13.86)	(7.71)
Number of observations	5927	4150	4028
Number of countries	157	147	146
Covered time period	1960-2015	1960-2015	1960-2015
R^2 (within)	0.64	0.68	0.73

t statistics in parentheses; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 1: Fixed effect regressions at country level.

Correlation Matrix

	Total fertility rates	log(tele-phone lines)	log(GDP per capita)	Populatio n density	Exports (% GDP)	Under 5-mortality rate	F/M schooling (20-24)	Access to electricity (% popul.)	Share of women in wage employmen	log (% of households with a fridge)
Total fertility rates	1.0000									
log(telephone lines)	-0.6961	1.0000								
log(GDP per capita)	-0.7082	0.7029	1.0000							
Population density	-0.1328	0.0619	-0.0198	1.0000						
Exports in % of GDP	-0.2855	0.3350	0.2945	0.0018	1.0000					
Under 5-mortality rate	0.8425	-0.7476	-0.7666	-0.0592	-0.3380	1.0000				
F/M years of schooling (ages 20-24)	-0.5966	0.5157	0.5506	0.0580	0.2761	-0.6101	1.0000			
log (access to electricity, % population	-0.7926	0.6821	0.7013	0.0183	0.1923	-0.8078	0.5203	1.0000		
Share of women in wage employment in the nonagricultural sector	-0.6525	0.5059	0.6093	-0.0587	0.3427	-0.5604	0.6023	0.4427	1.0000	
log (% of households with a fridge)	-0.7044	0.7030	0.9159	-0.0830	-0.2160	-0.8352	0.4591	0.9168	0.3357	1.0000

Summary of Data

Variable	Number of obs	Number of countries	Mean	Std. Dev.	Min	Max	Covered time period	Intervall of observations	Data Base
Fixed telephone subscriptions (per 100 people)	6242	157	8.21	10.55	0.00	61.57	1960-2015	every year	WB WDI
Mobile cellular subscriptions (per 100 people)	6668	157	21.21	39.78	0.00	208.94	1960-2015	every year	WB WDI
Fixed + mobile telephone subscr. (per 100 people)	6186	157	30.93	46.95	0.00	239.92	1960-2015	every year	WB WDI
Access to electricity (% of population)	3855	159	68.03	34.61	0.01	100.00	1990-2014	every year	WB WDI
% of households having a refrigerator	281	82	26.90	27.48	0.70	98.60	1985-2018	unbalanced	DHS
Fertility rate, total (births per woman)	8591	156	4.52	1.96	1.08	8.87	1960-2015	every year	WB WDI
GDP per capita (constant 2010 US$)	6484	145	3721.38	4478.19	115.44	33117.97	1960-2015	every year	WB WDI
Females: Average years of total schooling, ages 20-24	1457	112	5.72	3.81	0.01	14.16	1950-2010	every 5 years	Barro & Lee
Males: Average years of total schooling, ages 20-24	1457	112	6.44	3.25	0.01	13.97	1950-2010	every 5 years	Barro & Lee
F/M average years of total schooling, ages 20-24	1457	112	0.79	0.29	0.04	1.63	1950-2010	every 5 years	Barro & Lee
Population density (people per sq. km of land area)	8529	157	97.01	141.38	0.63	1363.88	1960-2015	every year	WB WDI
Exports of goods and services (% of GDP)	6320	133	32.41	19.88	0.01	166.36	1960-2015	every year	WB WDI
Mortality rate, under-5 (per 1,000 live births)	7502	153	96.66	81.03	2.60	443.50	1960-2015	every year	WB WDI
Share of women in wage employment in the nonagricultural sector (% of total nonagricultural employment)	1654	57	37.97	11.44	3.80	55.40	1990-2013	every year	WB WDI

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