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Abstract

For the better part of human history, life was most fragile and death most imminent during infancy and early childhood. The death of a child may be hardly bearable from a humanitarian perspective. Yet, certain currents in economic theory attach a silver lining to high mortality by claiming that the Malthusian check on population raises per capita income and facilitates the accumulation of capital. The present paper challenges this conventional wisdom. In essence, it argues that high levels of environmental risk produce genetic and behavioral adaptations which induce individuals to have many - in terms of parental investment - cheap offspring. Conversely, stable environments recast the tradeoff between child quantity and quality in favor of more quality-based reproductive strategies. Incorporating these biological relationships into the traditional Barro-Becker model of fertility, the paper finds that both declining extrinsic mortality and increased effectiveness of parenting effort potentially trigger a demographic transition. Thus, the economic benefits of Malthusian population checks are mitigated because high mortality endogenously produces high fertility whereas improved survival encourages human capital investment and fosters long-term growth. To assess whether the theoretical predictions conform with historical reality, I use smallpox vaccination in 19th century Germany as a natural experiment. Performing an econometric analysis of 67 districts in the Granduchy of Baden provides evidence, that comprehensive immunization and advanced medicalization came along with reduced mortality, significantly lower fertility and increased parental care. In sum, it therefore seems that Malthusian mechanisms are at least partly offset by countervailing biological adaptations.

JEL classification: I12, I15, N13, N33, O44

Keywords: Demographic Transition, Evolutionary Anthropology, Life History Theory, Economic Growth

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1. *Introduction*

Death is old. A skeletal figure, wrapped in black, carrying a huge scythe. Be it on gravestones or paintings, the image is ubiquitous – and deeply flawed. For in fact, throughout centuries of human history, the face of death was the face of an infant: As late as the turn of the 20th century, 3 out of 10 European children died before school age. And although progress has been made, WHO statistics continue to report sobering 16000 infant deaths per day worldwide.[1]

The enormous amount of human suffering behind these figures is undeniable. Still, a substantial body of macroeconomic literature attaches a silver lining to the high mortality rates in underdeveloped nations. Following Malthusian arguments, research like Clark (2007) stresses the fact that mortality acts as a buffer to reduce population growth and raises per capita income. In the same vain, Young (2005), Lagerlöf (2003) and Brainerd and Siegler (2003) postulate a benign effect of epidemics by arguing that they foster human capital acquisition or raise wages by increasing the scarcity of labor. Voigtländer and Voth (2005) went as far as dubbing death through infectious diseases a "horseman of the riches" because high mortality led to higher income which – by Engel's Law – created a positive feedback effect on the demand of manufactures.

A direct implication of these results – albeit rarely spelled out *expressis verbis* – is a strong skepticism regarding the economic benefits of medical and social progress. Neo-Malthusians would therefore probably agree with Azarnert (2006) who claims that "a premature public health intervention to reduce early child mortality, although in harmony with humanitarian approach in the short run, generates a mechanism that works against children's survival chances in the long run." (Azarnert (2006), p. 294)

The present paper challenges this received wisdom. Based on recent advances in evolutionary biology, it argues that high mortality triggers physiological and psychological adaptations which foil the prospects for sustained economic growth. The dimensions and potential implications of these behavioral responses are largely ignored by both (Neo-)Malthusian theories and the canonical "altruism model" proposed by Barro and Becker (1986): In the world of Malthus, individuals follow the irresistible "passion between the sexes" without adapting to their environment (Malthus (1798), ch. 2). As for the Barro/Becker model and its numerous extensions, they typically assume the relative costs of reproducing, rearing and educating offspring unaffected by changes in the environment.[2] In other words, high expected mortality does not prevent parents from attaching closely to their children and low mortality does not foster increased investment in child "quality". Offspring quantity and quality being treated as normal goods, these models predict that improved survival reduces the price of children which in turn will translate into population growth and declining living standards unless productivity and wages increase accordingly.

The life sciences reach different conclusions: In the world of Darwin, fertility is not the outcome of uncontrolled emotions, but a function of ecological conditions. Parents who seek to

[1] UNICEF, WHO, World Bank UN DESA/Population Division (2014), Data Appendix

[2] The model reaches the empirically unfounded prediction that a decline in mortality reduces the expected costs of surviving children which in turn raises the demand for offspring. As a result, improved survival will translate into population growth.

maximize their *fitness* (the combination of life expectancy, socio-economic rank and reproductive success) are expected to counter high mortality by "hedging their bet" and adopting a "high fertility-low investment" strategy. The "Malthusian gift" of positive checks on population growth therefore turns out a cold comfort because the evolved behavioral response to high mortality leads to high fertility, sluggish human capital accumulation and socio-economic stagnation. Conversely, improved survival, medical progress and the dissemination of medical knowledge carry a "Darwinian gift" of low fertility, higher investment in child quality and rising living standards. Hence, rather than fearing a Malthusian trap, biologists point to falling mortality as a necessary precondition for the fertility transition and the acceleration of human capital accumulation.

To assess if Malthus was wrong where Darwin was right, the present paper ventures into various fields outside the focus of traditional economics including evolutionary anthropology, ecology, and psychology. Concentrating on the interface between economics and the life sciences, it contributes to different strands of research. Regarding theory, it is the first to incorporate the principles of evolutionary *life history theory* into an economic optimization model. Doing so, it ties up some loose ends in the economic literature on the fertility decline. In particular, it provides a parsimonious explanation for one of the central forces in endogenous growth models like Galor and Weil (2000), Galor and Moav (2002), Kalemli-Ozcan (2002) or Soares (2005): the emergence of preferences which favor a small family size and heavy investment in human capital. At the same time, accounting explicitly for ecological conditions sheds new light on empirical findings which would otherwise contradict the classical theory of the demographic transition. For, standard accounts of the process typically require either a mortality decline before the fertility decline or a strong increase in per capita income. Unfortunately, empirical support for these claims is mixed. In fact, most studies of completed demographic transitions detect a negative nexus between fertility and income but fail to establish an unambiguous timing of the rise of per-capita income and the onset of the fertility decline.[3] Regarding the hypothesis of incremental habit formation, historical records include a number of cases in which the fertility decline paralleled or - rarely - preceded the fall in mortality.[4] Just like the emergence of preferences for increased offspring quality, these initially puzzling observations can – however – be explained as evolutionary adaptations to changed environmental conditions. How these adaptations form in the course of natural selection and how they contribute to our understanding of the demographic transition will be the central questions in the following sections: Section 2 introduces the paper's biological background, namely life history theory (LHT) and the Darwinian mechanism of r/K-selection. Section 3 analyzes how the traditional economic models of fertility are affected if evolutionary fitness maximization is incorporated in the household's objective function. Seeing that LHT has not been merged with economic theory so far, section 4 discusses the empirical plausibility of the "Darwinian" fertility model proposed in section 3. In order to gauge the potential size of adaptations to variation in selective pressure, section 5provides a historical case study of smallpox vaccination in 19th century Germany. The case is particularly valuable because vaccination caused a sizable decline in

[3] For a survey see Hotz, Klerman, and Willis (1993). More recent contributions include: Tertilt (2008) and Shoven(2011)

[4] For an overview see Caldwell (2006)

extrinsic mortality[5] and improved parents' ability to influence the survival chances of their children to an unprecedented extent. Having analyzed the historical impact of medical progress on the demographic transition, section 5 discusses potential policy implications and concludes.

2. Understanding the Economics of Nature: Life History Theory

Grasping the fundamentals of life history theory (LHT) is easiest on those days of spring, when nature turns into a huge and bustling bazaar: Birds twittering in the trees under your window, insects buzzing in the air, the neighbors' cat displaying and caterwauling on the roof at four o'clock in the morning – in a sense they all sell or purchase genes in order to pass them down to future generations. Life history theory (LHT) seeks to understand the economic logic of this exchange. Based on the insight that all organisms face binding genetic and energetic constraints,[6] LHT considers reproductive success or early death as the results of a series of optimization problems. Nature has solved these problems in a variety of ways: Some species like Atlantic Salmons produce thousands of offspring in one suicidal effort and die immediately afterwards. Others like rabbits compensate the risk of being a simple a prey by fast maturation and notorious fecundity. Finally, suburban humans invest in violin, chess and Chinese classes in order to make sure, their adored little cherub succeeds in life.

The above *life history strategies* can all be defined as optimal combinations of so-called *life history traits*. A life history trait is a numerical indicator (e.g. size at birth, age at first reproduction) which corresponds to a specific tradeoff between the conflicting energetic needs of survival, growth and reproduction. Following the convention of evolutionary biology, both single life history traits and entire *life history strategies*, are ordered along a "slow-fast" continuum. For example, males may solve the tradeoff between mating and parenting effort by marrying one woman and have few offspring (slow) or by trying their luck at serial seductions (fast). Conversely, females can continue the quest for their "Mr. Right" (slow) or be happy with the "Mr Not So Right" they have found and begin reproduction (fast). Finally, parents may choose to invest in few, highly competitive offspring (slow) or to have many children who might – however – fail to survive or reproduce.

Which of these strategies maximizes the fitness of an individual – or an entire species for that matter – is a function of ecological characteristics like food sources, predation, disease stress or climate. Since natural selection favors optimal adaptations to these characteristics, life history traits are subject to *evolutionary plasticity*. This implies that reproductive choice and nurturing behaviors – hence, the biological underpinnings of the demographic transition we are interested in – are predominantly shaped by the selective pressure of infant and childhood mortality. Biologists typically formalize the relationship between mortality and optimal fertility by the concepts of r- and K-selection.[7] To highlight the logic behind these prototypical LHT-strategies, consider the following stylized example: The population consists of only two competing dynasties who face an *extrinsic* mortality rate of μ which is unaffected by parental

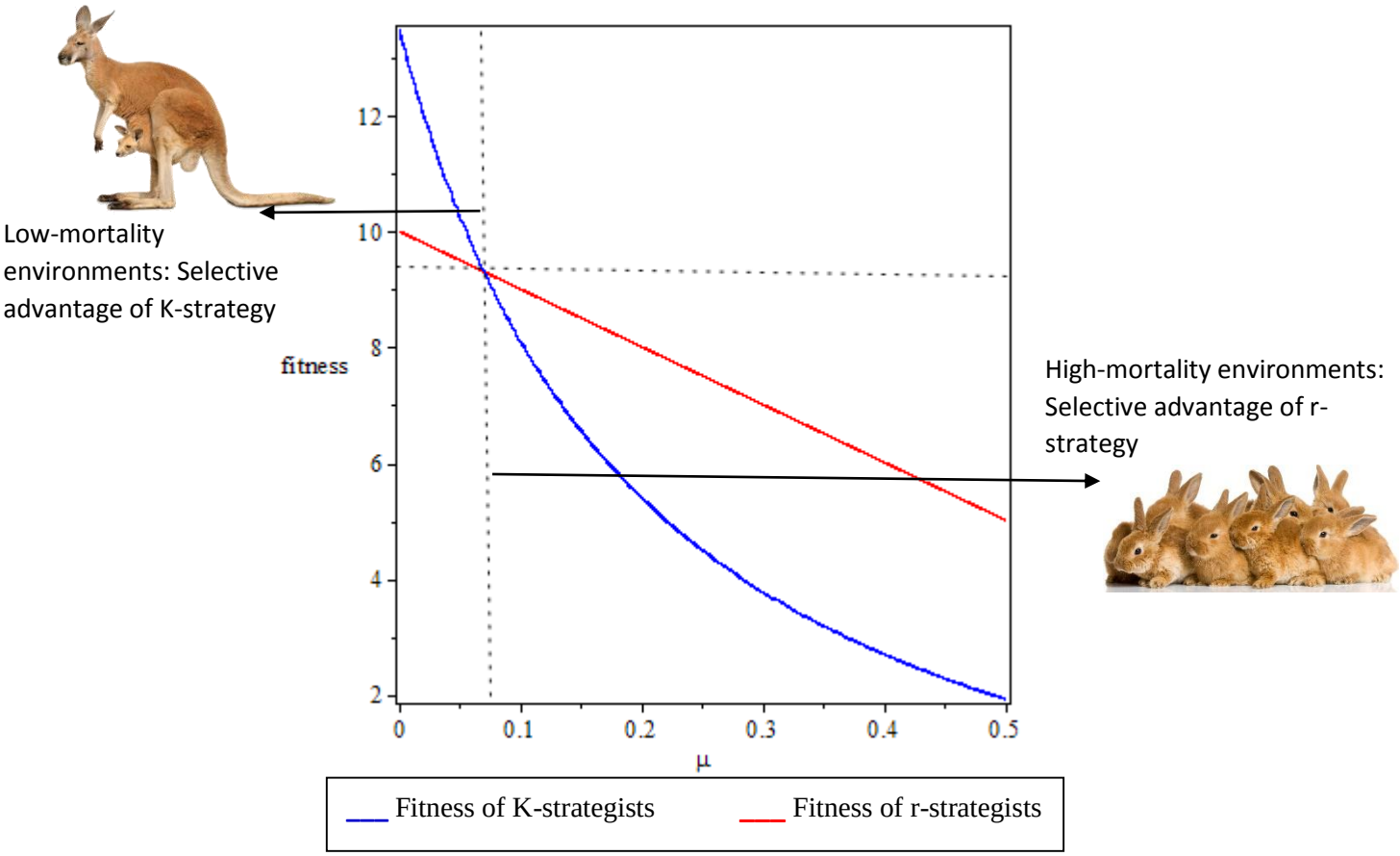
[5] The term "extrinsic mortality" is used by biologists to refer to mortality risks which are beyond human control.
[6] This precludes the emergence of *Darwinian Demons*, that is, of organisms which reproduce immediately after birth, have infinitely many offspring and live forever.
[7] For an overview see: Rockwood (2015)

care. Call the first lineage the "rabbits" or the r-lineage. Rabbit parents seek to maximize their fitness by producing as many descendants as biologically feasible but refrain from investing in their quality. By contrast, the second lineage, the "kangaroos" or K-lineage, reduces fecundity, and provides their few children with a "womb" of intensive care and education.[8] Which of the two dynasties will prove "fitter" in terms of passing down their genes to future generations depends on the environment. The dangers of highly unstable and unpredictable, r-selecting ecosystems are best countered by producing many (in terms of parental investment) cheap offspring. For even if many of them fall victim to predators, diseases, natural disaster or violence, there will always be some left to carry on the lineage. On the other hand, stable environments favor K-selective strategies because improved survival increases competition for resources and suitable mates. What is more, the marginal return to quality investment rises in the offspring's expected life span because quality investment – be it practical skills, academic attainment, reputation or socially preferable characteristics – is incorporated in individual children and cannot be transferred if the carrier of these traits dies.[9] Parents who seek to increase the future competitiveness of their descendants will therefore only collect the dividend of their investment if a sufficient number of offspring reaches adulthood and succeeds in the strive for mates and resources. These relationships are illustrated in Figure 1. The panels show the expected number of reproductively successful offspring under the "rabbit" and the "kangaroo" strategy. While μ is exogenous, total fitness – quantified by the reproductive success of future generations – depends on parenting effort and varies across the two dynasties. Thus, as mortality decreases, the fitness of the r-lineage increases proportionally because the expected number of survivors rises linearly as μ falls. By contrast, the fitness of K-strategists grows more than proportionally because in addition to the linear survival effect, their offspring also benefit from the rising competitiveness effect. As shown in figure 1, r-selective behavior provides a selective advantage in high mortality environments where the expected return to quality investments is low. Yet, as survival chances improve, this outcome is reversed such that fitness is maximized by parents who chose a K-selective strategy.

[8] In fact, the scholarly terms of r- and K- selection stem from r=rate and K=carrying capacity. Yet, thinking of rabbits and kangaroos is definitely more intuitive.

[9] In the animal kingdom, the ramifications of this fact are most palpable in the case of large mammals: Due to their long gestation and lactation periods, females of these species typically produce only one offspring per season. Their reproductive fitness therefore depends on the ability to survive multiple periods.

Figure 1: r-selection and K-selection under different environmental conditions



Before leaving biology and turning to economic theories of fertility, let us briefly summarize the gist of the previous section: To begin with, life history theory proposes that all living organisms solve economic optimization problems when allocating scarce energy resources. Moreover, whether fast (r-selective) or slow (K-selective) strategies are ultimately more successful depends on environmental characteristics, in particular on the prevailing mortality regime. In consequence, to be in line with evolutionary biology, an economic model of human reproduction must account for the fact that the relative rewards in the tradeoff between child quantity and quality change as mortality rises or falls. Keeping these results in mind, let us assess in more detail how the inclusion of LHT fits into the received economic theory of fertility.

3. From Biology to Economics – A Darwinian Fertility Model

It is not difficult to integrate adaptation to environmental risk into the standard economic theory of fertility. Yet, this simple modification leads to remarkable alterations in the predicted responses to declining mortality. In particular, it will turn out that evolutionary plasticity creates an endogenous feed-back mechanism which curtails Malthusian crises if the improvement in survival rates is substantial *and* sufficiently obvious to impact the households' family planning.

To support this claim, we rely on the classic Barro-Becker model, and tentatively integrate evolutionary fitness in the objective function.

As in the original Barro-Becker set-up, consider the problem of representative parents whose utility depends on the consumption $u(c)$ of energetic resources (including investment in own human capital) and on the value assigned to their offspring. The emotional bond between parents and children enters the model through the "altruism" parameter β which links parents' utility to the value of their children $f(N,q)$.[10] Of course, offspring "value" is determined by a variety of factors including survival, health, kinship support, mutual affection, wealth, success or social recognition. Still, irrespective of cultural particularities, these factors are nothing if not the socio-economic concomitants of evolutionary fitness. Thus, we can interpret the illusive "value" of children as their fitness which depends on parental quality investment q.

For mathematical convenience, utility from consumption $u(c)$ is assumed to exhibit the conventional functional characteristics, namely being twice continuously differentiable and exhibiting positive but decreasing marginal returns in *c*. The analytical treatment of fitness merits closer attention because it constitutes the major point of departure from the orthodox Barro-Becker framework. Following standard evolutionary models like Smith and Fretwell (1974), the fitness of each child is a sigmoid function of parenting effort.[11] At very low levels, the impact of quality investment is therefore modest but rapidly increasing. As parents increase their efforts, the corresponding marginal returns become smaller and eventually converge to zero as q approaches infinity. In the interest of analytical tractability, we will abstract from the possibility of birth order effects, sibling competition and correlated mortality risks. With this simplifications, the total fitness of the lineage is given by the expected number of survivors from N births multiplied by individual fitness, i.e.

$$f(N,\mu,q) = (1-\mu)\cdot Nf(\mu,q),$$

where μ denotes the exogenous part of mortality. Given that human infants require a minimum of care to survive at all, $f(N,\mu,0) = 0$ by construction. Furthermore, to capture the different evolutionary pressures of r- and K- selective environments, the fitness function meets the following criteria: First, the sensitivity of f with regard to q indicates the effectiveness of parental solicitude. Consequently, the elasticity of the fitness function ε_q can be considered a formal measure of parents' ability to control the fitness of their offspring. Next, mortality μ influences fitness via two different channels. To begin with, for given levels of q, higher mortality limits survival and therefore reduces $f(N,q)$ in *absolute terms*. In addition, high childhood mortality and morbidity prevent the accumulation of somatic capital (e.g. physical strength, beauty, academic and practical skills) and mitigate the expected impact of each unit of parental investment. Under high mortality regimes, K-selective strategies therefore loose their competitive advantage against r-strategies because a one-percent increase in q leads to smaller gains in offspring fitness than under more favorable conditions. We incorporate this

[10] For the complete model and the underlying assumptions see: Barro and Becker (1988), pp. 1-9
[11] This functional form was first introduced and discussed in: Smith and Fretwell (1974), pp. 499-503

selection effect into the model by requiring ε_q to be smaller the higher extrinsic mortality μ, i.e. $\frac{\partial \varepsilon_q}{\partial \mu} < 0$.

Translated into mathematical terms, the overall problem of a representative couple can now be expressed by the following objective function:

$$\max_{c,N,q} U(c,N,q) = \alpha ln(c) + \beta(1-\mu) \cdot Nf(\mu,q)$$

As parents attempt to choose their optimal reproductive strategy, the set of feasible solutions is constrained by the fact that rearing and educating children is a time consuming task and competes with income earning activities. Under the additional assumptions that (i) wages are exogenous, that (ii) all adults are endowed with one unit of time and (iii) income cannot be saved, parents' budget constraint takes the below form:

$$c = w(1 - Npq),$$

where w and p respectively denote the wage rate w and the "price" of parenting effort p. Using this expression, c can be eliminated from the objective function, such that the problem depends only on the two choice variables q and N. Normalizing wages to 1 and taking the derivatives of the modified function U delivers the following optimality conditions:

$$(i) \quad \frac{\alpha Np}{1 - Npq} = \beta(1-\mu) \cdot Nf'(\mu,q)$$

$$(ii) \quad \frac{\alpha pq}{1 - Npq} = \beta(1-\mu) \cdot f(\mu,q)$$

We can eliminate N from the system by dividing (ii) and (i) to obtain the following relationship:

$$(iii) \quad q^* = \left(\frac{f(\mu,q)}{f'(\mu,q)}\right) \leftrightarrow \varepsilon_{q*} = 1$$

The equation states the intuitive fact that at the optimum, fertility and parenting effort are set to the levels where the opportunity costs of having *one* more child or of providing *all* existing children with one additional unit of quality investment are exactly equal. More importantly though, the expression depends only on q, μ and exogenous parameters. This being the case, the optimal adjustment of quality investment in response to changes in mortality can be derived from the total differential of (iii)

$$\left(\frac{(f_{qq} \cdot q + f_q) \cdot f - f_q q \cdot f_q}{(f)^2}\right) dq + \left(\frac{q \cdot \partial \varepsilon_q}{\partial \mu}\right) \cdot d\mu = 0 \text{ (iv)}$$

Using that $q^* = \frac{f}{f_q} \leftrightarrow \frac{dq}{d\mu} = -\frac{\frac{q \cdot \partial \varepsilon_q}{\partial \mu}}{f_{qq} \cdot q} < 0$[12]

[12] Note that the sigmoid form of the fitness function allows for f'' > 0 at low levels of q. Yet, choosing such a small q violates the optimality condition $\varepsilon_{q*} = 1$. For since f(N,0) = 0, qf'(q) is strictly larger than f(q) for all q on the convex segment of f.

The interpretation of this expression is straightforward: As in the qualitative case of the "rabbits" and the "kangaroos", increased extrinsic mortality reduces the optimal investment in child quality. Yet, if this is the "quality" side of the parental tradeoff, what about "quantity"? To answer this question, we solve (ii) for N and compute the total derivative of the expression:

$$N = \frac{1}{pq} - \frac{\alpha}{\beta(1-\mu)f(\mu,q)}$$

$$dN = \left(-\frac{1}{pq^2} - \frac{\alpha f_q}{\beta(1-\mu)f^2}\right) dq - \frac{\alpha}{\beta}\left(\frac{f-(1-\mu)f_\mu}{(1-\mu)^2 f^2}\right) d\mu$$

Relying on the optimality condition $\varepsilon_{q*} = 1$, the relationship can be restated as follows:

$$\frac{dN}{d\mu} = \left(-\frac{N}{q}\right)\frac{dq}{d\mu} - \frac{\alpha}{\beta}\left(\frac{f-(1-\mu)f_\mu}{(1-\mu)^2 f^2}\right) \text{(v)}$$

The first product is strictly positive[13] and captures the fact that parents respond to harsh environments by substituting child quality by quantity. The second one is – however – negative because increased mortality reduces offspring fitness for any initial level of q^*. As a result, the tradeoff between reproduction and consumption is recast and adults face incentives to increase their own consumption while reducing both q *and* N. Contrary to quality investment, the total effect on optimal family size is therefore ambiguous and depends on the parameters of the fitness and utility functions.

Inspecting (v) is nevertheless instructing because we observe that high mortality environments produce large N but in two exceptional cases: In the first, the weight of consumption α is extremely large compared to the altruism or "child-preference" parameter β. In the second, mortality forces fitness to such low levels that parents balance the opportunity costs of reducing family size by switching from reproduction to increased consumption (i.e. f is small and f_μ large in absolute terms).

Why is it justified to consider the above scenarios "exceptional"? The answer is, because both biological and socio-economic arguments cast doubt on their applicability to real populations – in particular to those in a demographic transition. For one, demographic studies of ancestral populations have shown that very few successful reproductive events suffice to raise human fitness above average (Jones JH, Bird RB. (2014), pp. 65-71.). Unless the probability of survival virtually drops to zero, the biological opportunity costs of investing neither in child quality nor quantity will therefore be too high to be offset by higher parental consumption. Adding to that, it is frequently observed that parents in traditional societies compensate the lack of modern financial markets and social security by relying on children as a form of old-age insurance. Consequently, raising a certain minimum number of offspring to adulthood seems to be a socio-economic necessity in pre-demographic transition economies which in turn ensures that the propensity to consume (α) is not too large relative to the propensity to reproduce (β).

[13] Recall that $\frac{dq}{d\mu} < 0$!

Seeing this evidence, even critical spirits should agree that under realistic assumptions, high levels of μ reduce the relative price of fertility vs. child quality and translate into a shift towards higher reproduction and lower parenting effort. Conversely, improved survival boosts the benefits of offspring quality and serves to suppress the optimal level of fertility.

The central message of these results is that biology buffers Malthusian dynamics in that predictable, low-mortality environments produce an endogenous fertility decline whereas under inimical circumstances, this pattern is reversed and both birth and death rates remain on high levels. Even more intriguing for theorists, the model also predicts that a preceding fall in *absolute* mortality is no necessary condition for the onset of the fertility decline. Rather, parents will start to increase quality at the expense of offspring quantity as soon as the perceived effectiveness of parental effort rises. In this case, the elasticity of the fitness function with regard to q (ε_{q*}) will be larger and the optimal investment in offspring quality must rise in order to fulfill the fitness maximizing condition $\varepsilon_{q*} = 1$. Well in line with a number of historical studies, model therefore concludes that reductions in family size can accompany or precede the mortality decline provided that parents obtain better means to influence their children's fitness. Besides for its fit with historical evidence, this scenario is also relevant to current development policies because many transition societies experience improvements in medical care and public education as byproducts of social and economic progress. Finally, the suggested Darwinian fertility model provides theoretical support to sewer the empirically questionable link between rising per capita income and the demographic transition. For, since the optimal level of parenting effort – and hence the resources devoted to each child – are determined by environmental factors, higher real wages are neither a necessary nor a sufficient condition for incentives to increase offspring competitiveness and limit family size.

Closing the theoretical analysis, we note that the combination of Darwinian principles with economic modelling provides a remarkably simple explanation for otherwise puzzling demographic patterns. It is accordingly tempting to incorporate fitness maximization into a general equilibrium model in order to assess its role in human capital accumulation and endogenous economic growth. However, this analysis would be a mere academic exercise unless the evolutionary disposition to adopt faster or slower life history traits was evident in observed human fertility strategies. Let us therefore defray the calibration of a full-fledged endogenous growth model to future research and contend with the discussion of two fundamental preliminary questions: First, notwithstanding its theoretical appeal, is the incorporation of evolutionary fitness into parents' objective function equally plausible from an empirical point of view? Or, more concretely, are there biological processes which cause *actual* humans – as opposed to the hypothetical *homines oeconomici* of the model – to behave like fitness maximizers? Moreover, if individual humans turn out to maximize their fitness, what about entire societies? And finally, in case evolutionary algorithms permeate the social sphere, under which conditions do these adaptations trigger or impede the onset of a demographic transition in real societies?

4. Linking the Model to Reality – Are Humans Fitness-Maximizers?

4.1. Physiological Adaptations

The ability to switch from slower to faster life history strategies belongs to our evolutionary heritage. In fact, the mechanism is rooted so deeply that it operates partly through the endocrine – hormonal – system without surfacing to the level of conscious decision. In a sense, humans are *coded* to maximize fitness – be it despite themselves in some cases. This is the case because the human foetus reacts to environmental signals from the first months of gestation onwards. If environmental conditions (e.g. nutrition) are stable and favorable, the endocrine system "judges" the prospects for growth and successful reproduction good and facilitates rapid growth and early maturation.[14] Conversely, extreme levels of disease prevalence, physical stress and malnutrition indicate inimical future conditions and therefore impair maturation.[15] Finally, in cases between these prototypes, life history traits exhibit great scope for evolutionary plasticity and follow Darwinian optimization algorithms. For example, young organisms respond to environments where episodes of stability and affluence alternate with insecurity and famine by seizing the few - probably short - spells of favorable conditions and precipitate maturation to facilitate fast and frequent reproduction.(Worthman (1999) pp. 135-165) Unlike the permanently elevated levels of stress caused by exceedingly harsh environments, the moderate and pulsating hormone responses to unpredictable environments do not inhibit maturation, but affect the endocrine system's hypothalamic-pituitary-gonadal and hypothalamic-pituitary-adrenal axes. These two hormonal circuits in turn co-determine the development of stress-and steroid-responsive neural processes which are associated with reproductive timing.(Cameron (2008), pp. 795-801). When it comes to the feasibility of fast or low LHT strategies, evolutionary forces therefore apparently to nudge humans towards fitness-maximizing behavior regardless of individual preferences or socio-cultural conditions.

If this was the only evidence to support the integration of Darwinian fitness into the economic theory of fertility, critical readers would rush to ask: What is all the fuss about minor biological curiosities? And indeed, their critique would not go entirely astray. For one, physiological processes like the onset of puberty or the length of the reproductive period are ultimately subject to genetic constraints. Their demographic effect is therefore strictly limited. Moreover, these adaptations merely determine an individual's *ability* to reproduce. They say nothing about parents' *willingness* to have additional children or to invest heavier in existing ones. Thus, in order to be consistent with the idea that humans choose their reproductive strategy (more or less) consciously to maximize their *utility*, there ought to be a link between the gains in fitness and the gains in perceived utility. Put differently although we have modelled humans as fitness maximizers, few people will regard themselves as such. They are more likely to strive for "happiness", "love and mutual affection", "harmony with traditions and social norms" and many more. Given that physiological processes have just been showed to determine only a small fraction of the overall variation in human life history strategies other evidence is therefore needed to make fitness maximization a viable approximation of actual behavior. In particular,

[14] In actual population data, this reaction corresponds to the empirical observation of a sustained secular decline in the age of menarche in virtually all developed countries. See: Wood (2009), p. 417

[15]Corresponding evidence is discussed by Ellis (2004), pp. 920-958; Chisholm,and Quinlan (2005), pp. 233-265

high environmental risk should not only reduce the marginal impact of quality investment in the fitness function. It should also lower the expected utility gains – e.g. the emotional rewards – parents associate with caring for their children. Addressing these matters involves two empirical questions, namely first, whether parents adjust their *post-natal* investment – as opposed to the physiologically determined pre-natal ability to reproduce – according to the model's predictions and second, whether the underlying psychological processes really respond to mortality risks or to some other unobserved variable.

4.2. Psychological Adaptations:

Being used to think of the canonical quantity-quality tradeoff, economists might be surprised that deliberate discrimination in the allocation of scarce resources to individual offspring is not self-evident but constitutes a key difference between humans and other primates. For, no matter how pervasive and culturally enshrined the ideal of selfless and sacrificing mother love might be, it does not belong to our genetic blueprint. One important explanation for this is forwarded by anthropologists like Hrdy (1999) who point out that human infants differ from young primates by their inability to cling immediately after birth. As the neonate cannot cling and signal to its mother "care for me, I am worth the effort", the degree of parental investment hinges on the expected "value" parents associate with their newborn. The facultative nature of postpartum investment constituted a major selective advantage for early hominids because – following the rationale of fitness maximization – it ensured that the high costs of brain development and childhood dependency were only incurred if the survival of the child in question was sufficiently certain to justify the effort.

Traces of this evolutionary heritage can be detected in the infant mortality rates observed in pre-modern human societies. Advanced medical care being unavailable, the survival of newborns was critically dependent on costly parental behaviors like close supervision, protection and constant provision of high-quality nutrients (e.g. by regular breastfeeding). Consequently, if humans adapted psychologically to selective pressure, parental investment and its observable outcome – childhood survival – ought to exhibit a high degree of variation in response to environmental conditions. Following this intuition, Volk and Atkinson (2013) compared infant mortality rates in pre-modern Europe, present-day hunter and gatherer societies with those observed among primates and non-human monkeys. As figure 2 illustrates, their findings strongly support the hypothesis of facultative post-natal investment, because in spite of their parents' superior intellectual capacities, the depicted survival rates of human infants are extremely heterogenous and not necessarily higher than those of newborn monkeys.

Figure 2: Infant Mortality Rates in Human Societies and among Primates

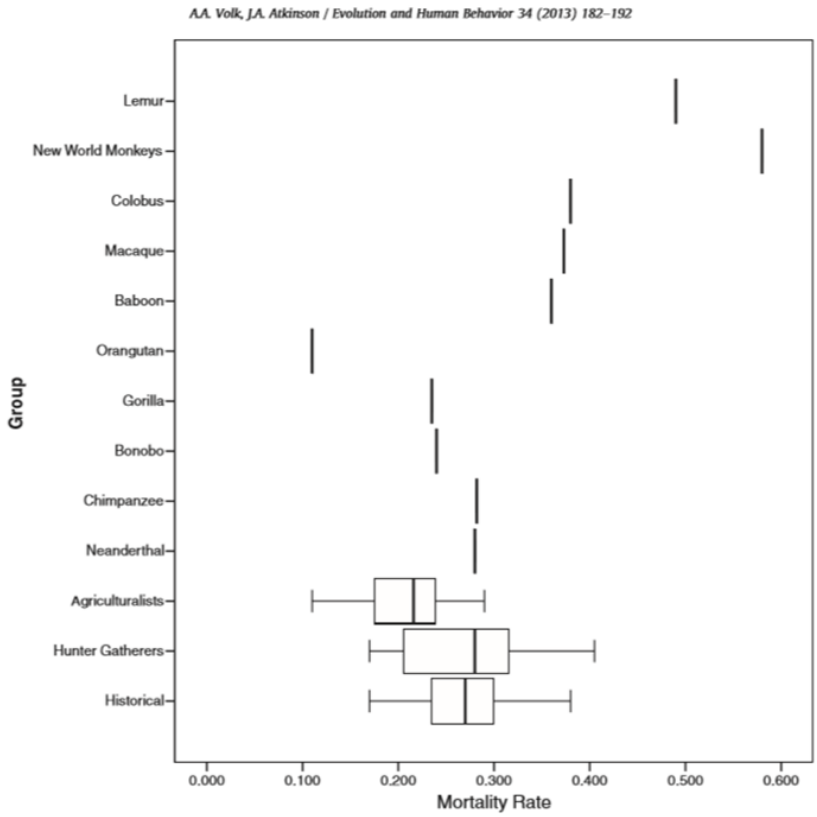


Fig. 1. Boxplot of infant mortality rate by group.

The above observation is a powerful antidote against excessive human self-esteem. More importantly though, it suggests that the human mind is probably as sensitive to extrinsic mortality as the endocrine system. Hence, as predicted by the Darwinian fertility model, human parents seem to follow psychological reaction norms which channel them towards a "high fertility and low investment strategy" whenever environmental conditions render this strategy fitness maximizing. The existence of this "Darwinian" development trap is indicated by a growing body of literature which suggests that the negative relationship between mortality and parenting effort and the positive correlation between mortality risk and fertility are universal patterns of human populations.

To give but a few examples of this work, Bereczkei (2001) found highly discriminative maternal effort based on child characteristics in a longitudinal study of 600 Hungarian women. In his sample, mothers of high-risk infants reduced their quality investment q by shortening the duration of breast-feeding and inter-birth intervals, compared to women whose infants stood better survival chances.(Bereczkei (2001), pp. 197-212). Similar results were forwarded by Nettle (2009) who used data from the Millennium Cohort Study (n = 8660 families) to show that in deprived neighborhoods in Britain, life expectancy was reduced while age at first birth was younger, breastfeeding duration shorter and reproductive rates higher. Remarkably enough, roughly the same pattern has been detected in historical European populations where – as contemporary medical textbooks put it – urban children raised in "precarious, immoral

conditions" tended to reproduce earlier than their peers in rural areas or in higher strata of the society (Krieger (1869), pp. 115). Again, the historical assessment is supported by present-day researchers including Anderson, Kermyt G. (currently developing countries), Caroline Uggla and Ruth Mace (Ireland), Charlotte Strömer and Virpi Lumaa (Pre-demographic Transition Europe) (2014), all of whom detect a positive relationship between fertility and mortality and negative effects on measures of child quality.

Seeing these corroborative correlations, it is sufficiently safe to consider the first question settled: Post-natal parenting effort is subject to evolutionary plasticity and it responds to signals of environmental harshness and unpredictability in the way predicted by the Darwinian model. Let us therefore turn to the components of the fitness function and proceed to the second question: Were we right in considering extrinsic mortality and the controllability of childhood survival (i.e. the effectiveness ε_{q*} of parenting effort) are the main causes of the observed variation in reproductive strategies? And if so, which psychological mechanisms translate high values of μ and low values of ε_{q*} into lower (perceived) utility gains from parental solicitude?

Scholars in the field of evolutionary psychology answer this question by pointing to the fact that high mortality, be it due to recurring food shortages, bad sanitary conditions, pollution or social conflict, exposes (prospective) parents to chronic stress. Prolonged exposure to harsh and unpredictable environments results in permanently elevated levels of glucocorticoids, the "stress hormones" which in turn influence the core hardware of human cognition and behavior. In particular, sustained stress affects two portions of the brain – the hippocampus and the prefrontal cortex – and impairs learning, emotional regulation and the control of aggressive outbursts. What is more, under stress complex choice problems are processed within the dorsolateral striatum of the prefrontal cortex which results in rapid, habit-based and increasingly myopic decision making. At the same time, glucocorticoids buffer the impact of neuropeptids like oxytocin and prolactin which promote bonding, trust and nurturing behavior.[16] This implies that higher extrinsic risk depresses the impact of parental effort q in the fitness *and* the individual utility function because the stress responses limit altruism, increase impatience and reduce emotional responsiveness. Under these conditions the value assigned to the (uncertain) future survival of children is low and the ability to enjoy stable and mutually affectionate relationships impaired which will discourage parents from investing too heavily in their offspring. The notion that quality investment necessitates a minimum level of security is corroborated by research in evolutionary psychology and economics alike. Thus, in a variety of different cultural and social contexts, it has been shown that parents' willingness to provide their children with formal education increased significantly after public health interventions that improved childhood survival rates.[17] Moreover, recent work by Quinlan reveals that parenting effort declines as aggressive pathogens render premature mortality an ubiquitous and uncontrollable phenomenon.[18] Finally, the influence of evolutionary algorithms is evident in defective parental behavior, particularly in postpartum depression PPD. With an

[16] Schwabe and Wolf (2009), pp. 7191-7198; Graybiel (2008), pp. 359-387; Porcelli, Lewis and Delgado (2012), p. 157

[17]Examples of this literature include: Bleakley (2007), pp. 73–117; Gibson et al. (2011), pp. 97 - 105

[18]These issues are discussed in Quinlan (2007), pp. 1606-1636

incidence rate of 5 to 25 percent (subclinical forms of the disorder not being accounted for), PPD occurs frequently enough to be of demographic and economic relevance. More importantly though, PPD is no random byproduct of the hormonal changes associated with puerperium. Rather, besides by certain genetic predispositions, post-natal depression is most accurately predicted by factors which inform mothers that either the costs of raising offspring are high (stress, lack of social and kinship support, unwanted/illegitimate pregnancy) or that the fitness gains from supporting a particular neonate are low (low birth weight, high birth order, wrong sex). Under such inimical circumstances, symptoms like fatigue, sadness, listlessness or aggression motivate mothers to withdraw investment from offspring with low reproductive value. As a result, scarce energy resources can be redirected to a new pregnancy (thereby increasing fertility and spreading the risk of reproductive failure among many offspring) or towards older evolutionary more valuable children.[19]

Let us briefly summarize the message of the above findings: Human reproductive strategies depend crucially on evolved psychological responses to environmental mortality cues. Moreover, the influence of these adaptations is highly persistent because parenting styles are "heritable" to a substantial extent. In other words, children whose parents have followed a fast life history strategy are more likely to exhibit opportunistic mating and limited nurturing effort. One reason for this is the fact that what constitutes "right" parental behavior belongs to the individual's assumptive worldview which is formed during childhood. Moreover, children who grow up under stressful conditions and insensitive or insufficient parental solicitude, experience permanently increased levels of glucocorticoids which impair their ability to form close and lasting interpersonal bonds in their adult life. (Kaplan and Lancaster (2003), pp. 170-223)

The heritability of parenting behavior is so remarkable because it leads to the perpetuation and diffusion of life history traits which maximize the fitness of their carriers. If this was not the case, individual adaptations would fail to translate into society-wide institutions and their impact would be too weak to play a perceptible role in the progression of the demographic transition. Seeing this concern, the following section will assess how high mortality stress affects the set of formal and informal institutions adopted by a population.

4.3. From the Individual to the Social Sphere:

Although losing a child is first and foremost a personal tragedy, societies with elevated levels of premature mortality tend to erect collective barriers against the traumatic impact of bereavement. The evolutionary purpose of these institutional shields is obvious: guaranteeing that parents maintain mental stability and continue to fulfill their social and familial responsibilities. Given this inherent logic, the workings of collective coping are best deciphered on the basis of their "targets", that is, based on the situational factors which determine the level of psychological stress associated with negative life events.

[19] An introduction to the topic is provided by Hahn et al. (2013), pp. 253-264

Concerning the intensity of psychological distress, trauma and resilience research posit that experiences are perceived more unsettling, the more disturbing and unforeseen the underlying event. The same holds, if the situation contradicts a person's learned world view or involves feelings of helplessness and loss of control.[20] Present day parents will hardly hesitate to associate all of the above characteristics with the death of a child. By contrast, ancestral populations adopted norms and practices which affected both adults' perception of and their expectations about childhood death.

To begin with, at times where the state of medical art did not allow to improve childhood survival significantly, the death of young children was widely considered a part of God's judgment and beyond the scope of human control. The idea that those who died young were blessed to "shuffle off their mortal coil" had an unbroken tradition from Greco-Roman times and was further reinforced by the Christian notion of a heavenly afterlife. Providing a rescue from feelings of guilt or from the emotional void of otherwise senseless loss, these beliefs permeate historical sources to the point leaving their imprint in every-day language. For example, in the 18th and 19th centuries, it was a common euphemism to say a child had "himmelt" (i.e. ascended to heaven) when referring to a premature death.[21] Moreover, religious rituals and popular traditions structured the transition from grief to the resumption of the family's normal life – a function which has been found to reduce the risk of complicated grief in both Western and non-Christian societies like e.g. China.[22]

Mostly stripped off religious connotations, a second set of psychological mechanisms targeted the unexpectedness and "injustice" of childhood death. In particular, unlike today, the first years were not regarded as a carefree prelude but as the most perilous period in life. Accordingly, high rates of infant mortality were viewed as a sad but natural condition. Like religious coping, resignation of this kind increased psychological resilience because prospective parents could emotionally prepare for the possibility to bury some of their children. At the same time, however, this process of *anticipatory mourning* produced a measure of ambivalence towards young children and caused parents to limit or postpone heavy emotional commitment.

The notion that parental attachment responds sensitively to mortality cues is supported by evidence from a wide range of past and present societies. Thus, in her seminal study on the social value of children, Zelitzer (1985) shows that until the 19th century, the death of young children was met with resignation rather than despair. Her findings are supported by the work of Stone on preindustrial England and Ariès' study on early modern France (Ariès (1982), pp. 82-83) which point to the fact that parents rarely attended the funerals of their infants or buried children "who had died to soon" in the backyard as we do with pets today.[23] With few exceptions in upper-class families, elaborate burial rites and mourning were equally uncommon in Roman Italy if a child died younger than five.(Rawson, Benjamin (2003), ch. 2)

[20] For an overview see: Zeidner and Endler (1996); Martz and Livneh (2007)
[21] Hazzi, (1802), p. 182, Wolff (1998), p. 267; Briese (2003), p. 263
[22] Lalande and Bonanno (2006), pp. 303-324.

[23] For an overview see: Stone (1977)

Of course, this does not imply that parents did not care for their children at all, it simply means that they followed a strategy, evolutionary theorists would refer to as "emotional bet-hedging". Rather than devoting all their love, physical energy and financial resources to one or two children, they spread their risk by allowing for more births and maintaining a certain distance until their offspring had survived the critical first years of life. In the words of Montaigne: "I have lost two or three children in infancy, not without regret but without great sorrow."[24] Ethnologists have documented similar attitudes in present-day traditional societies. In particular, many cultures consider children as "incomplete" and deny them full personhood until they have passed a certain age. Thus, for newborns of the Ayoreo in Bolivia it is "not unusual to remain unnamed for several weeks or months, particularly if the infant is sickly. The reason given is that – should the child die – the loss will not be so deeply felt." Similarly in Zambia, "when a Tonga child died before it was named, there was no mourning…the old women will tell the mother to hush her wailing, saying this is only a ghost."[25]

Curiously, it was as late as in the 19th century that doctors in Europe complained parents treated young infants with more or less apparent indifference. For example, a German doctor in Prussia noted that medical care was seldom asked for in case of small children, because under the age of 2 to 5 years they died too easily anyways. His confreres in Württemberg observed with barely suppressed disgust: "There are districts in our country, where parents watch 10 little children die till they call the doctor for the 11th ." And finally, country doctors in Bavaria reported that in times of economic hardship, it was always the youngest children of poor families who suffered most from indolence and therefore experienced dramatic excess mortality.[26]

Since variants of these practices have developed in uncounted cultural and historical contexts, there is little doubt that high mortality societies do transform individual adaptations into institutions at the population level. What is more, in historical settings, both the emergence and the decline of these institutions conformed closely with the predictions of the Darwinian fertility model. To appreciate this point, let us consider a set of social norms which contributed directly to elevated mortality and high birth rates. This category equally includes drastic behaviors like shortening the inter-birth interval by infanticide or abandonment of "defective" newborns and milder reactions like allo-parenting or cooperative child-rearing. While their impact on mortality is self-evident, these institutions also tended to raise fertility because "outsourcing" some childcare activities allowed parents to support more dependent children and because the spell of postnatal amenorrhea is shorter if mothers do not breastfeed or wean their babies early. A prominent example for this fragmentation of parental responsibilities is the practice of wet-nursing. In fact, the use of wet-nurses was so wide-spread in preindustrial Europe, that it had become a highly organized profession by the 17th century. Still, although some states – especially France – developed laws to regulate their employment, the majority of wet nurses were destitute peasant women and it was well known that children who were breastfed by their mothers stood much better chances at survival than nurslings.[27] Yet, since mortality was high

[24] Quoted by Zelitzer (1985), p. 18
[25] Quoted by Lancy (2014), p. 84
[26] Ärztlicher Verein Württemberg (ed.) (1868), pp. 26-28; Böing (1898), p. 64; Landeskundliche Gesellschaft Bayern (ed) (1865), pp. 399-400 , Ärztlicher Ausschuss (ed.), (1882), p. 165
[27] A survey of different countries has been undertaken by Stevens et al. (2009), pp. 32-39

anyways and – medical science being in its infancy – largely out of parental control, a couple could nevertheless increase their fitness by trying their luck at a higher number of pregnancies.

Things changed, when medical innovations like vaccination, bacteriology, disinfection and pasteurization rendered childhood survival less random. These advances not only boosted the impact of parenting effort but also tilted selective pressure from r- towards K-selective characteristics. As a result, wet-nursing became increasingly contested and vanished around the turn of the 20th century.[28] The salient feature of this process is that the decline of wet-nursing was paralleled by the rise of "modern" institutions which evidenced a trend towards higher valuation of children and "slower" life history strategies. Thus, confirming the predictions of the theoretical model, increased effectiveness of parental solicitude ($\varepsilon_q\uparrow$) caused society to redirect resources from fertility promoting to child quality promoting institutions. One example for these newly formed institutions is the establishment of pediatrics as a separate branch of medicine in late 19th century Europe.[29] Given that the differentiation occurred only *after* scientific progress had provided parents with the means to control offspring survival more effectively, the supply of specialized medical services can be interpreted as a sign of increased willingness to invest in children from a very young age onwards.

A second example relates to early childhood education: Around the middle of the century, reformers like Fröbel, Pestalozzi and – somewhat later – Montessori pioneered the idea that children were neither miniature nor incomplete or defective adults. Instead, infancy came to be considered a central developmental stage which required specific, age-appropriate stimulation of cognitive and social skills. As the new educational paradigm spread, more and more parents felt the pressure to commit precious time and resources to the education of their children. Refusing to breastfeed or failing to take basic hygienic precautions began to be publicly frowned upon just like swaddling infants, leaving them unattended, rocking them excessively or feeding them alcohol to keep them quiet.[30] This said, the fact that parental effort became fashionable while practices which had long served to facilitate frequent reproduction turned unacceptable, suggests that society was *in toto* moving from fast to slow life history strategies. Institutional change assumed a critical role in this transition because it contributed to the preservation and rapid diffusion of successful adaptations to the changed selective pressures. Due their mediating function between society and evolutionary environment, many more institutions were affected by the scientific and social leaps of the 19th century. Consequently, there is no doubt that much more could be said about labor laws and compulsory schooling or about maternity leave and the codification of child rights. However, to avoid going off on tangents, let us content with our glimpse on institutional development and summarize the major implications of the section: First, institutions mimic individual adaptations in that increased effectiveness of parental care and lower extrinsic risk trigger a self-reinforcing trend towards smaller families, higher quality investment and improved survival. Notwithstanding the potential to promote socioeconomic modernization, this result points also to development risks and suggests that improvements in survival rates alone are insufficient to promote the shift from

[28] A useful introduction is provided by: Hrdy (1994)
[29] In Germany, the first chair of pediatric medicine was established in Berlin in 1895, when the demographic transition was already on its way.
[30] Pollock (1983), pp. 2-18; Larass (2000), p. 176, Arnd (1835), p. 150

r- to K-strategies. This is the case because families will only modify fertility and parenting patterns if traditional institutions (e.g. castes, limits to social mobility) do not reduce the expected payoff of quality investments and if parents recognize the increased effectiveness of their efforts ($\varepsilon_{q\uparrow}$).

That problems of this sort are present in currently developing countries is highlighted by the notoriously poor record of birth control programs, many of which fail although contraceptives are widely available and survival rates often improved. Still, only if parents *know* that certain health interventions will prevent infant and childhood mortality, their subjective environmental risk is reduced and the tradeoff between child quantity and quality substantially altered. Consequently, societies which see for the provision of fundamental health care and the spread of medical knowledge ought to experience an earlier and more rapid fertility decline than populations where these conditions are not fulfilled. Assessing the empirical content of this proposition is of course possible, but it requires us to abandon the sphere of general psychology and cross cultural institutional patterns. For, to analyze the relative importance of biological factors rigorously, it is indispensable to control for countervailing influences like variation in geographic or socio-economic conditions.

5. Historical Case Study: Assessing the Darwinian Gift of Medicalization in 19th Century Germany

Historical evidence offers a unique possibility to test whether and to what extent medicalization promoted the transition from fast (r-selective) to slower (K-selective) life histories. The evidence in question is the experience of smallpox vaccination in 19th century Germany. The case is highly intriguing for several reasons. First, in the light of the previous sections, medical innovations must exert a strong and lasting impact on mortality if they are to alter parenting behavior perceptively. Moreover, the effect needs to be immediately apparent and the causality between the health intervention and improved survival must be sufficiently obvious to become common knowledge. Briefly summarizing the historical epidemiology of smallpox one finds that vaccination fulfills these criteria with ease.

5.1. A Brief History of Smallpox

The first unmistakable descriptions of smallpox date back to 4th century China. By the 13th century, the disease was endemic in the known world, extending its grip from Japan to Britain and from Iceland to northern Africa. From that time onwards, it followed a characteristic epidemiological pattern of regular explosive epidemics along the main trading routes of Eurasia and the Mediterranean. Since a single attack of smallpox conferred long-lasting immunity, epidemics mainly affected young children and spared communities until the pool of infectible individuals sustained a new outbreak. In spite of this periodicity, the number of children who became exposed was so overwhelming that 18th century scholars grimly observed that no-one would make a difference between the ravages of smallpox and the plague, were it not for the

habit to count children's lives only once they had survived the former.[31] Similarly stressing the omnipresence of smallpox, 19th century historians referred to them as a "communist disease" which struck rich and poor with blind disregard for class, sex or mode of living. (Bohn (1875), p.1).

For early periods, such assessments have to be taken at face value but from the 18th century onwards it is possible to quantify smallpox mortality in a number of European cities and regions. Swedish and French census data for example indicate that in the late 18th century, smallpox deaths on average accounted for 11% of overall mortality. These numbers are confirmed by some German states which feature shares between 11% (Berlin, 1754-1800), 12.5% (Eastern Prussia, 1765-1785) and 11% (Wurttemberg, 1750-1800).[32] Concerning smallpox prevalence, the picture drawn by the historical sources is even gloomier as 18th century scholars from France and Germany estimated that approximately 80% of each cohort would catch the disease – a number which their present-day confreres only slightly corrected to 66-75%. (Wolff (1998), p. 101). This situation changed dramatically with the discovery of the cowpox vaccination in 1796. In a mere 75-pages volume, English country doctor Edward Jenner revolutionized smallpox prevention by describing how immunity could be acquired by inoculating individuals with cowpox, a flu-like disease with local skin eruptions that caused no severe danger to the life of the infected person.(Jenner [1796])

Seeing the enormous death tolls of smallpox, the impact of vaccination on extrinsic mortality was substantial and it must have been sufficiently obvious to recast the tradeoff between the number and quality of children. This strong "treatment effect" alone is nevertheless insufficient to make vaccination a viable natural experiment for the demographic impact of medicalization. For any meaningful comparison it also needs exogenous variation in the spread of medical knowledge (to obtain untreated controls) and detailed data on vaccination rates, population characteristics and vital statistics. For research purposes it is therefore a fortunate fact that the South Western German states of Bavaria, Baden and Wurttemberg, passed mandatory vaccination laws in the early 19th century and carefully documented the effect of these laws ever afterwards. Statistical and anecdotal evidence are thereby particularly detailed in the case of the Grand Duchy of Baden, where the data are – for many years at least – available down to the district level. This fact bears central importance for identification because certain characteristics of Baden's vaccination system caused the impact of medicalization to be stronger in some districts than elsewhere.

5.2. Using Vaccination as an Indicator for the Perceived Effectiveness of Parenting Effort: Does Medical Knowledge Contribute to the Fertility Decline?

The reason for the differential spread of medicalization stemmed from the way inoculation was practiced during the 19th century. In practical terms, the success of the vaccination system hinged on the availability of fresh cowpox-lymph because preservation and cool storage of the vaccine remained on rudimentary standards throughout most of the 19th century. The lymph

[31] This is discussed by contemporaries and current research, see: Struve (1802), pp. 1-2; Baldwin (1999), p. 244
[32] All Data from Kübler (1901), chapter 4

used in the process was either derived from the dried material of some previous vaccination or was directly transferred from the pustules of one vaccinee to the open cuts on the forearms of another (arm-to-arm vaccination). In the first case, chances were high that the lymph had degenerated during storage and failed to cause the immunizing outbreak of cowpox. In the second case, doctors had to make sure that there was an unbroken "supply" of individuals seeking vaccination in order to maintain the process of vaccine transmission. Timing was all the more of essence as the lymph could be collected only within a limited time-frame: If the pustules were opened too early, they leaked only small amounts of fluid with little infectious material. If on the other hand the operation took place at an advanced stadium, the lymph would already be mixed with pus and debris which reduced the power of the vaccine and increased the risk of transmitting other diseases when inoculating new vaccinees.[33] To address this challenge, Baden was fast in backing up its immunization policies with an institutional infrastructure. In particular, the country established public vaccination institutes (*Impfinstitute*), that is, institutions where parents could have their infants vaccinated for free whenever they desired to do so. In exchange, they were obliged to allow the vaccinators to collect fresh lymph from the children once the pustules had reached the proper stadium. The doctors who worked for the vaccination institutes therefore needed to maintain close contact with the families in the proximity of the institute in order to make sure they would always find an unvaccinated child to produce fresh vaccine. This interaction required a great deal of patience and persuasion as a Mannheim doctor confessed in 1808:

> "...whenever vaccinations are to be performed, some children are reported ill, others do not show up because the mother has suddenly made up her mind or because the grandmother or the neighbors have argued against the operation. Or again, there is no recently vaccinated child available because the overly-protective mother refuses to wake her toddler from his sleep, because she wants to spare him the pain or because she fears to expose him to cold weather. And then probably after having waited for hours, the doctors have to restart the whole business and rash to find some other [recently vaccinated] child - a vexation that unnerves even the most patient personality."[34]

But what was arguably a nuisance for the physicians might have had life-saving consequences for the babies they "milked" for vaccine. This was the case because public doctors and publicly salaried midwives were exhorted to frequently check on the sanitary conditions in their constituencies, to inform parents of proper childcare and promote health preserving habits like breastfeeding. But of course, the zeal with which these duties were fulfilled were a matter of the respective health practitioners' discretion. Yet, these matters were more likely addressed if the doctor had to visit the families anyways.[35] What was more, while vaccination was mandatory for all children, the provision of lymph for future vaccinations was not. The vaccinators would therefore have to explain the benefits of the measure to young parents and convince them of its safety. By doing so they contributed to a profound change in the popular

[33] This particularity is discussed both by Cless (1875), chapter 1 and Heim (1838)
[34] GLA Karlsruhe 236-16034 (Sanitary Commission), Report of the *Physicus* of Mannheim, 1st of November 1808
[35] Laws and ordinances in: (Baden) Philipp Carl Baur von Eiseneck, Sammlung sämtlicher Gesetze, Verordnungen, Instructionen, Belehrungen und Entscheidungen, welche in dem Gross-Herzogthume Baden über Gegenstände der Gesundheitspolizey erscheinen sind, Karlsruhe 1830

conception of infant and childhood mortality. For, prior to vaccination, deeply rooted folk wisdom had perpetuated almost all of the adaptations predicted by the theory of anticipatory mourning, Thus, it held that diseases like smallpox were an inevitable ailment, a process of purification rather than a disease and were necessary to eliminate evil substances from the body before it reached adulthood. Sometimes, the idea of physical purification was moreover coupled with the religious belief that epidemics were manifestations of God's judgment and punishment.[36] As a result, early sources like the following 1813 report are littered with complaints of "popular ignorance and prejudice"

> "...Thus, the following prejudice is deeply rooted [in popular opinion], that the natural smallpox poison is a priori contained in the body (...), that this poison cannot be emitted from the body through the few pustules [after vaccination] and that this will eventually give rise to other diseases even if it might prevent the outbreak of smallpox."[37]

In spite of the vaccination's early success, these attitudes did not vanish in the course of time. If anything, traditional conceptions of smallpox took on an elitist and pseudo-scientific inflection from midcentury onwards. This tilt of balances resulted from the fact that increasing professionalization and medical progress went along with a heightened interest in what would today be referred to as "alternative medicine." Among other centers, the university towns and spas in the German South attracted all sorts of naturopathic practitioners – trained doctors as well as laymen – who produced an impressive body of literature and succeeded in conquering their share of the mass media including newspapers and popular journals. A motley group they were, the adherents of homeopathy, herbal cures or hydrotherapy were nevertheless united in their contempt for "unnatural" methods like vaccination and promised corporeal balance through "natural" cures and diets. Again, this attitude suggested that disease was an integral part of life, more a manifestation of physical disequilibrium than a harm to be combated. And since alternative medicine received an uncommonly intensive coverage in contemporary media, the naturopathic fashion fostered anti-vaccionism just the same way as traditional prejudices had before.

Traditional and seemingly "modern" opposition against vaccination are central for our purposes because they influenced attitudes towards environmental risk and thereby co-determined the expected impact of parenting effort (ε_q). Whether or not a household perceived childhood mortality as something inevitable or as a danger to be actively prevented depended critically on the frequent interaction and constant communication with academically trained doctors. Parents who participated in the vaccination system were therefore arguably better able to prevent infant mortality and might therefore have switched to a slower life history strategy than other households.

[36] This was particularly true during the first decades of the 19th century when widespread ignorance in medical matters fatally coupled with the symptoms and age-specific incidence of smallpox. Well before the bacteriological revolution of the 1860s, it was simply *too* plausible to assume an infection inevitable that used to affect more than two thirds of all children. In addition, symptoms like high fevers, intense pain, rashes and pustules leaking a fetid mixture of lymph and tissue debris were easily interpreted as signs of the body struggling to free itself from evil fluids.

[37] Werfer (1813), p. 146

5.3. Estimating the Impact of Medicalization:

To test this conjecture, I collected socio-economic indicators and population data of Baden's 67 districts (*Amtsbezirke*). Regarding the measure of medicalization, archival records allowed me to locate the vaccination institutes and their years of establishment. In addition, it was possible to retrieve information on economic characteristics of the districts in the sample including urbanization and poverty rates. Using these data[38], I estimated the following econometric model:

$$TotalFert_{i,t} = x_1 Totalmort_{i,t} + x_2 VaccIns_{i,t} + x_3 Poverty_{i,t} + x_4 City + Tim\ Controls + Regional\ Controls + \varepsilon_{i,t},$$

The dependent variable *TotalFert* corresponds to the number of births per 100 inhabitants in district i and year j. Whether local fertility levels responded to evolutionary pressures or not is assessed by the coefficient of *Totalmort*, that is, by the number of infant deaths per 100 inhabitants.[39] Positive values of x_1 thereby indicate that high mortality was associated with high fertility, whereas negative x_1 suggest an inverse relationship between the two. Since the effectiveness of parenting effort depends on an interplay of scientific and social institutions, ε_q is approximated by two indicators of medicalization which capture key determinants of parents' ability to improve the fitness of their offspring. The first, of these indicators is the binary variable "*VaccIns*" which takes the value of 1 if a vaccination institute was operating in district i during year j and zero otherwise. Given the institutes' reliance on popular support, *VaccIns* can reasonably be assumed to reflect the spread of medical knowledge – and hence parents' expected capacity to exert control on childhood survival. Knowledge was – however – of limited use to improve childhood survival, if medical services were not available. The second variable, *"DOC",* therefore assesses whether households had access to fundamental healthcare at all. The intuition behind the measure is as follows: In addition to local mortality data, the Badenese mortaliy records note whether the official certificate of death was signed by a doctor or a local official. The value of this information stems from the fact that fatal diseases or accidents are commonly considered the core expertise of a doctor. If a death was signaled to some petty official, it is natural to suspect that the bereaved family was either unable to reach a physician or did not trust in modern medicine. Hence, by computing the fraction of deaths signaled by a doctor, it was possible to construct a measure for the availability and the popular reliance on medical services. In order to control for the potential influence of socio-economic characteristics, I further introduced the variables "City" and "Poverty", which respectively

[38] The sources are: Generallandesarchiv Karlsruhe:) 236-16019-16045 and 234-6041, Staatsarchiv Freiburg, 908/1-135 (Leichenschau), Statistik der Inneren Verwaltung des Großherzogthums Baden, various issues 1851-1893

[39] Since the data contain only information on mortality within certain age brackets, I labelled all deaths age < 1 as "infant deaths"

account for urbanization and the prevailing poverty rate.[40] Finally, district dummies and time controls were employed in order to capture local and time fixed effects. The results of the estimation are depicted in Table 1. In addition to the simple OLS model, specification 2 uses district and time controls. Moreover, to reduce the risk of extreme observations biasing the estimates, specification 3 performs a quantile regression of the median.

Turning to the results, one finds that the estimated coefficient reflect the predictions of life history theory almost perfectly. For one, high overall mortality – i.e. high environmental risk – comes along with statistically significant increases in fertility. Next, arguably reflecting Malthusian dynamics, poverty reduces fertility, whereas the impact of urbanization remains – somewhat surprisingly – insignificant. More importantly though, medicalization did promote the expected shift towards reduced family size because the coefficients of *VaccIns* and *DOC* are statistically significant and negative in all (respectively in two out of three) specifications.

Table 1: Estimated Effects of Medicalization on Fertility

Model	***OLS***		***OLS, Panel***		***Quantile Regression***	
Variable	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
TotalMort	**1.0000306**	20.02	**1.175.945**	24.16	**1.089.841**	23.37
VaccIns	**-0.4718797**	-4.96	**-0.4563893**	-5.37	**-0.5315497**	-5.98
DOC	**-0.1364501**	-1.37	-0.1667520	-1.34	**-0.241978**	-2.54
Poverty	**-0.0453486**	-7.91	**-0.0393697**	-7.54	**-0.0443673**	-8.08
City	**-0.0636008**	-1.12	**-0.1561412**	-2.96	-0.0377227	-0.7
Time Controls	Yes		Yes		Yes	
Regional Controls	No		Yes (Amtsbezirke)		Yes (Amtsbezirke)	
Adj-R^2	0.51		0.62		Pseudo R^2 = 0.39	
Number of Observations	801		801		801	

Having recognized the congruence between the theoretical model and the historical dataset, let us dare a tentative assessment of the respective size of the mortality and medicalization effects: Addressing first things first, consider the coefficient of *Totalmort.* Across all specifications, x_1

[40] Poverty captures the fraction of individuals who were entitled to poor relief among the deceased in the corresponding year. Assuming that the poverty rate among the dead was approximately equal to that among the survivors, poverty should be an accurate measure of the actual poverty rate in a district.

is larger or equal to one which implies that each additional death was offset by a corresponding increase in fertility. This result is not trivial since it provides one of the central hypotheses of the Darwinian fertility model with empirical backbone: The effects of Malthusian checks are strictly limited because elevated levels of mortality channel the population towards an r-strategy with high levels of "replacement" fertility.

Reductions in environmental risk and increased effectiveness of parental effort produce exactly opposite results. The impact of improved information – as measured by *VaccIns* - is particularly strong with districts where a vaccination institute was located recording estimates of about 0.4-0.5 births less than elsewhere. Qualitatively, the impact of doctors' availability is similar, although the estimated coefficients do not attain statistical significance in all specifications. However, to the extent the estimates turn out significant, their quantitative impact is not negligible. In particular, having one percent more death certificates signed by a doctor comes along with approximately 0.13 - 0.24 fewer births per year.

There is yet another interesting link between the historical data and the Darwinian fertility model: Based on LHT, parents respond not only to cues of extrinsic mortality but also to variation in the effectiveness of their efforts. In particular, we expected fertility to be smaller, the greater the effectiveness of parental investment (ε_q). Using quantile regression and analyzing the estimated coefficients at different points of the distribution allows us to obtain some indication about the accuracy of this prediction. The intuition behind this procedure is as follows: If parents desired larger families when facing environments which reduced the impact of fitness promoting investment, the coefficients of the medicalization variables ought to be smaller for higher quantiles of the fertility distribution. This being the case, high fertility could be considered an indicator of ineffective or dysfunctional health institutions and – correspondingly – reduced parental inclination to adjust fertility plans downwards. The information to test this conjecture can be obtained from an interquantile range regression of the difference between quantiles. The coefficients in the difference regression are thereby interpreted as follows: If a coefficient x_i takes the value of zero, the sensitivity of fertility to variable i is the same at all points of the distribution. If x_i is significant in the interquantile regression and carries the same sign as in the original estimation, the expected effect of variable i is larger at higher levels of fertility. Finally, if x_i reverses its sign, the fertility response to changes in i is smaller at high levels than at lower ones. As shown in table 2, the coefficients of the medicalization variables seem to obey to the logic of LHT outlined above. Thus, although the difference is only significant for *VaccIns*, the absolute impact of medicalization is damped at the upper (90% quantile) than at the lower end (10% quantile) of the fertility distribution. Put differently, if fertility was high, the response to medical infrastructure was comparatively weak and parents apparently based their family planning on other factors. By contrast, at low levels of fertility, the response to medicalization is reinforced which is suggestive – albeit no conclusive proof – of a heightened sensitivity to improvements in ε_q and the presence of a quantity-quality tradeoff.

Table 2: Interquantile Regression

Model	***Interquantile Regression***	
Difference Variable	Coefficient	t-stat
TotalMort	-0.1644442	-0.66
VaccIns	**0.4907308**	**1.75**
DOC	0.0011318	0.32
Poverty	0.0165889	1.28
City	**-0.365399**	**-2.23**
Pseudo-R^2 0.1-quantile	0.43	
Pseudo-R^2 0.9-quantile	0.47	
Number of Observations	801	

5.4. Robustness against Endogenous Mortality:

At this point, critical readers might be troubled by the possibility of reversed causation in the relationship between fertility and mortality. This problem would occur if high mortality was a direct cause of high fertility. Given the facultative nature of parenting behavior, the idea is not too implausible. For example, parents might have sought to "correct" an unexpectedly large family size by withdrawing investment from children of higher birth orders or of the "wrong" sex.

In order to account for this problem and to obtain unbiased estimates for the effect of *extrinsic* mortality μ, I therefore performed an instrumental variable estimation for the coefficient of *Totalmort*. To be a viable instrument for exogenous mortality a variable should be strongly correlated with mortality while being independent of fertility. Fortunately, the scrutiny of Baden's statistical officers provides us with such a measure. For, besides information on fertility, mortality and core socio-economic characteristics, the records also feature annual statistics on the frequency of specific causes of death. Some of these, like diarrhea or frailty arguably reflect harsh environments (i.e. extrinsic mortality) *as well as* parental negligence. Others like accidents or coronary diseases had probably little impact on infant and childhood mortality. Yet, there is one disease which breaks with this pattern: pertussis. The reason for this is first that the disease follows a specific course which starts with mild cold-like symptoms before gradually escalating to the characteristic whooping cough. In addition, pertussis is an airborne disease which spreads when an infected person spills tiny droplets containing the

bacillus *Brodetella Pertussis*. Yet, although the latter causes the infection, the most severe symptoms are not the workings of the bacillus itself but stem from a toxic it produces to override the body's immune system. Thus, the disease is most contagious during its early stages when the concentration of *Brodetella Pertussis* is high whereas the symptoms are either mild and unspecified or missing altogether. In consequence, there was little to do for parents who sought to protect their children from the disease nor was it possible to expose unwanted children directly to contagion. At the same time, pertussis occurred epidemically and in a largely random manner. In other words, it is hard to conceive a channel through which high fertility might have influenced the prevailing level of pertussis mortality. Following this rationale and using the number of deaths from pertussis as an instrument for *Totalmort*, I found the estimation results depicted in Table 3.[41] As it turns out, the positive effect of mortality is robust and remains statistically highly significant. As predicted by life history theory, mortality therefore exerts a systematic influence on fertility.

Table 3: Instrumental Variables Estimation

Model	***IV***	
Variable	Coefficient	t-statistic
TotalMortIV	**0.7221714**	**2.15**
VaccIns	**-0.51874**	**-5.14**
DOC	-0.0006542	-1.39
Poverty	**-0.051114**	**-5.01**
City	**-0.1771814**	**-3.07**
Time Controls	Yes	
Regional Controls	Yes	
Adj-R^2	0.26	First Stage F_Statistic: 40.83 , Prob>F =0
Number of Observations	798	

[41] The data were drawn from the same sources as in Tables 1-2

5.5. Medicalization and the Quantity-Quality Tradeoff; Effects on the "Value" of Children

The previous results clearly suggest that the empirical patterns of human fertility respond to signals of elevated mortality. Still, with regard to theory, this is merely half the battle. After all, the Darwinian fertility model further predicts that the decline in fertility ought to initiate an increase in child quality investment. Thus, if the theory fits with socio-biological facts, we would expect parents in the better medicalized districts of the sample to have formed early emotional bonds and to have invested more heavily in the wellbeing of their children. Assessing this prediction is empirically more involved than identifying the effect on fertility because it requires to quantify the – almost immeasurable – degree of parental attachment and the propensity to invest in child quality.

At first glance, educational indicators like schooling or literacy rates seem suitable candidates for the desired measure of parental quality investment. Yet, there at least with respect to the Baden dataset, there are reasons to doubt the accuracy of these "natural" indicators. To begin with, literacy was almost universal in South Western Germany during the observation period. For example, a survey by the ministry of justice showed that 97% of the inmates in the prisons of the state of Baden had fundamental reading and writing skills in the 1850s.[42] In other words, being able to read and write was too common a characteristic to qualify as a measure of exceptionally high parental solicitude. Much the same holds for schooling because primary education was mandatory and free for all children under the age of 14. Secondary education by contrast was offered by many different institutions, ranging from the *Gymnasium* and the *Oberrealschule* to different types of vocational courses. As a result, data on the attendance of these – not necessarily public – schools is scattered and does probably not even capture the true extent of parents' quantity-quality tradeoff. For, while youngsters in an academic secondary school like the Gymnasium did not contribute to the family budget, students who enrolled in vocational schools like the *Höhere Bürgerschule* might also have pursued an apprenticeship and made a living on their own. Finally, schooling rates fail to reflect the influence of early childhood mortality because investments in formal education were made well after the critical first years of the child's life when mortality was highest.

Consequently there is little doubt that a different measure for the value placed in child quality is called for. In fact, the historical record does provide such an indicator. For, doctors, local officials, teachers and clergymen frequently observed that the mortality rate of legitimate children was far lower than that of illegitimate children. The same observers did not hesitate to spell out the reasons for this fact. As the prestigious Journal of Public Health (Zeitschrift für die Staatsarzneikunde) put it in its 1837 issue:

> "…having no other choice, mothers of illegitimate children leave their newborns with a nurse. In most cases, nurses are poor women who receive a mere pittance for the sad business of taking these starved, neglected children and letting them die as soon as possible. Only the friends of the poor and the doctors know in what sheds and cages these wretched little creatures are kept during their short lives, in what dirt they dwell, what disgusting stodge they are fed and what appalling maltreatment they experience every day…"[43]

[42] Diez (1863), p 102
[43] Zeitschrift für die Staatsarzneikunde (1837), p 448

To the extent that excess mortality of illegitimate children was chiefly due to neglect or maltreatment, it can be considered a sign of parents pursuing an exceedingly fast life history strategy and trying to get rid of the unwanted consequences. However, in districts where infant mortality rates were more or less the same for legitimate and illegitimate children, the value placed in each child – or the social sanctions for neglect - were probably high enough to set incentives for a slower "low fertility/high quality investment" strategy.

Relying on this intuition, I constructed the variable "*Value*" which measures the excess mortality of illegitimate children relative to overall infant mortality:

$$Value = \frac{Totalmort - Illegmort}{Totalmort}$$

The expression is easily interpreted: If there is no difference between the mortality rate of illegitimate children and the district average, *value* will be equal to zero. By contrast, if the risk of dying is higher for illegitimate than for legitimate children, *value* will be negative. Finally, in the unlikely case that the group specific mortality risks are reversed, value changes its sign and becomes positive.

As before, the underlying data were drawn from the medical statistics compiled by Baden's Ministry of Inner Affairs and comprise records of all births and neonatal deaths of legitimate and illegitimate children in the 67 districts (Amtsbezirke) during the period 1851 - 1863. Using this information, I estimated the following econometric model

$$Value_{i,t} = x_1 Totalmort_{i,t} + x_2 DOC_{i,t} + x_3 Poverty_{i,t} + x_4 VaccIns_{i,t} + x_5\, city + Tim\ Controls + Regional\ Controls + \varepsilon_{i,t}$$

The results of the estimation are depicted in table 4. As in the analysis of Baden's fertility patterns, the estimated coefficients fit well with evolutionary theory. In particular, high fertility and poverty seem to prevent early attachment and facilitate the neglect and abuse of unwanted illegitimate children (i.e. the coefficients of *Totalfert* and *Poverty* are significant and negative). By contrast, the indicators of advanced medical coverage, *DOC* and *VaccIns* come along with an increased valuation of children (although statistically not significant in the latter case). Thus, as predicted by LHT and the Darwinian model, parents who face low exogenous mortality ($\mu\downarrow$, small values of *Totalmort*) and who know that offspring survival is a matter of parenting effort and health investment ($\varepsilon_q\uparrow$, high values of *DOC* and/or *VaccIns* = 1) will be more willing to invest physically and emotionally in their children.

Table 4: The Determinants of Child "Value"

Model	***OLS***		***OLS, Panel***	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
TotalMort	**-0.0019081**	**-3.07**	**-0.0018655**	**-2.71**
DOC	**0.0000264**	**2.08**	**0.0000242**	**1.89**
Poverty	**-0.0001432**	**-1.96**	**-0.0001312**	**-1.78**
VaccIns	0.0011753	0.97	0.0013295	1.09
City	-0.0000692	-0.1	0.0001405	0.18
Time Controls	**Yes**		**Yes**	
Regional Controls	**No**		**Yes (Amtsbezirke)**	
Adj-R^2	**0.033**		**0.044**	
Number of Observations	**801**		**801**	

Summarizing the empirical evidence, the case of 19th century Baden comes down to two lessons, both of which support the earlier theoretical results: First, the transition from high to low levels of fertility is substantially accelerated if the extrinsic mortality risk is low and if fundamental medical knowledge is widely spread. Moreover, this beneficial effect on fertility carries over to the valuation of children and translates into reinforced parental effort and – arguably – higher investment in human capital.

4.6. Corroborative Evidence:

Seeing their theoretical and practical implications, it is indispensable to assess the general applicability of the above results. Fortunately, Baden's experience is no isolated case although it alone provides sufficiently detailed micro-level data to conduct a rigorous econometric analysis. In spite of these limitations, the notion that medicalization acts as a catalyst for the onset of a fertility decline is supported by the experiences of Baden's neighbors Württemberg and Alsatia. Starting with the former, one finds that medicalization in Württemberg was generally less comprehensive than in Baden. The country had not only failed to establish vaccination institutes but was also more lax in enforcing its vaccination laws. Moreover, in the course of the 19th century, Baden's universities turned into prestigious centers for medical research and provided the country with large numbers of academically trained doctors who – not the least for their own benefit – became important proponents of rapid comprehensive medicalization. By contrast, Württemberg was a hot-bet of vociferous anti-vaccination agitation

and a center of alternative medicine. Scholarly medicine was therefore met with more mistrust and information about new prevention and treatment methods spread much more slowly than elsewhere. There was – however – one district of Württemberg which broke with this pattern: In the Jaxtkreis, local schoolteachers and the clergy were convinced of the benefits from immunization and determined to promote the universal vaccination and revaccination of all young adults. Having no other means to accomplish this aim, they came up with the ingenious – albeit morally questionable – idea to officially announce a forged "amendment" to the Württemberg vaccination laws. The additional article was said to require the revaccination of all 14-year olds. Local officials saw no reason to prevent this staging and did not impede the regular revaccination of all students at the district's secondary schools.[44] The initiative of local officials, doctors and teachers therefore worked in a similar way as the Badenese *Impfinstitute* and spread fundamental medical knowledge. As a result, immunization in the Jaxtkreis was almost universal while smallpox mortality remained at negligible levels and hardly reached *half* the size of the Wurttemberg average. The remarkable feature of the story is that increased medicalization was not confined to successful prevention of smallpox. Rather it led to lower levels of general infant and childhood mortality and – as if to prove the predictions of life history theory true – this reduction of environmental risk translated into lower fertility rates. The available mortality and fertility rates of Württemberg and the Jaxtkreis are depicted in table 5. Both rates are significantly lower in the latter than the Württemberg average, although the dataset is too limited to construct the control variables for a multivariate regression as in the case of Baden.

Table 5: Mortality and Fertility in Wurttemberg and in the Jaxtkreis[45]

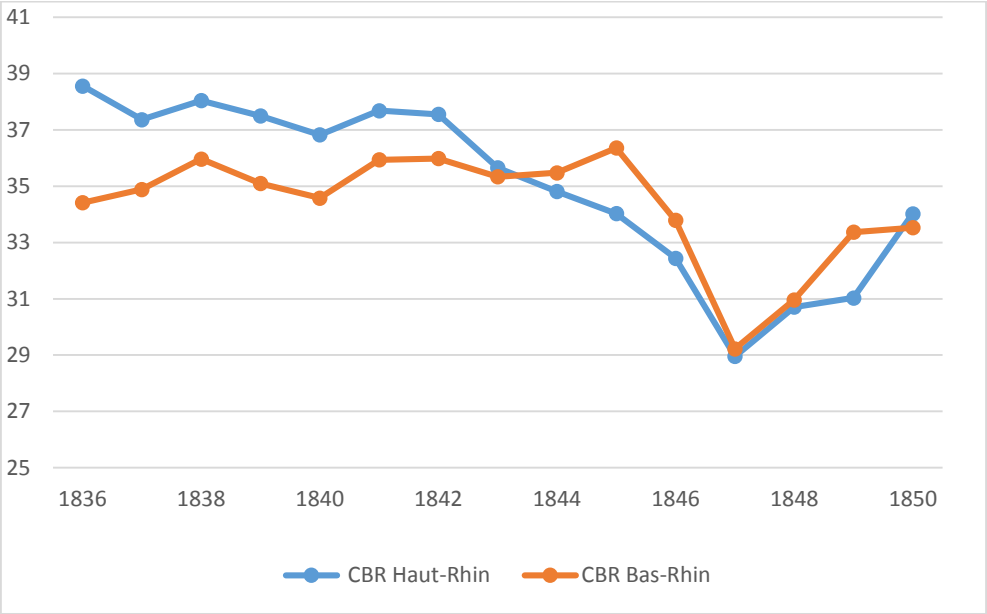
	1835-46	*1847-55*	*1856-67*	*1868-80*	*1881-95*
Infant Mortality Jaxtkreis (Deaths per 100 life births)	32.7	31.5	31.4	30.1	23.3
Infant Mortality Wurttemberg (Deaths per 100 life births)	33.9	34.8	35.4	31.9	24.8
Fertility Jaxtkreis (Births per 1000 inhabitants)	40.9	36.4	40.2	43.0	34.5
Fertility Wurttemberg (Births per 1000 inhabitants)	43.6	38.1	40.7	44.6	35.9

[45] Lange (1891), data appendix

Finally, similar findings can be established if one ventures a look across Baden's Western frontier to the French region of Alsatia. The adjacent two departments of the Bas-Rhin and the Haut-Rhin resembled their Eastern neighbor strongly in terms of socio-economic structure. Nevertheless, their health infrastructure deviated substantially from Baden's path In the Bas-Rhin, the prefectural administration had established so called *médecins cantonaux* at the beginning of the 19th century. Besides offering public vaccinations, these doctors were in charge of providing free health care for the poor and of supervising the sanitary conditions in their constituencies. A similar office was not established in the Haut-Rhin until a smallpox epidemic had ravaged the department in 1836/37 claiming more than 10000 lives. Medicalization was therefore less advanced and perceived extrinsic mortality arguably higher than in the Bas-Rhin. Figure 3 shows the effect of the institutional differences on fertility rates. Again, as predicted by LHT, the closer net of fundamental medical services apparently helped to lower fertility rates. Moreover, after the introduction of a local health-care system similar to that of the Bas-Rhin in the 1840s, the fertility difference between the two departments vanishes and eventually reverses.

Figure 3: Fertility in Two French Départements 1836-1851[46]

(Crude Birth Rates = Births per 1000 Inhabitants)



This impression is further corroborated by the available evidence on regional levels of school attendance. Since elementary schooling was less universal in rural France than in South-Western Germany, differences in the two departments' attendance rates are a more reliable indicator of variation in child quality investment than in Baden (or Wurttemberg for that matter). Here again, the Bas-Rhin outperformed its Southern neighbor in the 1830s and 1840s with an average attendance rate of 71% versus 64% in the Haut-Rhin. Yet, the difference disappears in the mid-1850s, where both departments recorded approximately equal schooling

[46] Data drawn from Archives Départementales du Bas-Rhin, 5M67 and Archives Départementales du Haut Rhin, 5M68

rates of 75.9% and 76.4%.[47] Still, with all due caution, the evidence seems to support life history theory in that lower fertility in the Bas-Rhin came along with higher human capital investment and more advanced medicalization.

6. Conclusion:

For the better part of human history, life was most fragile and death most imminent during infancy and early childhood. Today, the death of a child is considered a tragedy, hardly bearable and deeply unnatural. Yet, what seems abhorrent to present-day observers, was a sad but commonplace experience for our ancestors. While this is deeply revolting from a humanitarian perspective, certain currents in macroeconomics and economic history claim that the Malthusian check on population growth ultimately raised per capita income, facilitated capital accumulation and thereby contributed to slow but sustained growth in pre-industrial Europe. The present paper has questioned this convention. Its doubts are founded in recent results forwarded by the life sciences, including anthropology, evolutionary biology, medicine and psychology. Based on life history theory, researchers in these fields provide ample evidence that human reproductive behavior is subject to evolutionary plasticity. Mating and parenting strategies are apparently tailored to different ecological niches in order to maximize long term fitness. Fitness in turn has been shown to be a function of exogenous characteristics with unpredictable, high-mortality environments favoring high fertility low investment and stable, predictable environments giving a selective advantage to more investing low fertility high quality strategies.

Putting these observations into mathematical form and incorporating them into a conventional economic model of fertility the paper has established that declining extrinsic mortality or increased effectiveness of parental effort both lead to a switch from the pre-demographic transition pattern of high fertility and mortality to the post-transition pattern of reduced family size and heavy investment in child quality. That this result is more remarkable than it appears at first glance stems from the fact that evolution has created strong mechanisms which nudge parents towards faster or slower life history strategies. Thus, a number of physiological and psychological adaptations determine both the feasible number of births and parents expected costs and benefits from investing in the competitiveness of their offspring. Whether or not parents face a quantity quality tradeoff at all and how they value the different alternatives thereby depends on the prevailing mortality framework. Consequently, we expected fertility to decline earlier and child quality investment to increase faster the lower environmental mortality risk.

To test this proposition empirically, the paper has studied the effects of smallpox vaccination in 19th century Baden. Besides for its exceptionally good availability of statistical data, the case of smallpox was particularly instructive because prevalence was high and the decline in mortality after the introduction of universal immunization dramatic. Adding to that, the state of Baden was fast in establishing a highly institutionalized health system. This feature proved

[47] Unfortunately, the surviving statistics contain only averages and no annual data. Therefore a more precise analysis of schooling rates was impossible.

crucial for identification purposes because the centralized vaccination system required the establishment of so called vaccination institutes to ensure a constant supply of high quality vaccine. Seeing the technical constraints of the commonly practiced arm to arm vaccination this implied that the doctors of a vaccination institute needed to maintain permanent contact with the population in their district. Medical knowledge and fundamental health services were therefore more accessible in districts which had a vaccination institute than elsewhere. Using this difference allowed us to estimate the effect of reduced environmental risk through improved health conditions. As it turned out, progress in medicalization came along with lower fertility and higher valuation of the individual child even if socio-economic factors were controlled for. The results were moreover robust against potentially endogenous mortality and were backed by anecdotal evidence from adjacent regions.

The bottom line of these findings is quickly stated: Neither biology nor history obey neatly to Malthusian rules. If anything, the two of them have crafted human behavior in a way that mitigates the impact of positive checks on population and precludes the emergence of preventive ones under adverse conditions. Thus, where the provision of fundamental health care and educational progress are concerned, there is no contradiction between economic and humanitarian objectives. For, in essence the logic of evolution is simple: If death lurks around every corner, he can only be bet on numbers. Of course, this strategy ensures survival but it does so at the cost of reduced human capital investment, stagnation and miserable living conditions. Only if survival is sufficiently certain, the evolutionary dividend of parental effort rises and the population converges towards a new equilibrium in which families are smaller but – arguably – a great deal better off.

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